Strategic Sourcing to Sustain Supplier Competition - Theoretical and Experimental Analyses

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Florian Wilken

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Chapter 1

Introduction

In a bilateral oligopoly where buyers source a good from competing suppliers over time, firms find themselves in a situation shaped by their strategic interplay. Taking current decisions, both buyers and suppliers have to account for the impact of their actions on the future competitive situation since firms may exit the respective market when in the long run they are not sufficiently profitable. Hence, buyers face a tradeoff between sourcing solely from the supplier offering the best current conditions and sourcing from multiple suppliers to ensure competition among these is sustained in the future. In turn, suppliers face a tradeoff between competing fiercely, allowing them to win a large share of current demand as well as increasing the probability of rival suppliers exiting and accommodating to buyers who aim to sustain competition.

In reality both single and multiple sourcing as well as aggressive competition and accommodating supplier behavior are observed[1]. Also, several industries exhibit many of these characteristics. One is the market for large commercial aircraft, where a small number of airlines sources from two suppliers, Airbus and Boeing. These are at times accused of exclusionary behavior[2], while occasionally being also regarded as a "cosy duopoly"[3]. Although some airlines have opted for sourcing from a single supplier, the majority operates aircraft from both suppliers[4]. Also, competing manufacturers of aircraft have exited the market in the last decades[5]. Another example is provided by the automotive industry, with a few relevant car manufacturers[6] frequently accounting for a substantial share of the sales of suppliers[7], who are often in a financially vulnerable position[8].

[1] Examples are provided in chapters 2-4.

[2] E.g., in a recent WTO dispute Airbus was accused of displacing Boeing from some markets through aggressive pricing but found to be not guilty (WTO 2010).

[3] Cf. The Economist (2010).

[4] All but two of the 25 largest customers by deliveries in 1974-2009 purchased from both suppliers. The exceptions, Ryanair and Southwest Airlines, exemplify the approach of many low cost airlines to source from only one manufacturer (Airbus 2009; Boeing 2009).

[5] E.g., Fokker filed for bankruptcy in 1996 (Eglau 1996), while the aircraft models of McDonnell Douglas were discontinued after its merger with Boeing in 1997.

[6] The top ten car manufacturers produced more than a third of all cars worldwide in 2008 (OICA 2009).

[7] This holds especially for firms such as Delphi who originated from integrated divisions (Babich 2010).

[8] E.g., 30% of North American suppliers declared bankruptcy in 2008 (Wadecki, Babich, and Wu 2010).

Different aspects of this strategic interplay of buyers and suppliers are addressed by distinct strands of literature. Traditionally, industrial organization research has focused on the supplier side of the market and only recently has the role of powerful buyers received considerable attention[9], while the optimality of sourcing decisions is explored in another body of works[10]. Regarding supplier strategies, in addition to the exclusion of competing firms through predatory behavior[11], also the use of exclusivity contracts to prevent efficient entry has been extensively investigated[12]. However, only a couple of works have explicitly analyzed the strategic interplay between buyers and suppliers who might exit the market[13]. We address this gap by contributing a thorough analytical and numerical characterization of a model designed to capture this interplay. In addition, to the best of our knowledge, we provide the first experimental investigation of this strategic situation and indeed the first dedicated experimental analysis of strategic sourcing from alternative suppliers. Accordingly, our findings of the consequences of coordinating sourcing decisions and of employing different procurement processes add novel perspectives to the experimental literature.

We model the strategic interplay of buyers and suppliers as a two period asymmetric cost Bertrand duopoly, where in the second period only those suppliers are active whose profit is sufficiently high in the first period. Thus, the first period represents the current, the second period the future competitive situation. One or two buyers have an inelastic demand for the good in each period and decide how to source this demand from the suppliers. While buyers thus benefit from a duopoly in the second period and therefore often have an incentive to sustain competition, suppliers frequently have an incentive to monopolize the market.

This model is investigated in three self-contained chapters. In chapter 2 we solve it analytically with continuous prices and quantities for a single buyer. Employing backward induction, we find that in the first period the buyer dual sources and sustains competition when prices are high whereas for low prices single sourcing prevails. When the cost difference of suppliers is small, a unique subgame-perfect equilibrium in pure strategies exists. The more efficient supplier sets prices at or below the cost of the less efficient supplier and the buyer sources all demand from him. Exclusion of the competing supplier is successful and the more efficient supplier then often enjoys a monopoly in the second period. With multiple identical buyers, equilibrium results do not change. Implementing the model numerically, we find that results are robust for coarse quantities. Exclusion can then occur in equilibrium even for large cost differences, while also equilibria exist where the buyer dual sources and competition is often sustained. In addition, we implement

[9] Cf., e.g., Inderst and Mazzarotto (2008), while Ruffle (2005) includes also experimental works.

[10] The relevant literature is surveyed, e.g., by Elmaghraby (2000).

[11] Bolton, Riordan, and Brodley (2000) provide an overview, whereas the relevant experiments are introduced by Gomez, Goeree, and Holt (2008).

[12] This literature originates from Rasmusen, Ramseyer, and Wiley (1991) and Segal and Whinston (2000). Experimental investigations include Landeo and Spier (2009) and Smith (2011).

[13] These include Lewis and Yildrim (2002), Clark and Polborn (2006) and Bergès and Chambolle (2009).

an alternative procurement process where the buyer first sets the quantities to be sourced dependent on the relative prices. When sustained competition has a sufficiently high value for the buyer, equilibria where the buyer sources from both suppliers and competition is sustained with a high probability exist even for small cost differences. The surplus of the buyer can, but need not, increase compared to the initial process.

Using this model with its predicted predominance of exclusion as a baseline, in the subsequent chapters two routes to an increase in the probability of sustained competition are explored experimentally with two buyers. While improved coordination of sourcing decisions among buyers is not predicted to impact results, employing alternative procurement processes often is.

Coordination improves in chapter 3 from the baseline model with two independent buyers across experimental treatments by allowing communication, introducing a single buyer and automating buyers. Outcomes in the second period are not observed to differ between treatments. We then find that in the first period, buyers nearly always dual source and sustain competition when this is rational for all treatments. When it is not rational however, dual sourcing persists. This can be attributed mostly to errors of single subjects whereas fairness motivations play only a limited role. With two independent buyers we observe exclusionary pricing to be predominant and accordingly competition is frequently not sustained. Contrary to the subgame-perfect prediction of no difference however, with improved coordination of buyers, pricing becomes more accommodating. Accordingly, competition is sustained more often and there is weak evidence that also buyer surplus increases in turn. In contrast, complete rationality of buyers is not found to have a substantial impact on results.

The role of the procurement process is analyzed in chapter 4. Again, in the non-strategic setting of the second period, experimental outcomes for all procurement processes are comparable. In the first period, supplier exclusion is predominant not only in the baseline process which corresponds to a procurement auction, but also for nonlinear prices in split-award auctions. Then, suppliers demand premia for small quantities which would allow to sustain competition, an option buyers however frequently do not use. When subsidies can be paid to suppliers or when buyers take their sourcing decisions before suppliers bid however, suppliers price more passively and competition is sustained substantially more often than in the baseline, in line with the prediction. Buyer sourcing is relatively close to rational behavior across procurement processes, although buyers are not always successful in sustaining competition when this is optimal. Therefore, the predicted increase in buyer surplus for subsidies and pre-announced sourcing is not observed.

We thus find that both theoretically and experimentally, even with strong incentives for buyers to sustain competition, aggressive supplier behavior often entails exclusionary outcomes. However, both improved coordination of sourcing decisions and modifications of the procurement process are experimentally found to induce more accommodating pricing and lead to competition being sustained frequently.

Our results accordingly hold valuable implications primarily for firms acting as buyers, highlighting how coordinating sourcing with other firms and cautiously selecting procurement processes can increase the power vis-à-vis suppliers and further strategic objectives. Meanwhile, in the realm of antitrust policy, we find predatory behavior of suppliers to be unexpectedly widespread and confirm that powerful buyers can indeed exert a countervailing influence to sustain competition among suppliers[14]. However, the marked differences between experimental treatments also highlight that this power may not always be effective.

[14] As recognized by, e.g., the EU Guidelines on Vertical Restraints (EU 2010).

Chapter 2

Supplier Exclusion when Selling to Strategic Buyers

To investigate when a strategic buyer sustains competition among her suppliers, a two period asymmetric cost Bertrand duopoly is analyzed. In the second period only suppliers are active whose first period profit is sufficiently high. We find that for high prices, the buyer dual sources to sustain competition while at low prices single sourcing is preferred. When the difference of supplier costs is not too large, unique subgame-perfect equilibria in pure strategies exist. The more efficient supplier excludes the less efficient supplier by pricing equal to or below the marginal cost of this supplier and the buyer purchases only from the more efficient supplier. With multiple identical buyers the equilibrium prediction is unchanged. For large cost differences and coarse quantities, a numerical analysis yields equilibria where exclusion is also often prevalent although there can also exist equilibria which sustain competition. An alternative procurement process which allows to guarantee quantities to suppliers can substantially alter the probability of sustained competition and buyer surplus.

2.1 Introduction

Buyers who repeatedly procure a good from competing suppliers are faced with a strategic decision of how to source the good optimally from these suppliers. Correspondingly, the sourcing of buyers will have a profound influence on the competitive behavior of suppliers.

In practice, in many situations buyers are observed to multiple source from more than one supplier. For example, in the market for large commercial aircraft, all but two of the 25 largest customers in 1974-2009 purchased from both Airbus and Boeing, despite advantages of operating a fleet of aircraft from one supplier (Airbus 2009; Boeing 2009). Even single orders are split between the two suppliers as recently by United Airlines (Carey and Michaels 2009)[1]. Nevertheless, buyers are also frequently observed to single source as

[1] Examples of firms which use multiple sourcing in other industries include Motorola (Metty et al. 2005), Sun Microsystems (Tunca and Wu 2009) and General Motors (Anton, Brusco, and Lopomo 2010).

the Department of Defense did in the second (subsequently contested) round of procuring a new generation of tanker aircraft, where the joint Airbus/Northrup Grumman bid was selected over the Boeing offer (Cole 2008)[2].

When there is a threat that a substantial share of suppliers might exit the market, the strategic impact of sourcing on the future supply situation is especially relevant. In the commercial aircraft industry, e.g., the bankruptcy of Fokker in 1996 saw the exit of a competitor for the smallest Airbus and Boeing planes[3]. In addition to outright bankruptcy, firms might only exit specific markets. Strategic buyers thus have to weigh the expected benefit of inducing fierce current competition and the advantages of sustaining future competition among suppliers.

Accordingly, suppliers have to weigh competing aggressively, thereby potentially gaining both a large share of current demand as well as excluding rival suppliers for the future, and competing accommodatingly in the face of buyers who aim to sustain competition. Relating to the above example, in a recent WTO dispute (WTO 2010), the US accused Airbus of having been enabled by subsidies to price aggressively, thereby displacing Boeing from some markets[4]. At the same time Airbus and Boeing are sometimes regarded as not competing too fiercely and enjoying a "cosy duopoly" (The Economist 2010).

This interplay between strategic buyers and competing suppliers is also recognized by antitrust policy, where, e.g., the EU Guidelines on Vertical Restraints (EU 2010) state that "powerful buyers will not easily allow themselves to be cut off from the supply of competing goods" and will therefore take sourcing decisions accordingly. This counteracts exclusionary tendencies by suppliers, who might seek "single branding" agreements (which need not be explicit), leading a buyer to "concentrate its orders... with one supplier". The possible risk is then "foreclosure of the market to competing suppliers".

Different aspects of this situation are addressed by distinct strands of theoretical literature. Regarding the role of powerful strategic buyers, overviews are provided, e.g., by Chen (2007) with a focus on antitrust implications and by Inderst and Mazzarotto (2008) from a retailing perspective, while merger-related questions are highlighted by Inderst and Shaffer (2008).

Several characteristics are found to confer power to buyers, thereby leading to better terms of trade. Among these are a large demand of individual buyers (cf., e.g., Chipty and Snyder 1999; Inderst and Wey 2003), the option to integrate backwards (Katz 1987; Scheffman and Spiller 1992) and the ability to control access to downstream markets (Mazzarotto 2004; Inderst and Shaffer 2007). For a single supplier, quantity discounts arise only

[2]Beker and Hernando-Vecianaz (2009) provide further examples of single sourcing in the public and private sector, including, e.g., medical supplies and IT outsourcing respectively. Also, as described by Tunca and Wu (2009), Sun Microsystems awards some of its contracts to a single supplier.

[3]Also, McDonnell Douglas ceased to exist as a provider of aircraft through the discontinuation of its models after the merger with Boeing in 1997. Other examples include North American car parts suppliers, a third of which went bankrupt in the downturn of 2008 (Wadecki, Babich, and Wu 2010).

[4]However, Airbus was cleared of this specific charge. In other recent cases France Telecom was found guilty (ECJ C-202/07 P 2009) but a subsidiary of AT&T acquitted (SC 555 U.S.___ 2009) of predatory pricing for internet access.

for increasing marginal costs (Chipty and Snyder 1999; Inderst and Wey 2003), while for competing suppliers sequential interactions (Snyder 1998) as well as a commitment to single sourcing (Inderst and Shaffer 2007) can induce lower prices. Nevertheless in some situations a large demand may also be detrimental as demonstrated by Raskovich (2003) and Inderst (2005). In addition to extracting better terms of trade, powerful buyers may negatively affect incentives of suppliers to invest (Battigalli, Fumagalli, and Polo 2007) and reduce product variety (Chen 2004). However, innovation may also be spurred as this allows suppliers to open alternative channels as in Inderst and Wey (2003).

Most closely related to our work, powerful buyers can make foreclosure both on the supplier and buyer side more likely. In the latter case, buyers may compensate suppliers for excluding other buyers, for example through upfront payments (Marx and Shaffer 2007). Analyses of foreclosure on the supplier side often focus on contractual "naked exclusion", with only a couple of works addressing the exit of previously competing suppliers resulting from market interactions. These articles are discussed below.

In addition, a large body of literature examines the optimality of single and multiple sourcing. For an overview, cf., e.g., Elmaghraby (2000). Generally, the optimal sourcing approach depends critically on the exact situation. While for example a single buyer purchasing from suppliers with convex costs is often better off when committing to single sourcing (Anton and Yao 1989), for multiple buyers in a related setting, Inderst (2008) finds that multiple sourcing can be optimal for small buyers. Similarly, while in Anton and Yao (1992) split-awards occur in equilibrium, this need no longer be the case with scale economies (Anton, Brusco, and Lopomo 2010). Meanwhile, the commitment to dual source can decrease the costs of procuring a good as in the model with costly entry of Klotz and Chatterjee (1995a). Then, by guaranteeing a quantity to each entering supplier, participation increases and procurement costs are reduced. A similar logic applies in the case of a dynamic model with learning efficiencies in Klotz and Chatterjee (1995b). However, announcing only the number of suppliers to be sourced from can also yield higher procurement costs as shown by Seshadri, Chatterjee, and Lilien (1991).

Regarding the behavior of suppliers, these can engage in predatory behavior, excluding competing suppliers by pricing aggressively and recouping foregone profits through the ensuing monopolization of the market. Predatory pricing is rational in different contexts, e.g., with incomplete information in the literature originating from Milgrom and Roberts (1982) and Kreps and Wilson (1982). Also, Bolton and Scharfstein (1990) highlight how predatory behavior can arise from the threat of funding termination. An overview is provided by, e.g., Bolton, Riordan, and Brodley (2000).

An alternative for a monopolistic supplier is the "naked exclusion" of a more efficient entrant. By offering contracts to buyers which grant exclusive sourcing in return for compensation payments, the entrant can be successfully excluded as buyers face a coordination problem. This is analyzed in the literature originating from Rasmusen, Ramseyer, and Wiley (1991) and Segal and Whinston (2000). Allowing for discrimination exacerbates the problem (Segal and Whinston 2000), while the ability to profitably exclude is diminished with downstream competition (Fumagalli and Motta 2006; Abito and Wright 2008).

In addition to these articles, a small number of works address the interplay of the issues described in the introduction. In Romano (1991), buyers consume excessively above their demand to realize positive surplus from a monopolist who might otherwise not produce at all. A single strategic buyer balances the benefits of learning-by-doing with a future reduction in competition in an infinitely repeated model in Lewis and Yildrim (2002). Competition among suppliers is then only sustained when cost reductions from learning are small. In Biglaiser and Vettas (2005), two firms whose capacity is constrained over two periods compete to supply buyers. Buyers would then often benefit from being able to procure only in the current period or from committing to single sourcing. Fumagalli and Motta (2008) examine a model where an incumbent monopolist faces the threat of entry of a more efficient competitor. Coordination failures among buyers may then prevent efficient entry in the case of weak downstream competition, a problem which becomes less pronounced with fewer buyers.

Also, Clark and Polborn (2006) examine a two period Hotelling duopoly, where in the second period only suppliers are active who attain a profit threshold in the first period. Then, in the subgame of the first period, buyers close to indifference may source strategically from the myopically inferior supplier to sustain competition. However, in equilibrium strategic sourcing may not occur, although first period prices can be different from the corresponding one period model. Meanwhile, in the work of Bergès and Chambolle (2009) suppliers compete in a two period Bertrand duopoly. In an extreme case of learning-by-doing, suppliers are not active in the second period when the quantity sold in the first is too low. Then, for sufficiently different discount factors of the suppliers and the single buyer, there exist equilibria where suppliers price above the valuation of the buyer in the first period. Both are sustained but extract all surplus. In addition, for low supplier discount factors there exist equilibria where the less efficient supplier is excluded.

We add to this literature by analyzing the interplay between buyers and suppliers in a dedicated model, obtaining in parts different results than the works discussed above. Also, we explore the dependence of results on the costs of suppliers as well as the number of buyers and relate the findings to those for an alternative procurement process.

A two period homogeneous good Bertrand duopoly with asymmetric costs of suppliers is analyzed. Suppliers compete to sell to a single buyer with an inelastic demand for the good. In the second period only those suppliers are active whose profit attains a minimum value in the first period.

We solve the model for subgame-perfect equilibria using backward induction. In the second period, the buyer benefits from sustained competition while monopolizing the market allows suppliers to realize an additional profit. In the buyer subgame in the first period, the buyer strategically dual sources to sustain competition when prices are high, while for lower prices, myopic single sourcing is optimal. The best responses of the suppliers in the first period are dominated by underbidding. Hence, for small cost differences unique subgame-perfect pure strategy equilibria exist with the more efficient supplier pricing either at or below the cost of the less efficient supplier, thereby gaining all demand of the buyer and often enjoying a monopoly in period 2. Meanwhile, the less efficient supplier sets a price equal to his cost or to the valuation of the buyer and exits after the first period. Committing to myopic sourcing then never increases buyer surplus. We show that for large cost differences, no pure strategy equilibria exist. When multiple identical buyers source from the suppliers, aggregate sourcing behavior is identical to that of a single buyer and the same equilibria arise.

For exemplary sets of parameters we implement the model numerically with coarse quantities. Pure strategy equilibria for small cost differences are closely reproduced. Also for large cost differences there often exist equilibria where the more efficient supplier excludes the other supplier. However, there are also equilibria where the buyer dual sources and competition is sustained with positive probability. In addition, we analyze an alternative procurement process, where first the buyer sets the quantities to be sourced dependent on relative prices. Now, when sustained competition is valued sufficiently high by the buyer, for all cost differences often equilibria exist with a high probability of sustained competition. For small cost differences, expected buyer surplus can therefore increase compared to the initial process, while for higher differences it may decrease.

We thus find that in a procurement auction as in the initial model, exclusionary tendencies are quite strong, while an alternative procurement process is able to mitigate these, leading to a higher probability of sustained competition. The accompanying change in expected surplus of the buyer then depends critically on the exact situation.

This article introduces the model in section 2.2. It is solved analytically in section 2.3 for a single buyer and results are extended to multiple buyers. Numerical analyses are included in section 2.4, while section 2.5 concludes. Proofs are relegated to the appendix.

2.2 Model

Two suppliers $i \in \{1, 2\}$ produce a homogeneous good with constant but different marginal costs $0 \leq c_1 < c_2$. Thereby, firm 1 designates the more efficient firm throughout this work. Different costs are assumed to accentuate that there is a weak supplier who might need to be sustained. Suppliers compete for two subsequent periods $t \in \{1, 2\}$ in a Bertrand market by posting prices for a unit quantity of the good, $p_i^t \geq 0$ as visualized in figure 2.1. Capacity constraints do not bind so each supplier can serve the whole market.

A single buyer has an inelastic demand of D for the good in each period for prices up to her valuation V[5], with $V > c_i$. Given the prices, the buyer sets the quantities Q_i^t to be sourced from each supplier i with $D = Q_1^t + Q_2^t$. Accordingly, period 1 models the current supply conditions while the future market structure is given by period 2.

[5]Cf. also the discussion of assumption 2 below.

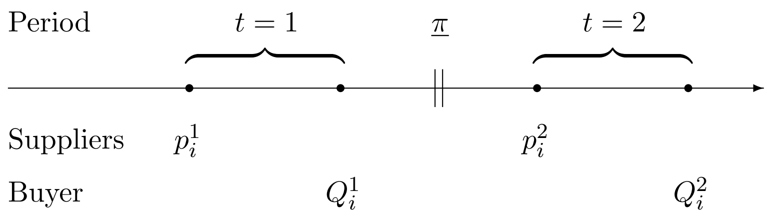

Figure 2.1: Timing and strategic variables.

A supplier is only active in the second period when his first period profit is at least as high as $\underline{\pi}$ with $\underline{\pi} > 0$. This profit threshold models the requirement for firms to operate profitably in the long run to be active in a market. The positive profit may be needed, e.g., to cover costs which have not been modeled explicitly. Also, investors are likely to force firms to exit a market if they do not generate positive returns (cf., e.g., Bolton and Scharfstein 1990). Various other works model firm exit based on some measure of performance. While similar profit thresholds are employed by Biglaiser and DeGraba (2001) as well as Clark and Polborn (2006), alternative approaches make use of the difference between earnings and liabilities or the ratio of assets to liabilities (Babich 2010; Wadecki, Babich, and Wu 2010).

Second period surplus values of the suppliers and the buyer are discounted by $\delta \in (0, 1]$. The resulting total profit for supplier i is therefore

$$\pi_i = Q_i^1 \left(p_i^1 - c_i\right) + \delta\, Q_i^2 \left(p_i^2 - c_i\right) , \tag{2.1}$$

while total surplus for the buyer follows as

$$\mathrm{BS} = \sum_i Q_i^1 \left(V - p_i^1\right) + \delta \sum_i Q_i^2 \left(V - p_i^2\right) . \tag{2.2}$$

Both prices and quantities are modeled as continuous variables. The good is thus either of a physical nature which allows the trading of arbitrary amounts or the number of relevant units is so large that treating it as continuous is a good approximation.

2.3 Analytical Analysis

We solve the model for subgame-perfect pure strategy equilibria using backward induction.

2.3.1 Second Period

In the second period $t = 2$, either both suppliers, a single supplier or no supplier are active. Since this is the last period, market participants behave myopically and therefore outcomes correspond to those of the respective one period models.

When two suppliers are active, the buyer sources all demand D from the supplier with the lower price and thus for $p_i^{2\mathrm{D}} > p_{-i}^{2\mathrm{D}}$ we have $Q_i^{2\mathrm{D}} = 0$ and $Q_{-i}^{2\mathrm{D}} = D$. Throughout this article we designate suppliers by $i \in \{1, 2\}$ and $-i \in \{1, 2\} \setminus \{i\}$. Furthermore, in the case of equal prices $p_1^{2\mathrm{D}} = p_2^{2\mathrm{D}}$ we assume the buyer to purchase only from the more efficient supplier, $Q_1^{2\mathrm{D}} = D$ and $Q_2^{2\mathrm{D}} = 0$. For prices $p_{-i}^{2\mathrm{D}} > V$ no purchases are made. If only a single supplier i is active, the buyer sources all demand from him up to $p_i^{2\mathrm{M}} = V$.

In a duopoly, suppliers are assumed to set only prices which are continuous limits of weakly undominated prices in a version of the model with a discrete price space. Prices of supplier i are therefore $p_i^{2\mathrm{D}} \in [c_i, V]$. This follows the approach introduced by Deneckere and Kovenock (1996) and eliminates all weakly dominated prices except for the marginal cost[6]. With these assumptions, the following equilibria are obtained.

Lemma 1. *Three situations can arise in period 2.*

A) If two suppliers are active, then a unique equilibrium of the subgame exists with prices $\left(p_1^{2\mathrm{D}}, p_2^{2\mathrm{D}}\right) = (c_2, c_2)$. *The buyer sources only from supplier 1,* $\left(Q_1^{2\mathrm{D}}, Q_2^{2\mathrm{D}}\right) = (D, 0)$.

B) If a single supplier i is active, then a unique equilibrium of the subgame exists with a price $p_i^{2\mathrm{M}} = V$. *The buyer sources only from supplier i,* $Q_i^{2\mathrm{M}} = D$.

C) If no supplier is active, no market activity occurs.

Proof of lemma 1. Omitted. □

The duopoly case A) corresponds to a standard asymmetric cost Bertrand duopoly. Then, an equilibrium in pure strategies exists with continuous prices only for the tie-breaking rule specified above[7], where for equal prices all demand is purchased from the more efficient supplier (cf., e.g., Blume 2003; Hoernig 2007). Alternatively, this tie-breaking rule can be interpreted as a property of the unique equilibrium of lemma 1. When discrete prices are assumed with a smallest unit of account Δ_p, then two equilibria exist[8] with $p_1^{2\mathrm{D}} = c_2$ as well as $p_1^{2\mathrm{D}} = c_2 + \Delta_p$ and $p_2^{2\mathrm{D}} = p_1^{2\mathrm{D}}$. The buyer purchases only from supplier 1 and the continuous limit $\Delta_p \to 0$ yields again the unique solution $\left(p_1^{2\mathrm{D}}, p_2^{2\mathrm{D}}\right) = (c_2, c_2)$. If a single supplier i is active in case B) of lemma 1, he maximizes surplus by pricing at the valuation of the buyer, who has to purchase all demand from supplier i.

Due to the uniqueness of the equilibria, period 2 surplus of all market participants is uniquely determined for each of the market structures. The buyer is indifferent between a single or both suppliers exiting after period 1 since surplus is zero in both cases. Hence, she has an incentive to preserve a duopoly, as this allows to realize a positive surplus $\mathrm{BS}^{2\mathrm{D}} = \delta\, D\, (V - c_2)$. Conversely, both suppliers have a predatory incentive to monopolize the market in the second period and thereby increase profits. Notably, the predatory motivation can be interpreted as being equally strong for both suppliers as the differential

[6] Allowing all prices, every $p_1^{2\mathrm{D}} \in [c_1, c_2]$ can be supported as an equilibrium by $p_2^{2\mathrm{D}} = p_1^{2\mathrm{D}}$.

[7] E.g., for equal-sharing tie-breaking no equilibrium exists as there is no profit-maximizing $p_1^{2\mathrm{D}} \in [\, c_1\,,\, c_2\,)$.

[8] For discrete prices there exist equilibria also for equal-sharing tie-breaking. For $\Delta_p \to 0$, these also converge to $\left(p_1^{2\mathrm{D}}, p_2^{2\mathrm{D}}\right) = (c_2, c_2)$.

profit gain from successful predation, $\pi_i^{2M} - \pi_i^{2D} = \delta\, D\,(V - c_2)$ is equal for both suppliers. Due to the inelastic demand this additional predatory profit is equal to the surplus BS^{2D} lost by the buyer when competition is not sustained.

2.3.2 First Period - Buyer

With the results for period 2, we identify equilibria of the buyer subgame in period 1. Prices are thus considered as exogenously given. First we make an assumption regarding model parameters which serves to make further analysis more straightforward while at the same time imposing only a light restriction.

Assumption 1. *The profit threshold is lower than the discounted second period monopoly profit of supplier 2,* $\underline{\pi} < \delta\, D\,(V - c_2)$.

This assumption about the relative size of the (not directly related) profit values will generally be fulfilled. The two periods can be regarded as modeling some accounting periods. Therefore, the discount factor should differ from $\delta = 1$ only by a foregone rate of return which will typically be an order of magnitude smaller. Then, generally the monopoly profit of the less efficient supplier in the next accounting period will have a higher present value than the minimal profit needed for firm survival in the current period. Alternatively, $\delta\, D\,(V - c_2)$ can also be interpreted as the discounted surplus increase of the buyer when competition is sustained (cf. section 2.3.1).

Depending on the ensuing period 2 market structure, we define two types of equilibria.

Definition 1. *A strategic sourcing equilibrium is an equilibrium of the buyer subgame in period 1 where purchases are such that both suppliers are active in period 2. A myopic sourcing equilibrium is an equilibrium which is not a strategic sourcing equilibrium.*

Either a single or no supplier is therefore active in the second period when the buyer purchases according to a myopic sourcing equilibrium. Also, with the definition, every quantity allocation $\left(Q_1^1, Q_2^1\right)$ which is an equilibrium can be characterized as either a strategic sourcing or a myopic sourcing equilibrium.

As described in section 2.2, the demand of the buyer is D for prices lower or equal to the valuation and zero above. Ensuring consistency with the behavior in the second period we make the following assumption.

Assumption 2. *The buyer does not purchase at prices above the valuation* V.

The buyer thus follows a procurement policy which does not allow to make losses from individual purchases. The policy is communicated to suppliers, e.g., as part of the request for bids. This assumption is realistic since it is generally easier for a firm to justify both internally and externally sourcing from a myopically non-optimal supplier than incurring actual losses from sourcing. The assumption avoids suppliers conspiring to charge prices above V and exploiting the buyer[9].

[9] Cf. Bergès and Chambolle (2009) for such a situation. The buyer keeps both suppliers active to secure second period surplus but is then indifferent to not purchasing at all in the first period.

With assumption 2, we conclude that if both suppliers price above V, no purchases are made at all, $\left(Q_1^1, Q_2^1\right) = (0,0)$. Meanwhile, for $p_i^1 > V$ and $p_{-i}^1 \leq V$, the buyer sources exclusively from supplier $-i$. The same holds when at least one supplier prices below his cost, as it is then not possible to sustain competition. In all cases, at most one supplier is sustained and thus a myopic sourcing equilibrium arises. As discussed in section 2.3.3, suppliers then set only prices $p_i^1 \in [c_i, V]$ and we therefore limit the following analysis to $\mathcal{P} = \left\{\left(p_1^1, p_2^1\right) \mid p_1^1 \in [c_1, V], p_2^1 \in [c_2, V]\right\}$.

To describe the buyer behavior in more detail, several parameters and functions are defined. Thereby,

$$\mu_i = c_i + \underline{\pi}/D \tag{2.3}$$

gives the minimum price at which supplier i can be sustained when the buyer sources only from this supplier. Conversely, the minimum quantity which has to be sold at price p_i^1 to ensure survival is

$$\underline{Q}_i = \frac{\underline{\pi}}{p_i^1 - c_i}\,. \tag{2.4}$$

The quantities which are actually sourced at unequal prices in the strategic sourcing equilibria ($Q_i^{1\mathrm{S}}$) and the myopic sourcing equilibria ($Q_i^{1\mathrm{M}}$) can then be expressed as

$$Q_i^{1\mathrm{S}} = \begin{cases} D - \underline{Q}_{-i} & \text{if } p_i^1 < p_{-i}^1 \\ \underline{Q}_i & \text{if } p_i^1 > p_{-i}^1 \end{cases}, \quad Q_i^{1\mathrm{M}} = \begin{cases} D & \text{if } p_i^1 < p_{-i}^1 \\ 0 & \text{if } p_i^1 > p_{-i}^1 \end{cases}. \tag{2.5}$$

This ensures that if supplier i posts the higher price and the buyer sources strategically, the supplier is just kept active with the minimum required quantity. In the converse case, when supplier i posts the lower price, the complete demand which is not required to sustain the other supplier is sourced from him. In the myopic case, the buyer purchases only from the supplier with the lower price.

For a strategic sourcing equilibrium to exist, two conditions on prices have to be fulfilled. First, prices have to be such that it is possible for the buyer to source her demand D in such a way that both suppliers are sustained with a profit of at least $\underline{\pi}$. Expressing this as a condition on p_{-i}^1 with $p_{-i}^1 < p_i^1$ yields (cf. the proof of proposition 1) that this price has to be at least as high as

$$P_i(p_i^1) = c_{-i} + \frac{\underline{\pi}\,\left(p_i^1 - c_i\right)}{D\,\left(p_i^1 - c_i\right) - \underline{\pi}}\,. \tag{2.6}$$

Second, for strategic sourcing to be equilibrium behavior it has to be rational for the buyer to sustain competition, i.e., total surplus must not be lower than with myopic sourcing. This then requires p_{-i}^1 to be at least as high as

$$R_i(p_i^1) = p_i^1 - \frac{\delta\,D\,(V - c_2)}{\underline{\pi}}\left(p_i^1 - c_i\right)\,. \tag{2.7}$$

When prices are equal it is always rational to sustain competition since no surplus can be foregone in period 1, while keeping both suppliers active increases surplus in period 2. The minimum price at which competition can then be sustained is given by

$$\eta = \frac{c_1 + c_2}{2} + \frac{\underline{\pi}}{D} + \sqrt{\left(\frac{c_2 - c_1}{2}\right)^2 + \left(\frac{\underline{\pi}}{D}\right)^2}\,. \tag{2.8}$$

We consolidate these constraints by introducing the set $\mathcal{S}_{\mathrm{U}}^{i}$ of unequal prices for which strategic sourcing occurs, with supplier i being the higher-priced supplier,

$$\mathcal{S}_{\mathrm{U}}^{i} = \left\{\left(p_1^1, p_2^1\right) \mid p_{-i}^1 \in \left[\max\left\{P_i(p_i^1), R_i(p_i^1)\right\}, p_i^1\right), p_i^1 \in (\eta\,, V]\right\}\,. \tag{2.9}$$

The set of unequal prices for which competition is sustained then follows as $\mathcal{S}_{\mathrm{U}} = \mathcal{S}_{\mathrm{U}}^1 \cup \mathcal{S}_{\mathrm{U}}^2$. Accordingly, at equal prices the buyer sources strategically for prices in

$$\mathcal{S}_{\mathrm{E}} = \left\{\left(p_1^1, p_2^1\right) \mid p_1^1 = p_2^1, p_2^1 \in [\eta\,, V]\right\}\,. \tag{2.10}$$

In addition, we make the following assumption regarding behavior of the buyer.

Assumption 3. *If the buyer is indifferent between sourcing strategically and myopically, the buyer sources strategically.*

This assumption asserts that when expected surplus from sustaining and not sustaining competition is equal, the buyer sources such that both suppliers remain active. This is only relevant when $p_{-i}^1 = R_i(p_i^1)$ binds in $\mathcal{S}_{\mathrm{U}}^{i}$ and then ensures a unique prediction of buyer behavior. We thus assume that in the case of indifference, the buyer opts for the safe approach of sustaining competition and securing any additional unexpected future surplus. The following proposition then details buyer behavior in the first period.

Proposition 1. *The following equilibria of the buyer subgame in period 1 exist.*

A) For prices $p_1^1 \neq p_2^1$, a strategic sourcing equilibrium exists if and only if $(p_1^1, p_2^1) \in \mathcal{S}_{\mathrm{U}}$. Then $\left(Q_1^1, Q_2^1\right) = \left(Q_1^{1\mathrm{S}}, Q_2^{1\mathrm{S}}\right)$ is the unique equilibrium demand allocation. A myopic sourcing equilibrium exists if and only if no strategic sourcing equilibrium exists, with $\left(Q_1^1, Q_2^1\right) = \left(Q_1^{1\mathrm{M}}, Q_2^{1\mathrm{M}}\right)$ being the unique equilibrium demand allocation.

B) For prices $p_1^1 = p_2^1$, a strategic sourcing equilibrium exists if and only if $(p_1^1, p_2^1) \in \mathcal{S}_{\mathrm{E}}$. Then $\left(Q_1^1, Q_2^1\right) = \left(D - \underline{Q}_2, \underline{Q}_2\right)$ is an equilibrium demand allocation. A myopic sourcing equilibrium exists if and only if no strategic sourcing equilibrium exists, with $\left(Q_1^1, Q_2^1\right) = (D, 0)$ being an equilibrium demand allocation.

Proof of proposition 1. The proof is included in the appendix. □

For unequal prices $\left(p_1^1, p_2^1\right) \in \mathcal{S}_{\mathrm{U}}$, the buyer behavior in period 1 is uniquely determined due to assumption 3. The buyer maximizes her surplus by sourcing the quantity $\underline{Q}_i$ from the supplier with the higher price, which is necessary for the supplier to realize a profit of exactly $\pi_i^1 = \underline{\pi}$. Meanwhile, for unequal prices not in $\mathcal{S}_{\mathrm{U}}$, all demand is single sourced from the supplier with the lower price.

At equal prices, often many equilibria exist as the buyer surplus in period 1 is independent of the demand allocation. As described above, if it is possible to keep both suppliers active, this increases period 2 surplus and is therefore strictly preferred by the buyer. Apart from this, all demand allocations are optimal. However, the proposition asserts that for $\left(p_1^1, p_2^1\right) \notin \mathcal{S}_{\mathrm{E}}$, the tie-breaking of period 2 with the buyer purchasing only from the more efficient supplier is also equilibrium behavior in period 1. For $\left(p_1^1, p_2^1\right) \in \mathcal{S}_{\mathrm{E}}$ meanwhile, only strategic sourcing equilibria exist. A modified tie-breaking rule, which has the buyer sourcing only the quantity from supplier 2 required to ensure his survival and the remainder from supplier 1, is then an equilibrium sourcing strategy. In the following we assume that these equilibria are implemented by the buyer[10].

The proposition asserts that for every price combination either only a myopic or a strategic sourcing equilibrium exists. Defining $\mathcal{S} = \mathcal{S}_{\mathrm{U}} \cup \mathcal{S}_{\mathrm{E}}$, competition is thus sustained if and only if $(p_1^1, p_2^1) \in \mathcal{S}$. Then, competition is not sustained if and only if $(p_1^1, p_2^1) \in \mathcal{M}$ with $\mathcal{M} = \mathcal{P} \setminus \mathcal{S}$. While in a strategic sourcing equilibrium both suppliers are active in the second period by definition, in a myopic sourcing equilibrium one of the suppliers enjoys a monopoly in the second period for a sufficiently high price in period 1. By proposition 1 both suppliers might exit however if the price of supplier $-i$ at which the buyer purchases is below μ_{-i}. Nevertheless, for the buyer this is not worse than the monopoly outcome as her second period surplus is zero in both cases by lemma 1.

Proposition 1 thus implies that strategic sourcing occurs when at least one of the suppliers sets a high price. This can also be seen from figure 2.2, where $\mathcal{S}$ and $\mathcal{M}$ are depicted for exemplary parameter values. This result is slightly counterintuitive as it might be expected that strategic sourcing takes place particularly when the difference of posted prices is small and accordingly also the surplus foregone by sourcing from the supplier with the higher price is small. However, this effect is in most cases overcompensated by the inverse dependence of the quantity required for supplier survival $\underline{Q}_i$ on the price of the supplier p_i^1 (cf. equation 2.4). For high prices, this quantity can reach low levels, thereby facilitating strategic sourcing and reducing foregone surplus.

The strategic sourcing equilibria are similar to the excessive consumption equilibria of Romano (1991). Consuming above demand from a monopolist to ensure production is similar to sourcing from the higher-priced supplier i to allow survival in our model. Accordingly, myopic sourcing corresponds to the non-consumption equilibrium. However, an important difference is that in our model a myopic sourcing equilibrium does not necessarily exist alongside a strategic sourcing equilibrium. Indeed, for a single buyer this is at most the case when the buyer is indifferent between equilibria, while in section 2.3.4 we find that for $n \geq 2$ buyers, both equilibrium types can exist simultaneously.

We now analyze how changes in parameters impact the main characteristics of a strategic sourcing equilibrium. These are the quantity purchased from the supplier with the

[10] Using the equal sharing tie-breaking rule in period 2 as well as in period 1 for $\left(p_1^1, p_2^1\right) \notin \mathcal{S}_{\mathrm{E}}$ and equally sharing "excess demand" not required to sustain a duopoly for $\left(p_1^1, p_2^1\right) \in \mathcal{S}_{\mathrm{E}}$ in period 1 yields, with marginal underbidding by ϵ, equilibrium predictions similar to proposition 2 below.

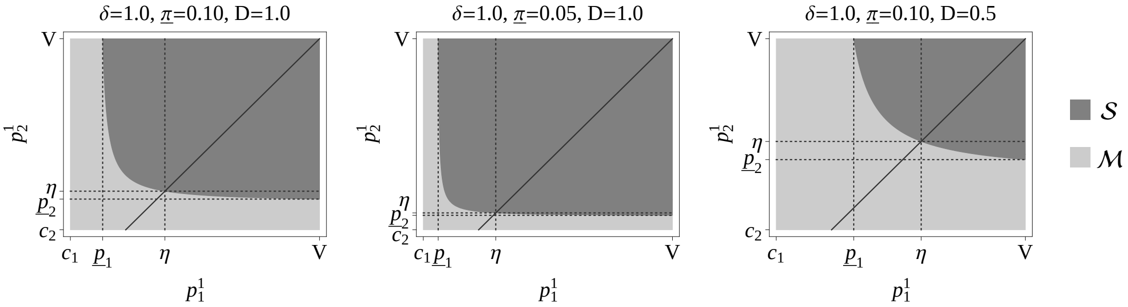

Figure 2.2: Buyer equilibrium types in period 1. Thereby $c_1 = 0.1$, $c_2 = 0.3$ and $V = 1.0$.

higher price $\underline{Q}_i$ for given prices $p_i^1 > p_{-i}^1$ and the range of price combinations $\mathcal{S}$ for which a strategic sourcing equilibrium exists.

When the discount factor decreases to $\delta' < \delta$, for those prices for which a strategic sourcing equilibrium exists also for δ', the quantity $\underline{Q}_i$ is unchanged as it is matched to the unchanged $\underline{\pi}$. With $P_i(p_i^1)$ and thus also η independent of δ, but $R_i(p_i^1)$ decreasing in δ, we have $\mathcal{S}(\delta') \subseteq \mathcal{S}(\delta)$. A lower present value of sustained competition can thus decrease the range of prices for which strategic sourcing equilibria exist if the rationality of sustaining competition is the limiting factor. When however P_i binds, $\mathcal{S}$ is unchanged as in figure 2.2, where ranges of $\mathcal{S}$ and $\mathcal{M}$ are identical for $\delta = 1.0$ and $\delta = 0.5$.

A decrease in the profit threshold to $\underline{\pi}' < \underline{\pi}$ decreases the quantity purchased from the supplier i with the higher price, $\underline{Q}_i(\underline{\pi}') < \underline{Q}_i(\underline{\pi})$ at given prices in $\mathcal{S}(\underline{\pi})$, as now a smaller quantity is sufficient to attain the profit required for survival. With $P_i(p_i^1)$, $R_i(p_i^1)$ and η decreasing, the set of prices for which a strategic sourcing equilibrium exists grows, $\mathcal{S}(\underline{\pi}') \supset \mathcal{S}(\underline{\pi})$ as shown in figure 2.2, since it is now for more prices possible and rational to sustain both suppliers.

When instead the market demand decreases to $D' < D$, then $\underline{Q}_i$ remains constant for prices in $\mathcal{S}(D')$. Meanwhile, the range of strategic sourcing decreases by equations 2.6-2.10, $\mathcal{S}(D') \subset \mathcal{S}(D)$ since a decreased market demand diminishes the options to keep both suppliers in the market and also decreases the benefit from sustained competition in the second period (cf. figure 2.2).

Some of these results differ from the findings of Clark and Polborn (2006) for given prices in a related two period Hotelling duopoly with multiple buyers. While in our model decreasing the minimum profit required for survival always decreases the quantity sourced strategically, Clark and Polborn (2006) find that it can, dependent on parameters, either increase or decrease the expected quantity purchased at the myopically inferior supplier. Furthermore, this quantity is smaller when the benefit of sustained competition decreases. This corresponds to a lower δ, which in our model leaves the quantity sourced from the higher-priced supplier unchanged. These differences stem mainly from the random distribution of buyers on the Hotelling line. Strategic sourcing thus only increases the probability of sustained competition, while in our model the buyer can ensure survival.

As we focus on strategic sourcing, we make the following assumption before proceeding.

Assumption 4. *The set of price combinations $\mathcal{S}$ for which strategic sourcing equilibria exist is non-empty.*

For $\mathcal{S}$ to be non-empty, $\eta \leq V$ is required by equations 2.8-2.10. Rewriting this condition yields $\underline{\pi} \leq D\,(V - c_V)$ with $c_V = \left(V^2 - c_1 c_2\right) / \left[2V - (c_1 + c_2)\right]$. We observe that $c_2 < c_V < V$. Thus, assumption 4 requires that the minimum profit $\underline{\pi}$ is at most as high as the monopoly profit of a supplier with a cost of c_V. Thus the assumption will generally be fulfilled, as in a monopoly even a supplier with costs higher than supplier 2 would be expected to realize a profit exceeding the minimum required for survival.

For further analyses, we express the conditions on parameters of assumptions 1 and 4 in terms of the marginal costs. Solving $\eta \leq V$ of assumption 4 for c_1 and calculating the maximum c_2 from the bounds on c_1, we obtain $c_1 \leq c_1^{\mathrm{A4}} = V - \underline{\pi}\,(V - c_2) / \left[D\,(V - c_2) - \underline{\pi}\right]$ and $c_2 \leq c_2^{\mathrm{A4}} = V - \underline{\pi}\,V / (D\,V - \underline{\pi})$, while assumption 1 yields $c_2 < c_2^{\mathrm{A1}} = V - \underline{\pi}/\delta D$. We consolidate these conditions and obtain the set of all cost combinations compatible with the assumptions

$$\mathcal{C} = \left\{(c_1, c_2)\,|\,c_1 \in \left[0, c_2\right) \cap \left[0, c_1^{\mathrm{A4}}\right], c_2 \in \left(0, c_2^{\mathrm{A1}}\right) \cap \left(0, c_2^{\mathrm{A4}}\right]\right\} . \tag{2.11}$$

This set is depicted in figure 2.3 below for different parameter values as the union $\mathcal{C} = \mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L1}} \cup \mathcal{C}_{\mathrm{L2}}$. Non-emptiness of the c_2 interval requires both $DV > \underline{\pi}/\delta$ and $DV \geq 2\,\underline{\pi}$. Thereby, DV corresponds to the monopoly profit of a supplier with a cost of zero. In the discussion of assumption 1 we argued that often δ does not differ significantly from one. Accordingly, by the arguments used in the discussion of assumptions 1 and 4, the monopoly profit of a zero cost supplier will generally be substantially higher than a small multiple of the minimum profit required for survival $\underline{\pi}$. With the c_2 interval therefore generally non-empty, by construction the c_1 interval is non-empty as well.

2.3.3 First Period - Suppliers

With the previous results, supplier equilibria in period 1 and thus subgame-perfect equilibria of the whole model are determined. As in period 2, we assume the suppliers to post only prices which are continuous limits of weakly undominated prices in a version of the model with discrete prices. Prices below the marginal cost $p_i^1 < c_i$ yield a profit $\pi_i \leq 0$, while prices above the buyer valuation $p_i^1 > V$ yield $\pi_i = 0$. Such prices are weakly dominated by any price $c_i < p_i^1 \leq V$ since then $\pi_i \geq 0$, with the inequality always holding for some prices of the other supplier $-i$. Thus, analyses can be limited to prices in $\mathcal{P}$.

We calculate equilibria using the best responses of the suppliers. In order to deduct these, two additional lemmas are required. The first details when a supplier i can respond to a price of supplier $-i$ by setting a price $p_i^1 \geq p_{-i}^1$ such that both suppliers are sustained by the buyer.

Lemma 2. *There exists a price $p_i^1 \geq p_{-i}^1$ such that competition is sustained if and only if $p_{-i}^1 \in \left[\underline{p}_{-i}, V\right]$. Thereby, $\underline{p}_{-i} = \max\{P_i(V), R_i(V)\}$ with $\underline{p}_{-i} \in (\mu_{-i}, \eta]$.*

Proof of lemma 2. The proof is included in the appendix. □

The lemma thus asserts that the lowest price $p_{-i}^1 = \underline{p}_{-i}$ at which both suppliers are sustained for $p_{-i}^1 \leq p_i^1$ is determined by the situation when supplier i sets the highest possible price V. This follows since both the minimum price p_{-i}^1 making sustaining competition possible, $P_i(p_i^1)$ as well as the minimum price making it rational for the buyer, $R_i(p_i^1)$ decrease with an increase in p_i^1.

Hence, when supplier $-i$ posts a price between $\underline{p}_{-i}$ and V, supplier i can respond with a price which will keep both suppliers active. Conversely, when supplier $-i$ sets a price $p_{-i}^1 < \underline{p}_{-i}$, then competition is never sustained regardless of the price of the other supplier, who can thus always be excluded. With the buyer single sourcing from supplier $-i$ and $\underline{p}_{-i} > \mu_{-i}$, survival is ensured and supplier $-i$ monopolizes the market in period 2.

We now detail the relative size of $\underline{p}_{-i}$ and the marginal cost of supplier i. For $-i = 2$, any price $p_2^1 \geq \underline{p}_2$ is always above the marginal cost of supplier 1 since $\mu_2 > c_1$. Accordingly, supplier 1 can then not only price accommodatingly by setting a higher price but also always match or marginally underbid the price of supplier 2 without incurring losses. In contrast, when $-i = 1$ and $p_1^1 \geq \underline{p}_1$ the relative size of $\underline{p}_1$ and c_2 determines whether these options are also open to supplier 2. Following the approach of equation 2.11, we express the relevant value of c_1 at which $\underline{p}_1$ is equal to the cost of supplier 2 as a function of c_2,

$$\underline{c}_1 = c_2 - \frac{\underline{\pi}\,(V - c_2)}{D\,(V - c_2) - \underline{\pi}}\,. \tag{2.12}$$

Due to assumption 1, $\underline{c}_1$ is always smaller than c_2. Depending on the size of the marginal cost of supplier 1 relative to $\underline{c}_1$, we have three sets of cost combinations,

$$\mathcal{C}_{\mathrm{L}} = \{(c_1, c_2)\,|\,(c_1, c_2) \in \mathcal{C}, c_1 \leq \underline{c}_1\}\ , \tag{2.13}$$

$$\mathcal{C}_{\mathrm{H1}} = \{(c_1, c_2)\,|\,(c_1, c_2) \in \mathcal{C}, \underline{c}_1 < c_1 \leq \underline{c}_1 + \underline{\pi}/D\}\ , \tag{2.14}$$

$$\mathcal{C}_{\mathrm{H2}} = \{(c_1, c_2)\,|\,(c_1, c_2) \in \mathcal{C}, c_1 > \underline{c}_1 + \underline{\pi}/D\}\ . \tag{2.15}$$

Furthermore, we define $\mathcal{C}_{\mathrm{H}} = \mathcal{C}_{\mathrm{H1}} \cup \mathcal{C}_{\mathrm{H2}}$ and observe that these sets partition the set of cost combinations compatible with the assumptions of equation 2.11: $\mathcal{C} = \mathcal{C}_{\mathrm{L}} \cup \mathcal{C}_{\mathrm{H}}$ and $\mathcal{C}_{\mathrm{L}} \cap \mathcal{C}_{\mathrm{H}} = \emptyset$. For a constant c_2, the marginal cost of supplier 1 is then below or equal to $\underline{c}_1$ and therefore lowest for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$. For marginal costs in $\mathcal{C}_{\mathrm{H}}$ it is accordingly higher. Correspondingly, the cost difference is large for costs in $\mathcal{C}_{\mathrm{L}}$ and small for $\mathcal{C}_{\mathrm{H}}$. For exemplary parameter combinations, the sets are depicted in figure 2.3 which is discussed in more detail below.

The set $\mathcal{C}_{\mathrm{H}}$ is always non-empty when $\mathcal{C}$ is non-empty due to $\underline{c}_1 < c_1^{\mathrm{A4}} = \underline{c}_1 + (V - c_2)$ and $\underline{c}_1 < c_2$. In contrast, $\mathcal{C}_{\mathrm{L}}$ is non-empty if and only if $D\,(V - c_2)\,/\underline{\pi} \geq V/c_2$, which follows directly from requiring $\underline{c}_1 \geq 0$. Multiplying the numerator and denominator of the right-hand side by D, this condition requires that the ratio of the supplier 2 monopoly profit to the minimum profit required for survival is not smaller than the ratio of the monopoly profit to the profit in a duopoly for a zero-cost supplier competing with supplier 2. This inequality will often be fulfilled for sufficiently small $\underline{\pi}$, as then enjoying a monopoly is likely to enhance the profit from the minimum required for survival by a higher factor for supplier 2 than a change from duopoly competition to a monopoly does for a supplier with a cost of zero.

With these definitions, the following lemma provides a relationship between the marginal costs and the size of the lowest price of supplier 1 at which competition is sustained.

Lemma 3. *The relative size of $\underline{p}_1$ for supplier 1 is given by the following relations,*

$$\begin{aligned} \underline{p}_1 \le c_2 &\iff (c_1, c_2) \in \mathcal{C}_{\mathrm{L}}\,, \\ c_2 < \underline{p}_1 \le \mu_2 &\iff (c_1, c_2) \in \mathcal{C}_{\mathrm{H1}}\,, \\ \underline{p}_1 > \mu_2 &\iff (c_1, c_2) \in \mathcal{C}_{\mathrm{H2}}\,. \end{aligned}$$

Proof of lemma 3. The proof is included in the appendix. □

In order to express best responses of suppliers, we formalize marginal underbidding behavior by introducing $\epsilon > 0$ with $\epsilon \to 0$ always. As prices are continuous, $p_i^1 - \epsilon$ is therefore interpreted as the highest price which is smaller than p_i^1 and for which the difference to p_i^1 is discernible by and relevant for the market participants. Introducing ϵ is necessary to avoid the non-existence of profit-maximizing prices on open price sets when underbidding marginally. Alternatively, ϵ can also be interpreted as a smallest unit of account, which generally exists in real currencies. It then defines a discrete price grid, as is used in the numerical analysis in section 2.4, yielding results which are very similar to the continuous solution.

Observing that the profit of supplier 1 depends on both the relative price compared to supplier 2 as well as the period 2 market structure induced by the respective supplier behavior, the best response of supplier 1 can be deducted, yielding the next lemma.

Lemma 4. *The best response of supplier 1 to a price p_2^1 of supplier 2 is to either match the price or underbid, $p_{1,\mathrm{r}}^1(p_2^1) \le p_2^1$.*

Proof of lemma 4. The proof is included in the appendix. □

We thus find that for the more efficient supplier incentives for aggressive pricing are quite strong. Matching occurs as a best response only because of the tie-breaking rule which leads supplier 1 to often sell the same quantity as when marginally underbidding, while the higher price increases the profit. As shown in the proof, for low prices $p_2^1 < \eta$, matching the price is optimal since this leads to myopic sourcing of the buyer. Supplier 1 thus successfully excludes supplier 2 and for sufficiently high prices enjoys a monopoly in period 2. For even higher prices $p_2^1 \ge \eta$, exclusionary pricing can still prevail but now requires supplier 1 to price below both $P_2(p_2^1)$ and $R_2(p_2^1)$. However, also matching can be optimal. Then, both suppliers are sustained but the buyer still sources as high a quantity as possible from supplier 1, who in addition realizes the duopoly profit in the second period.

To detail the corresponding best response of supplier 2, we define the inverse functions of P_i and R_i from equations 2.6 and 2.7, which now depend on the lower price $p^1_{-i} < p^1_i$,

$$P_i^{-1}(p^1_{-i}) = c_i + \frac{\underline{\pi}\left(p^1_{-i} - c_{-i}\right)}{D\left(p^1_{-i} - c_{-i}\right) - \underline{\pi}}\,, \tag{2.16}$$

$$R_i^{-1}(p^1_{-i}) = \frac{c_i\,\delta\,D\,(V - c_2) - p^1_{-i}\,\underline{\pi}}{\delta\,D\,(V - c_2) - \underline{\pi}}\,. \tag{2.17}$$

These functions allow to express $\mathcal{S}^i_{\mathrm{U}}$ with conditions on p^1_i which depend on p^1_{-i} (cf. proof of lemma 5). Hence, for prices to be in $\mathcal{S}^i_{\mathrm{U}}$, now $p^1_i \geq \max\left\{P_i^{-1}(p^1_{-i}), R_i^{-1}(p^1_{-i})\right\}$ has to hold. By proceeding as for supplier 1, we acquire the best response of supplier 2.

Lemma 5. *The best response of supplier 2 to a price p^1_1 of supplier 1 is to underbid, $p^1_{2,\mathrm{r}}(p^1_1) < p^1_1$, except for the following prices.*

A) If $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$, then

$$p^1_{2,\mathrm{r}}(p^1_1) \in \begin{cases} [c_2\,,\,V] & \textit{for } p^1_1 \in \left[c_1, \underline{p}_1\right) \\ \left[\max\left\{P_2^{-1}(p^1_1), R_2^{-1}(p^1_1)\right\}, V\right] & \textit{for } p^1_1 \in \left[\underline{p}_1, \mu_2\right] \end{cases}.$$

B) If $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$, then

$$p^1_{2,\mathrm{r}}(p^1_1) \in \begin{cases} [c_2, V] & \textit{for } p^1_1 \in [c_1, c_2] \\ \left[\max\left\{P_2^{-1}(p^1_1), R_2^{-1}(p^1_1)\right\}, V\right] & \textit{for } p^1_1 \in \left[\underline{p}_1, \mu_2\right] \end{cases},$$

where the second interval is non-empty only for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H1}}$.

Proof of lemma 5. The proof is included in the appendix. □

Thus, also for supplier 2 optimal pricing is often aggressive and dominated by underbidding. Due to the tie-breaking rule which confers an advantage to the more efficient supplier, matching the price is never optimal for prices above the cost of supplier 2. In the case of prices $p^1_1 \leq \eta$, if underbidding is optimal, then supplier 2 underbids marginally and excludes supplier 1. Meanwhile, for $p^1_1 > \eta$, exclusion of supplier 1 requires drastic underbidding below P_1 and R_1. Either this is optimal or marginal underbidding is, with both suppliers being sustained but supplier 2 selling the larger quantity share.

However, there are also intervals of supplier 1 prices where for supplier 2 it is optimal to accommodate and respond with a higher price in $\mathcal{S}$. Then, he is sustained in a duopoly by strategic sourcing of the buyer with a profit of exactly $\pi_2 = \underline{\pi}$. Accordingly, supplier 2 is indifferent between all prices which induce strategic sourcing. This accommodating response occurs for the lowest prices of supplier 1 which can lead to sustained competition, $p^1_1 \geq \underline{p}_1$. They have to be so low however that supplier 2 will never be sustained when responding by underbidding and therefore does not enjoy a monopoly in period 2, $p^1_1 \leq \mu_2$. This interval is then non-empty only for large cost differences with $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}} \cup \mathcal{C}_{\mathrm{H1}}$, as then $\underline{p}_1 \leq \mu_2$. For costs in $\mathcal{C}_{\mathrm{L}}$ this includes prices of supplier 1 below c_2, i.e., even for prices below his cost, supplier 2 can "force" strategic sourcing by setting a high price. Regardless of the relative size of costs, when supplier 1 prices so low that supplier 2 is always excluded ($p_1^1 < \underline{p}_1$), then the latter is indifferent between all of his prices $p_2^1 \in [c_2, V]$.

To be able to deduct equilibria, the best response of supplier 1 has to be detailed for $p_2^1 = V$ and costs $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$. In the proof of lemma 4 we found that either drastic underbidding below $\underline{p}_1$ or matching the price is optimal. In the latter case competition is sustained while in the former case it is not. Via $\underline{p}_1$ optimality depends on the costs of the suppliers. Hence, we define three reference values of the marginal cost of supplier 1,

$$\tilde{c}_1 = V - \left[\frac{\delta\, D\,(V - c_2)}{\underline{\pi}} + \frac{\underline{\pi}}{D\,(V - c_2) - \underline{\pi}}\right](V - c_2)\ , \tag{2.18}$$

$$c_1^R = V - \frac{\delta\, D\,(V - c_2)}{\underline{\pi}}\,\frac{D\,(V - c_2) - \underline{\pi}}{\underline{\pi}}\,(V - c_2)\ , \tag{2.19}$$

$$c_1^P = \frac{V - c_2}{D\,(V - c_2) - \underline{\pi}}\left[D\,V - \delta\, D\,(V - c_2) - \underline{\pi} - \frac{\underline{\pi}\, V}{V - c_2} - \frac{\underline{\pi}^2}{D\,(V - c_2) - \underline{\pi}}\right]. \tag{2.20}$$

Thereby, for $c_1 \leq \tilde{c}_1$, $R_2(V)$ binds in $\underline{p}_1$, while for higher costs $P_2(V)$ binds. The values c_1^R and c_1^P are the additional upper and lower bounds for which drastic underbidding is superior for supplier 1 to matching the price of the less efficient supplier. These cost values then define the sets

$$\mathcal{C}_{\mathrm{L2R}} = \left\{(c_1, c_2)\,|\,(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}, c_1 \leq \tilde{c}_1, c_1 < c_1^R\right\}\ , \tag{2.21}$$

$$\mathcal{C}_{\mathrm{L2P}} = \left\{(c_1, c_2)\,|\,(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}, c_1 \geq \tilde{c}_1, c_1 > c_1^P\right\}\ . \tag{2.22}$$

Accordingly, we define $\mathcal{C}_{\mathrm{L2}} = \mathcal{C}_{\mathrm{L2R}} \cup \mathcal{C}_{\mathrm{L2P}}$, which is the set of costs for which drastic underbidding is a best response of supplier 1. Defining $\mathcal{C}_{\mathrm{L1}} = \mathcal{C}_{\mathrm{L}} \setminus \mathcal{C}_{\mathrm{L2}}$, the set of marginal costs compatible with the assumptions is then partitioned as $\mathcal{C} = \mathcal{C}_{\mathrm{L1}} \cup \mathcal{C}_{\mathrm{L2}} \cup \mathcal{C}_{\mathrm{H}}$. We can thus state the next lemma.

Lemma 6. *For $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$ and a price $p_2^1 = V$ of supplier 2, $p_{1,\mathrm{r}}^1(V) = \underline{p}_1 - \epsilon$ is a best response of supplier 1 if and only if $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}}$.*

Proof of lemma 6. The proof is included in the appendix. □

While for costs in $\mathcal{C}_{\mathrm{L2}}$ drastic underbidding is therefore generally the unique best response of supplier 1 to a price $p_2^1 = V$, for some costs the supplier is indifferent between underbidding drastically and matching the price. Accordingly, for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L1}}$, the unique best response of supplier 1 to a price $p_2^1 = V$ is to match the price, $p_{1,\mathrm{r}}^1(V) = V$. With $\mathcal{C}_{\mathrm{L}}$ non-empty by assumption and $\tilde{c}_1 < \underline{c}_1$ always, $\mathcal{C}_{\mathrm{L2}}$ is non-empty when, e.g., $c_1^P < \underline{c}_1$. This in turn is fulfilled for $\delta \geq 1 - \underline{\pi}/\left[D\,(V - c_2) - \underline{\pi}\right]$, which by assumption 1 holds, e.g., for $\delta = 1$. Thus, there exist parameter combinations such that $\mathcal{C}_{\mathrm{L2}}$ is non-empty. By identifying pure strategy equilibria as mutual best responses, we can then state the second proposition.

Proposition 2. *The following subgame-perfect pure strategy equilibria of the model exist.*

A) If $(c_1, c_2) \in \mathcal{C}_{L2}$, then there exists a unique equilibrium where suppliers set prices $\left(p_1^{1*}, p_2^{1*}\right) = \left(\underline{p}_1 - \epsilon, V\right)$. The buyer sources myopically from supplier 1 only, $\left(Q_1^{1*}, Q_2^{1*}\right) = (D, 0)$ and supplier 1 enjoys a monopoly in period 2.

B) If $(c_1, c_2) \in \mathcal{C}_{H}$, then there exists a unique equilibrium where suppliers set prices $\left(p_1^{1*}, p_2^{1*}\right) = (c_2, c_2)$. The buyer sources myopically from supplier 1 only, $\left(Q_1^{1*}, Q_2^{1*}\right) = (D, 0)$. Supplier 1 enjoys a monopoly in period 2 if and only if $c_2 \geq \mu_1$, otherwise both suppliers exit.

C) If $(c_1, c_2) \in \mathcal{C}_{L1}$, then no pure strategy equilibrium exists.

Proof of proposition 2. The proof is included in the appendix. □

For a price combination to be an equilibrium both $p_1^{1*} \in p_{1,\mathrm{r}}^1(p_2^{1*})$ and $p_2^{1*} \in p_{2,\mathrm{r}}^1(p_1^{1*})$ have to hold. With supplier 1 always matching or underbidding the price of supplier 2 according to lemma 4, only those prices p_1^1 can be part of an equilibrium for which by lemma 5, supplier 2 responds by matching or setting a higher price. Prices $p_1^1 \in \left[\underline{p}_1, \mu_2\right]$ are however not part of an equilibrium, as the best response of supplier 2 is then always such that $\left(p_1^1, p_2^1\right) \in \mathcal{S}$. In turn, supplier 1 responds according to the discussion of lemma 4 by either underbidding such that $p_{1,\mathrm{r}}^1$ does not lie in $\mathcal{S}$ or by matching the price, which is then higher than the original price, $p_{1,\mathrm{r}}^1 > \mu_2$. Hence, only the ranges of p_1^1 where supplier 2 is indifferent between all his prices can support an equilibrium. These then yield the unique equilibria of the proposition, depending on whether $\underline{p}_1 - \epsilon$ or c_2 is the highest price at which supplier 2 is indifferent and in the former case on whether drastic underbidding is a best response of supplier 1 to $p_2^1 = V$. When this is not the case for $(c_1, c_2) \in \mathcal{C}_{L1}$, no subgame-perfect equilibrium in pure strategies exists.

In all equilibria of proposition 2, supplier 1 successfully excludes supplier 2 and forces or entices the buyer to single source in the first period. Depending on the difference of marginal costs, supplier 1 then often enjoys a monopoly in period 2. Despite strong incentives for the buyer to sustain competition, in equilibrium exclusionary underbidding is thus the more powerful factor, leading to the exclusion of the less efficient supplier. For $(c_1, c_2) \in \mathcal{C}_{L2}$, behavior is therefore clearly predatory. Although supplier 1 does not price below his own cost, he prices below the cost of the competing supplier 2 and is in all cases successful in recouping the profit foregone in period 1 from pricing below c_2 by monopolizing the market in period 2. For costs in $\mathcal{C}_H$, successful recoupment requires according to proposition 2 costs to be sufficiently different, $c_2 - c_1 \geq \underline{\pi}/D$. Then, it suffices for supplier 1 to price at the cost of the less efficient supplier to gain exclusivity.

The equilibria for $(c_1, c_2) \in \mathcal{C}_H$ are closely related to those of the associated one period model. In both cases, supplier 1 prices just so low that supplier 2 cannot underbid further without making losses. This yields the same equilibrium prices in a strategic and myopic setting. For costs in $\mathcal{C}_{L2}$ however, supplier 2 prices as high as possible. This minimizes the quantity the buyer has to source to sustain supplier 2 and therefore maximizes the range

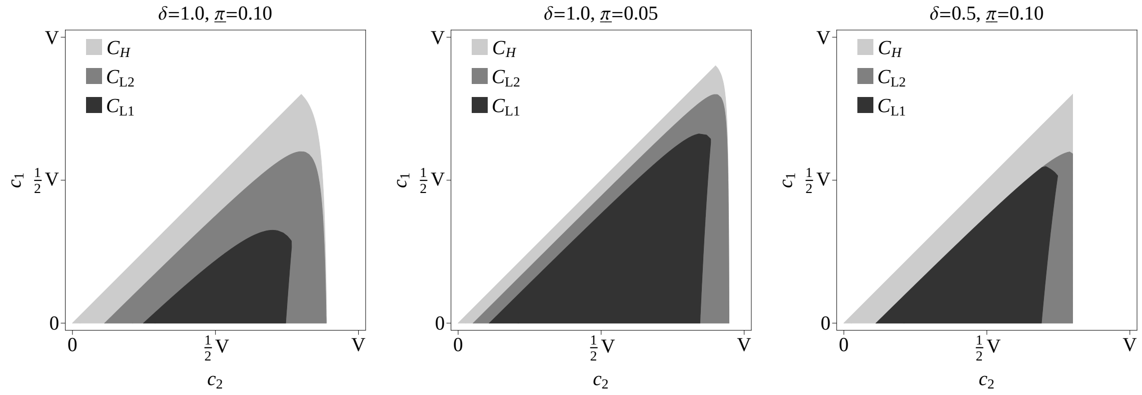

Figure 2.3: Sets of marginal cost combinations. Thereby $D = 1.0$, $V = 1.0$.

of prices of supplier 1 for which supplier 2 realizes a positive profit. Meanwhile, supplier 1 prices so low that the buyer sources exclusively from him. When $R_2(V)$ binds in $\underline{p}_1$ for $(c_1, c_2) \in \mathcal{C}_{\text{L2R}}$, this follows because it yields higher total surplus, while when $P_2(V)$ binds for costs in $\mathcal{C}_{\text{L2P}}$, the demand of the buyer is insufficient to keep both suppliers active. Exclusive sourcing is thus guaranteed for all prices $p_1^1 < \underline{p}_1$ and supplier 1 maximizes his profit by pricing as close as possible to $\underline{p}_1$. We express this optimization on an open set as $p_1^{1*} = \underline{p}_1 - \epsilon$, similar to the one period situation with an equal-sharing tie-breaking rule[11]. The robustness of this approach is demonstrated by the numerical results with a discretized price space in section 2.4, where we find basically the same equilibrium types as in the continuous case for $(c_1, c_2) \in \mathcal{C}_\text{H} \cup \mathcal{C}_{\text{L2}}$.

For exemplary parameter values, figure 2.3 depicts the sets of marginal costs of proposition 2. An identical inverted structure would arise for $c_1 > c_2$, which is not shown however. The cost combinations for high values of c_2 are excluded by assumptions 1 and 4 on $\mathcal{C} = \mathcal{C}_\text{H} \cup \mathcal{C}_{\text{L1}} \cup \mathcal{C}_{\text{L2}}$ (cf. equation 2.11). For $(c_1, c_2) \in \mathcal{C}_\text{H}$, supplier 1 prices at $p_1^{1*} = c_2$ in equilibrium. As discussed above (cf. lemma 3), this case arises when c_1 values are high for a given c_2 and therefore the cost difference between suppliers is small. However, for large c_2 values, $\mathcal{C}_\text{H}$ can also encompass comparably large cost differences. The lower bound on $\mathcal{C}_\text{H}$ values is given by $\underline{c}_1$ and therefore with $\partial_{\underline{\pi}} \underline{c}_1 < 0$, the range of costs in $\mathcal{C}_\text{H}$ decreases with a decrease in the profit threshold as evidenced by figure 2.3. Then it is more often possible to sustain competition and $\underline{p}_1$ decreases, requiring prices below c_2 to exclude supplier 2. A lower discount factor leaves $\mathcal{C}_\text{H}$ unchanged as $\underline{c}_1$ is independent of δ, except for the impact of the smaller range of costs compatible with the assumptions.

The set of costs $\mathcal{C}_{\text{L2}}$ for which a pure strategy equilibrium with $p_1^{1*} < c_2$ arises corresponds for a given c_2 to medium costs of supplier 1, while $\mathcal{C}_{\text{L1}}$ encompasses the lowest costs. The range of costs in $\mathcal{C}_{\text{L2}}$ then never increases with a reduction in the profit threshold. With $\underline{p}_1$ being lower for decreased values of $\underline{\pi}$, at $p_2^1 = V$ it becomes less attractive

[11]When $R_2(V)$ binds, changing assumption 3 to the buyer sourcing myopically in the case of indifference resolves marginal underbidding in equilibrium. When $P_2(V)$ binds, requiring a profit strictly higher than $\underline{\pi}$ for survival can address the issue. Then however, to sustain supplier i with $p_i^1 > p_{-i}^1$, the buyer has to optimize Q_i on an open set.

for supplier 1 to exclude supplier 2. Instead the best response is to match the price and be sustained in a duopoly (cf. lemma 6). Costs are then in $\mathcal{C}_{\mathrm{L1}}$ as in figure 2.3. When however the discount factor decreases, enjoying a monopoly in period 2 becomes less valuable for supplier 1 while now also $\underline{p}_1$ can increase, leading to no unambiguous change in the relative sizes of $\mathcal{C}_{\mathrm{L1}}$ and $\mathcal{C}_{\mathrm{L2}}$.

In all pure strategy equilibria of the model, no strategic sourcing occurs in equilibrium according to proposition 2. However, for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}}$ the price in period 1 is reduced compared to the price in a one period interaction. This result is similar to that in the model of Clark and Polborn (2006), where also no strategic sourcing might occur in equilibrium but prices of suppliers can be altered from the one period equilibrium. Furthermore, the equilibria for costs in $\mathcal{C}_{\mathrm{L2}}$ are also related to those of Bergès and Chambolle (2009) where the more efficient supplier prices below the cost of the less efficient supplier and excludes him. However, then the less efficient supplier prices always at his cost, while in our case the equilibrium price $p_2^{1*} = V$ can be interpreted consistently as a result of accommodating behavior, due to survival of suppliers depending on the profit. Furthermore, in Bergès and Chambolle (2009) the equilibrium arises only when the discount factor of the suppliers is low, while we find that exclusion can occur under very general circumstances.

With the unique subgame equilibria of proposition 2, also surplus of all market participants is uniquely determined. The buyer realizes a surplus of $\mathrm{BS} = D\left(V - p_1^{1*}\right)$. Meanwhile, the profit of supplier 1 is $\pi_1^1 = D\left(p_1^{1*} - c_1\right)$ in period 1, while an additional profit of $\pi_1^{2\mathrm{M}} = D\left(V - c_1\right)$ follows in period 2 if the supplier is sustained in a monopoly. For supplier 2 the profit is always $\pi_2 = 0$.

We now compare these surplus distributions to those from a procurement process where the buyer commits to always single source myopically from the supplier with the lower price only[12]. Then, for all prices a myopic sourcing equilibrium as in proposition 1 is implemented in the buyer subgame and the equilibrium of part B) of proposition 2 with $p_1^{1*} = c_2$ arises for all costs $(c_1, c_2) \in \mathcal{C}$.

Hence, for small cost differences in $\mathcal{C}_{\mathrm{H}}$, the buyer realizes the same surplus when committing to myopic sourcing as when keeping open the option to source strategically. However, when for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}}$ the cost difference is of medium values, in period 1 the price of supplier 1 is lower at $p_1^{1*} < \underline{p}_1 \leq c_2$ when not committing to myopic sourcing. Accordingly, with myopic sourcing the surplus of the buyer is decreased by more than $D\big(c_2 - \underline{p}_1\big)$, while the surplus of supplier 1 increases by the same amount. The threat of sourcing strategically from both suppliers forces the more efficient supplier to post a lower price in period 1 than he would have done had the buyer committed to myopic sourcing ex-ante. For both regimes of costs, the buyer thus never looses power by retaining the option to source strategically.

This finding contrasts with some of the related analyses. In the two period Hotelling model of Clark and Polborn (2006) there exist cases in which buyers would benefit from

[12]A myopic procurement process can be implemented, e.g., by publishing explicit rules (Biglaiser and Vettas 2005) or through the rotation of purchasing managers (Lewis and Yildrim 2002).

committing to source myopically only. This is also the case for those equilibria in Bergès and Chambolle (2009) where suppliers set prices so high in the first period that they can extract all surplus. Also, in the model with intertemporal capacity constraints of Biglaiser and Vettas (2005), often buyers would receive a higher surplus if they announced and followed a myopic purchasing policy. In line with our finding, for the exclusion equilibria of Bergès and Chambolle (2009) it would be to the detriment of the buyer to commit to purchase only myopically. Hence, it depends on the structure of the equilibrium and thus on the exact situation and parameter values whether retaining the option to source strategically can increase the surplus of the buyer.

2.3.4 Multiple Buyers

While results in the previous sections were deducted for a single buyer, we now analyze how these change when there are $n \geq 2$ identical buyers $j \in \{1, \ldots, n\}$ in the market. Each buyer has a demand of $d = D/n$ for the homogeneous good and decides how to source this from suppliers, $d = q^t_{1,j} + q^t_{2,j}$. All buyers together thus purchase the aggregate quantity $Q^t_i = \sum_j q^t_{i,j}$ from supplier i.

In a duopoly in period 2, each of the j buyers sources only from the supplier with the lower price for unequal prices and only from supplier 1 for equal prices. With aggregate demand and therefore also supplier behavior unchanged, the same equilibrium prices as for a single buyer in lemma 1 arise and all buyers now purchase their complete demand d from supplier 1. The same holds for a monopoly where all buyers source from supplier i. Accordingly, each buyer realizes additional surplus of $\mathrm{BS}^{\mathrm{2D}}_j = \delta\, d\,(V - c_2)$ in the second period from sustaining competition.

In period 1, the price at which a buyer j can sustain supplier i alone is now given by

$$\mu^{\mathrm{d}}_i = c_i + \underline{\pi}/d\,. \tag{2.23}$$

Furthermore, it is optimal for buyer j to sustain the higher-priced supplier alone if and only if the lower price p^1_{-i} is at least as high as

$$r_i(p^1_i) = p^1_i - \frac{\delta\, d\,(V - c_2)}{\underline{\pi}} \left(p^1_i - c_i\right)\,. \tag{2.24}$$

While for a single buyer only either strategic or myopic sourcing equilibria exist for given prices (except for cases of indifference), now both equilibrium types can exist simultaneously. We define the range of unequal prices for which a profitable deviation of a buyer j from myopic sourcing at the lower-priced supplier $-i$ is possible,

$$\mathcal{M}^{\mathcal{C},i}_{\mathrm{U}} = \left\{\, \left(p^1_1, p^1_2\right) \mid p^1_{-i} \in \left[\max\left\{P_i(p^1_i), r_i(p^1_i)\right\}, p^1_i\right), p^1_i \in \left[\mu^{\mathrm{d}}_i, V\right] \cap (\eta, V]\,\right\}. \tag{2.25}$$

With $\mathcal{M}^{\mathcal{C}}_{\mathrm{U}} = \mathcal{M}^{\mathcal{C}1}_{\mathrm{U}} \cup \mathcal{M}^{\mathcal{C}2}_{\mathrm{U}}$ and $\mathcal{P}_{\mathrm{U}} = \left\{\left(p^1_1, p^1_2\right) \mid \left(p^1_1, p^1_2\right) \in \mathcal{P}, p^1_1 \neq p^1_2\right\}$, a myopic sourcing equilibrium then exists for all unequal prices in $\mathcal{M}_{\mathrm{U}} = \mathcal{P}_{\mathrm{U}} \setminus \mathcal{M}^{\mathcal{C}}_{\mathrm{U}}$. Here we have limited analysis to prices in $\mathcal{P}$ by the same arguments as in section 2.3.2. The range of equal prices for which a myopic sourcing equilibrium exists is given directly by

$$\mathcal{M}_{\mathrm{E}} = \left\{ \left(p_1^1, p_2^1\right) \mid p_1^1 = p_2^1, p_2^1 \in \left[0, \mu_2^{\mathrm{d}}\right) \right\} . \tag{2.26}$$

We define $\mathcal{M} = \mathcal{M}_{\mathrm{U}} \cup \mathcal{M}_{\mathrm{E}}$ analogously to $\mathcal{S}$ and can thus state the following proposition.

Proposition 3. *The following equilibria of the buyer subgame with $n \geq 2$ identical buyers exist in period 1.*

A) A strategic sourcing equilibrium exists for prices (p_1^1, p_2^1) if and only if a strategic sourcing equilibrium exists for a single buyer. For prices $p_1^1 \neq p_2^1$, the aggregate demand allocation is uniquely determined as $(Q_1^1, Q_2^1) = (Q_1^{1\mathrm{S}}, Q_2^{1\mathrm{S}})$. For prices $p_1^1 = p_2^1$, there exist strategic sourcing equilibria with an aggregate demand allocation of $\left(Q_1^1, Q_2^1\right) = \left(D - \underline{Q}_2, \underline{Q}_2\right)$.

B) A myopic sourcing equilibrium exists if and only if $(p_1^1, p_2^1) \in \mathcal{M}$. For prices $p_1^1 \neq p_2^1$, the aggregate demand allocation is uniquely determined as $\left(Q_1^1, Q_2^1\right) = \left(Q_1^{1\mathrm{M}}, Q_2^{1\mathrm{M}}\right)$. For prices $p_1^1 = p_2^1$, there exists a myopic sourcing equilibrium with an aggregate demand allocation of $\left(Q_1^1, Q_2^1\right) = (D, 0)$.

Proof of proposition 3. The proof is included in the appendix. □

In a strategic sourcing equilibrium for unequal prices, the aggregate quantity $\underline{Q}_i$ then keeps the higher-priced supplier i in the market with exactly $\underline{\pi}$ profits. Then, all other aggregate demand allocations either do not sustain competition or allow a single buyer to increase surplus by purchasing less from supplier i. Also for equal prices, the same aggregate demand allocation as for a single buyer can be implemented as an equilibrium. We assume in the following that this is done. The proposition thus assures that the aggregate quantities sourced in equilibria of the buyer subgame are identical for multiple and a single buyer. Hence, strategic sourcing equilibria exist for the same prices and the same aggregate quantities are sourced for $n \geq 2$ buyers as for a single buyer.

With multiple buyers, a myopic sourcing equilibrium can exist also for prices where a strategic sourcing equilibrium exists, i.e., $\mathcal{S} \cap \mathcal{M}$ can be non-empty. Even then however, for unequal prices the aggregate demand allocation in equilibrium is identical to that in a myopic sourcing equilibrium of a single buyer. Also for equal prices, the same aggregate demand allocation can be implemented as an equilibrium. With $\mu_2^{\mathrm{d}} > c_2$ we observe that $\mathcal{M}_{\mathrm{E}}$ and thus $\mathcal{M}$ are always non-empty, i.e., there are always some prices for which myopic sourcing is equilibrium behavior. Furthermore, for all price combinations in $\mathcal{P}$ for which there is no strategic sourcing equilibrium, a myopic equilibrium exists.

For use in the next corollary we define

$$\mathcal{R}_{\mathrm{U}}^i = \left\{\left(p_1^1, p_2^1\right) \mid p_{-i}^1 = R_i(p_i^1), p_i^1 > p_{-i}^1\right\} , \tag{2.27}$$

the set of prices where a single buyer $n = 1$ is indifferent between purchasing strategically and myopically. Defining also $\mathcal{R}_{\mathrm{U}} = \mathcal{R}_{\mathrm{U}}^1 \cup \mathcal{R}_{\mathrm{U}}^2$, we can detail which demand allocations of individual buyers can support a strategic sourcing equilibrium.

Corollary 1. *For $n \geq 2$ identical buyers a symmetric strategic sourcing equilibrium exists for all $(p_1^1, p_2^1) \in \mathcal{S}$. In addition, infinitely many non-symmetric strategic sourcing equilibria exist for $(p_1^1, p_2^1) \in \mathcal{S} \setminus \mathcal{R}_{\mathrm{U}}$.*

Proof of corollary 1. The proof is included in the appendix. □

Thus, for every price combination in $\mathcal{S}$ a symmetric strategic sourcing equilibrium exists where each of the n buyers decides on exactly the same demand allocation. In addition, except for prices in $\mathcal{R}_{\mathrm{U}}$, infinitely many quantity allocations which are not identical for all buyers can be equilibria, although by proposition 3 all yield the same aggregate demand allocation. These equilibria exist because every arbitrarily small additional quantity purchased by a buyer j from the supplier with the higher price allows all other buyers to purchase less from this supplier. As long as it is not more profitable for buyer j to source from the lower-priced supplier only, this is then a strategic sourcing equilibrium. It may thus be challenging to implement a strategic sourcing equilibrium as buyers have to coordinate on specific quantities to be sourced from suppliers. The next corollary offers additional insight on this.

Corollary 2. *For $n \geq 2$ identical buyers, strategic and myopic sourcing equilibria always exist simultaneously for some price combinations. Then, all strategic sourcing equilibria are at least weakly pareto-superior for buyers to the myopic sourcing equilibria. There are prices for which only strategic sourcing equilibria exist if and only if $\mu_1^{\mathrm{d}} \leq V$ and $\eta < V$.*

Proof of corollary 2. The proof is included in the appendix. □

The prices for which only strategic sourcing equilibria exist are thereby exactly those prices for which a buyer j can profitably sustain the higher-priced supplier alone, since this defines a profitable deviation from a myopic sourcing demand allocation. This is also evident from the condition $\mu_1^{\mathrm{d}} \leq V$, which states that it is possible for a buyer j to sustain the more efficient supplier at V alone. The existence of prices $p_2^1 < V$ for which this is also rational is assured by $\eta < V$ as then $\mathcal{S}_{\mathrm{U}}$ is non-empty. For small numbers of buyers n and thus comparably large values of d the first condition will generally be fulfilled, while the second is a slightly more restrictive version of assumption 4. This is also discernible from figure 2.4, where the range of prices which are in $\mathcal{S}$ but not in $\mathcal{M}$ decrease with an increase in the number of buyers n at constant market demand D. This is not unlike the finding of Fumagalli and Motta (2008) that the probability of buyers failing to coordinate on sourcing such that entry of a more efficient supplier is possible increases in the number of buyers.

By corollary 2 both equilibrium types always exist for some prices. The weak pareto superiority of strategic sourcing equilibria for buyers follows directly from the fact that it is not profitable for any buyer j to deviate to myopic purchasing and thus realize the

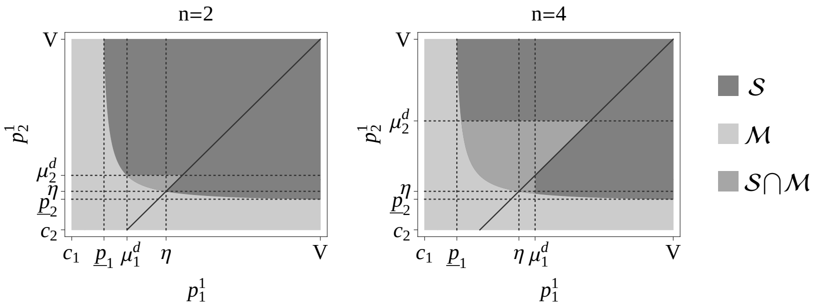

Figure 2.4: Buyer equilibrium types in period 1. Thereby $\delta = 1.0$, $\underline{\pi} = 0.1$, $D = 1.0$, $c_1 = 0.1$, $c_2 = 0.3$ and $V = 1.0$.

same surplus as in the myopic sourcing equilibrium. Accordingly, we find that strategic sourcing is either weakly preferred by all buyers or the only equilibrium outcome.

Implementing one of the strategic sourcing equilibria requires buyers in any case to coordinate. Strategic sourcing is then for unequal prices structurally similar to a discrete public good game. Sustained competition allows all buyers j to realize an additional surplus of $\mathrm{BS}_j^{2\mathrm{D}}$ in the second period if the contributions of quantities sourced from the supplier i with the higher price $q_{i,j}^1$ attain the quantity $\underline{Q}_i$ required for survival, while the remaining demand ensures that also supplier $-i$ attains the profit threshold. Free riding in equilibrium is somewhat mitigated as any deviation by a buyer to purchasing less from the higher-priced supplier results in competition not being sustained. However, in contrast to many public good games, there are also often prices where it may be rational for a single buyer to sustain competition, thereby reducing the coordination problem.

With $D = n\,d$, both the range of prices $\mathcal{S}$ for which a strategic sourcing equilibrium exists as well as the quantity sourced from supplier i with the higher price, $\underline{Q}_i$ depend on the number of buyers with demand d in the same way as on the market demand D. Using the results from section 2.3.2, we thus have for $n' < n$ that $\mathcal{S}(n') \subset \mathcal{S}(n)$, while $\underline{Q}_i$ does not change. When however overall demand D is constant, then according to proposition 3 both measures are unchanged, which can also be observed from figure 2.4. The first finding is again in contrast to the corresponding result in the Hotelling model of Clark and Polborn (2006), where the quantity sourced from the myopically inferior supplier can increase or decrease with a lower number of buyers, due to the random positions of buyers on the Hotelling line.

To be able to deduct behavior of suppliers in period 1 in the presence of $n \geq 2$ buyers, we make the following assumption[13].

Assumption 5. *Buyers purchase only according to pareto-optimal equilibria.*

In combination with assumption 3 in the case of weak pareto optimality, we thus assume that when for a posted price combination at least one strategic sourcing equilibrium exists,

[13]Cf., e.g., Romano (1991) for a similar approach in a related model.

then buyers purchase according to it. The next corollary then details the resulting overall equilibrium outcome.

Corollary 3. *For $n \geq 2$ identical buyers, the existence of subgame-perfect pure strategy equilibria as well as equilibrium prices, aggregate quantities and the ensuing period 2 market structure are identical to those for a single buyer.*

Proof of corollary 3. The proof is included in the appendix. $\square$

With the additional assumption 5, the aggregate behavior of the $n \geq 2$ buyers is identical to that of a single buyer and therefore pricing in period 1 is unchanged. Accordingly, also the equilibria arising for different cost combinations as given by proposition 2 are the same, except that now individual equilibrium quantities are given by $\left(q^{1*}_{1,j}, q^{1*}_{2,j}\right) = (d, 0)$.

2.4 Numerical Analysis

2.4.1 Implementation

We implement the model numerically by discretizing the strategic variables. Continuous prices in $\mathcal{P}$ are approximated by a price grid with a step size of Δ_p, $p^t_i \in \{c_i, c_i + \Delta_p, \ldots, V\}$. Accordingly, possible quantities are given by $Q^t_i \in \{0, \Delta_Q, \ldots, D\}$ with a step size of Δ_Q. Both discrete prices and quantities are also observed in reality. While currencies generally have a smallest unit of account Δ_p, some goods are traded in fixed units Δ_Q only or cannot be split up further physically.

The discretized model is analyzed for a single buyer $n = 1$. We choose $V = 1.0$ and $D = 1.0$ as points of reference for the numerical implementation, yielding quantities as fractions of the overall demand. To test the robustness of the analytical results of section 2.3 when possible quantities are coarse, we set $\Delta_Q = 0.1$. Approximating continuous prices while limiting numerical effort is achieved by $\Delta_p = 0.01$. We analyze three combinations of the discount factor and the profit threshold, $(\delta, \underline{\pi}) \in \{(1, 0.1), (1, 0.05), (0.5, 0.1)\}$. For each of the $(\delta, \underline{\pi})$ values, the model is solved by backward induction for all costs compatible with the assumptions of the analytical model[14], $(c_1, c_2) \in \mathcal{C}$ in steps of $\Delta_{c_i} = 0.05$.

In period 2, for a single and no active supplier, results in the discretized model are identical to those of lemma 1. In the case of a duopoly, now two equilibria exist with $p^{2\text{D}}_1 = c_2$ and $p^{2\text{D}}_1 = c_2 + \Delta_p$ (cf. section 2.3.1). Since the price of the first equilibrium is identical to the price in the continuous model and since for $\Delta_p \to 0$ the price of the second equilibrium converges to this value as well, we assume that the first equilibrium arises.

In the first period, the optimal demand allocation of the buyer is identified for all possible price combinations. Implementing assumption 3, strategic sourcing equilibria are thereby preferred over myopic sourcing equilibria in the case of indifference. When prices are equal, demand is split according to the tie-breaking of proposition 1. With buyer behavior given, best responses of the suppliers are calculated and pure strategy equilibria

[14]Only costs which fulfill assumption 4 with the respective Δ_p and Δ_Q are included in the analysis.

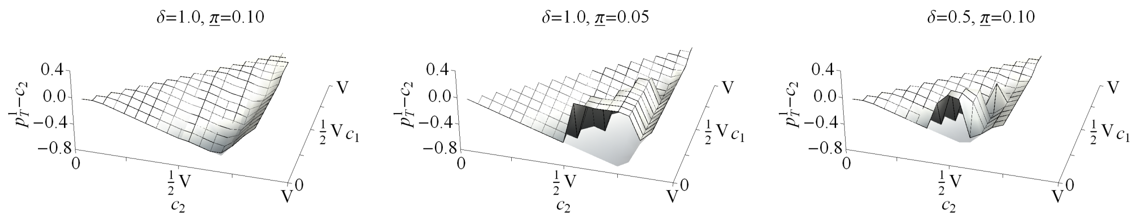

Figure 2.5: Deviation of the expected transaction price in period 1 from the cost of supplier 2. The grid depicts the numerical solution, analytical reference prices are included in gray color. Thereby $D = 1.0$, $V = 1.0$.

identified as mutual best responses. When multiple equilibria exist, the following selection is made to yield a unique result. If $p_1^{1*} = p_2^{1*} = c_2$ is among the equilibria, in accordance with the approach in period 2, this equilibrium is selected. When instead $p_1^{1*} = p_2^{1*} = V$ is an equilibrium (as might occur for the alternative procurement process in section 2.4.3), then this is selected. Finally, when all $p_1^{1*} < c_2$ are equal, the maximum price p_2^{2*} is used to reproduce equilibria of proposition 2.

If no pure strategy equilibrium exists, we employ the linear complementarity algorithm of Lemke and Howson (1964) as implemented in Gambit (McKelvey, McLennan, and Turocy 2007) to identify mixed strategy equilibria, which is however not guaranteed to return all equilibria (Shapley 1974). When the algorithm yields more than one equilibrium, selecting the pareto-optimal one for suppliers always ensures uniqueness.

For each of the three parameter sets, the model is solved for 120-171 marginal cost combinations. Calculations then require less than 1h for the model described above but 11h for the alternative procurement process on a PC with an Intel P8700 processor.

2.4.2 Initial Procurement Process

The expected transaction prices $\overline{p}_{\mathrm{T}}^{1*}$ paid by the buyer to source her demand D in period 1 are depicted in figure 2.5 for the equilibria of the numerical solution. Thereby, the deviation from the price of the one period solution, $\overline{p}_{\mathrm{T}}^{1*} - c_2$, is shown with calculated values corresponding to intersections of the grid lines. Furthermore, prices of the analytical solution of proposition 2 are included in gray color for costs in $\mathcal{C}_{\mathrm{H}}$ and $\mathcal{C}_{\mathrm{L2}}$, while for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L1}}$ also $\underline{p}_1$ is included as a reference. The respective sets of marginal costs are shown in figure 2.3 for the three parameter sets.

We find that for small cost differences $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$, the analytical transaction price $p_{\mathrm{T}}^{1*} = c_2$ is exactly reproduced even with coarse quantities. This is discernible from figure 2.5. Also the mean absolute deviations of numerical from analytical prices are $|\Delta p_{\mathrm{T}}^{1*}| = \overline{|\overline{p}_{\mathrm{T}}^{1*} - p_{\mathrm{T}}^{1*}|} = 0.0$ for all sets of $(\delta, \underline{\pi})$ values. This holds also for even coarser quantities $\Delta_Q = 0.2$ and $\Delta_Q = 0.5$, since costs are multiples of Δ_p and the buyer single sources in equilibrium.

For costs in $\mathcal{C}_{\mathrm{L2}}$ the analytical transaction price $p_{\mathrm{T}}^{1*} = \underline{p}_1 - \epsilon$ is smaller than c_2. Again, the numerically calculated values with coarse quantities of $\Delta_Q = 0.1$ reproduce the analytical solution quite well in figure 2.5, yielding only small mean absolute deviations for all parameter sets of $|\Delta p_{\mathrm{T}}^{1*}| \leq 0.009$. For even coarser quantities these increase up to $|\Delta p_{\mathrm{T}}^{1*}| \leq 0.046$ for $\Delta_Q = 0.5$. Accordingly, reducing the coarseness to $\Delta_Q = 0.005$ decreases mean absolute deviations, albeit only slightly so, to $|\Delta p_{\mathrm{T}}^{1*}| \leq 0.008$. Employing instead a finer price grid with $\Delta_p = 0.005$ also reduces deviations, but only to $|\Delta p_{\mathrm{T}}^{1*}| \leq 0.006$, indicating that the price space is sufficiently fine.

These deviations of $\bar{p}_{\mathrm{T}}^{1*}$ from the continuous price p_{T}^{1*} are an effect of the discretization. Coarse quantities do not allow the buyer to purchase exactly the quantity $\underline{Q}_i$ from the higher-priced supplier to sustain him but instead require to source the next highest multiple of Δ_Q. This results in a stepwise structure of $P_2(p_2^1)$ and $R_2(p_2^1)$ (cf. figure 2.2 for the continuous case). Also, Δ_p needs to be sufficiently small to capture this structure. Then $\underline{p}_1$ is shifted to higher values in the discrete model $\underline{p}_1^{\mathrm{N}} > \underline{p}_1$, altering the equilibrium price for costs in $\mathcal{C}_{\mathrm{L2}}$. Furthermore, the equilibrium price of supplier 2 may no longer be uniquely determined but instead be a range of prices, which however always includes V.

As in the continuous case for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L2}}$, the buyer sources only from supplier 1 in the numerical subgame-perfect equilibria and competition is never sustained as depicted in figure 2.6. Hence, both the structure as well as the prices of the equilibria in the continuous model are closely reproduced by the numerical solution even for very coarse quantities. We can therefore state the first result.

Numerical Result 1. *In a discretized version of the model with coarse quantities, for* $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L2}}$ *the equilibrium differs only marginally from the continuous case.*

From proposition 2 we know that for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L1}}$, no pure strategy equilibria exist in the continuous model. However, pure strategy equilibria can exist in the discretized model even then. As noted above, for a given cost combination, the coarse quantity shifts $\underline{p}_1^{\mathrm{N}} > \underline{p}_1$. Then, also for some costs in $\mathcal{C}_{\mathrm{L1}}$, setting $\underline{p}_1^{\mathrm{N}} - \Delta_p$ is a best response to $p_2^1 = V$ and therefore defines an equilibrium (cf. lemma 6). Furthermore, although the best response to $p_2^1 = V$ may not be to set $\underline{p}_1^{\mathrm{N}} - \Delta_p$, due to the stepwise structure of P_2 and R_2 this can still be the case for a price $p_2^1 \leq V$, which then forms an equilibrium as supplier 2 is indifferent between all his prices. Furthermore, even when no pure strategy equilibria exist, the discrete price space guarantees the existence of a mixed strategy equilibrium (Nash 1950).

Expected transaction prices of the numerical solution for costs in $\mathcal{C}_{\mathrm{L1}}$ are included in figure 2.5. With $\underline{\pi} = 0.05$ and with $\delta = 0.5$, there are transaction prices which exceed c_2 for low values of c_1 and medium values of c_2. Both suppliers then mix over prices and there is a positive probability that the buyer sources strategically from both suppliers. Accordingly, competition is sustained with a probability of $f_{\mathrm{D}} \geq 0.5$ as shown in figure 2.6. There are thus cost combinations for which equilibria exist which often sustain competition. Comparing to figure 2.3 we observe however that these do not arise for all costs in $\mathcal{C}_{\mathrm{L1}}$ but at most for 0.26 of cost combinations and indeed for none in the case of $\delta = 1.0$ and $\underline{\pi} = 0.1$. With coarser quantities of $\Delta_Q = 0.2$ the fraction is reduced further to at most 0.16 of

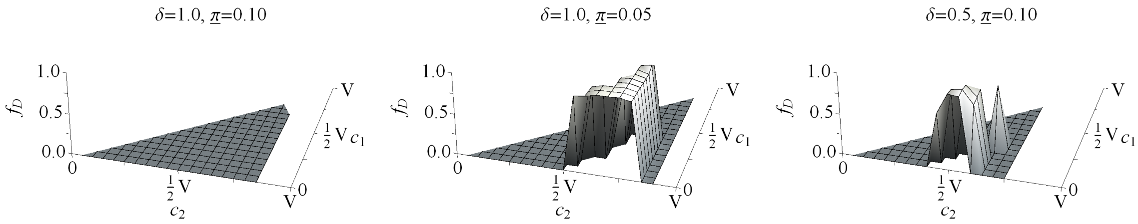

Figure 2.6: Probability of sustained competition for the numerical solution. Thereby $D = 1.0$, $V = 1.0$.

prices. Also, when $\Delta_Q = 0.5$, then there are no equilibria where both suppliers mix. Even for less coarse quantities of $\Delta_Q = 0.05$, the fraction rises only to maximally 0.29.

In all other equilibria for $(c_1, c_2) \in \mathcal{C}_{\text{L1}}$, supplier 1 sets a unique price $\overline{p}_1^{1*} = \underline{p}_1^{\text{N}} - \Delta_p$ which is very close to $\underline{p}_1$ of the continuous model as is seen from figure 2.5. The buyer then purchases exclusively from supplier 1, and supplier 2 is not sustained. Hence, supplier 2 is indifferent between all his prices and thus in some equilibria mixes over prices while in others he sets a unique price. The equilibrium structure of proposition 2 and approximately even the prices of supplier 1 are thus also often found in equilibria for costs in $\mathcal{C}_{\text{L1}}$ in a discrete model. We can thus formulate the second numerical result.

Numerical Result 2. *In a discretized version of the model with coarse quantities, for* $(c_1, c_2) \in \mathcal{C}_{\text{L1}}$ *there often exist exclusionary equilibria where competition is never sustained. There can however also exist equilibria where the buyer often dual sources and competition is sustained with a positive probability.*

2.4.3 Alternative Procurement Process

We investigate how an alternative procurement process alters the results of the initial process analyzed in the rest of this article. In each period the buyer now announces first the quantities to be sourced from the supplier posting the higher and the lower price, $D = Q^t_{\text{low}} + Q^t_{\text{high}}$. Adapting the tie-breaking rule of proposition 1, at equal prices Q^t_{low} is sourced from supplier 1. Next, the active suppliers post their prices p^t_i and depending on the relative prices are awarded the respective quantities. All other model specifications are identical to the initial process described in section 2.2. While the alternative process thus allows to guarantee a non-zero quantity to the supplier with the higher price, it also encompasses the option to implement a myopic sourcing process by setting $Q^t_{\text{low}} = D$. The outcome in the second period is then given by the following lemma.

Lemma 7. *For the alternative procurement process, equilibria in period 2 are unchanged from the initial process.*

Proof of lemma 7. The proof is included in the appendix. □

In the case of no active supplier and a monopoly the equivalence to the initial process is straightforward. When both suppliers are active, the buyer sets $Q^{\text{2D}}_{\text{low}} = D$, which yields

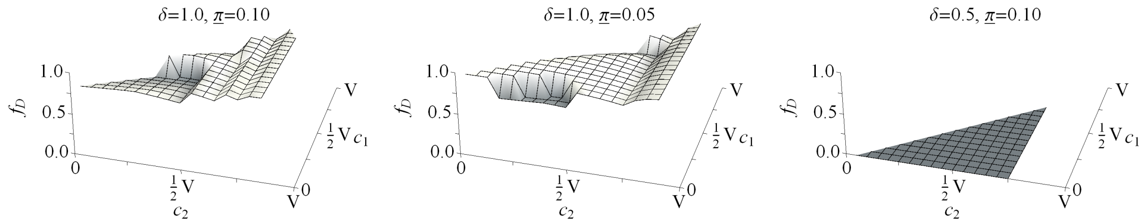

Figure 2.7: Probability of sustained competition for the numerical solution of the alternative procurement process. Thereby $D = 1.0$, $V = 1.0$.

purchasing behavior identical to the initial model. Any $Q^{2\mathrm{D}}_{\mathrm{high}} > 0$ entails purchases at prices above c_2 and is thus inferior. In addition, a qualification regarding transaction prices in the first period can be made.

Lemma 8. *For the alternative procurement process, the expected transaction price in period 1, $\overline{p}^1_{\mathrm{T}}$ is never lower than the marginal cost of supplier 2.*

Proof of lemma 8. The proof is included in the appendix. □

Supplier 2 will not price below his cost as these prices are weakly dominated. Then there is no need for supplier 1 to set a price below c_2 as any $p^1_1 \leq p^1_2$ ensures that he sells Q^1_{low}. Hence, at least for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}}$, equilibrium prices in period 1 will differ from the initial process where $p^{1*}_{\mathrm{T}} < c_2$ according to proposition 2.

We implement the alternative procurement process numerically using the approach described in section 2.4.1. In the subgame-perfect equilibrium, for $\delta = 1.0$ the buyer then always dual sources by splitting demand in the first period. Accordingly, except for the highest values of c_2, both suppliers mix over prices in equilibrium and as depicted in figure 2.7, competition is sustained with a probability $f_{\mathrm{D}} \geq 0.5$, which is often close to one. However, when c_2 is high, supplier 2 requires more than half of the demand to be sustained even at the highest price $p^1_2 = V$. It is then optimal for the buyer to either set $Q^1_{\mathrm{low}} = D$, realizing $\mathrm{BS} = D(V - c_2)$ in period 1 or to post $Q^1_{\mathrm{high}} \geq D/2$ such that both suppliers price at $p^1_i = V$, thereby realizing the same surplus in period 2. The latter approach is selected due to assumption 3 as it sustains competition.

For $\delta = 0.5$ meanwhile, the value of sustained competition for the buyer is markedly reduced and thus cannot increase surplus above $\mathrm{BS} = D(V - c_2)$. Since now current surplus is valued higher, this leads the buyer to implement myopic purchasing by setting $Q_{\mathrm{low}} = D$. Accordingly, both suppliers price at c_2, with the buyer sourcing only from supplier 1 and competition is never sustained (cf. figure 2.7).

We therefore find that compared to the initial process, the character of competition is changed away from the predominance of exclusion towards more accommodating outcomes when the buyer values sustained competition sufficiently high.

In addition, in figure 2.8 the difference of the expected buyer surplus for the alternative and initial procurement processes, $\overline{\mathrm{BS}}^{\mathrm{A}} - \overline{\mathrm{BS}}^{\mathrm{I}}$ is depicted. When the buyer values sustained competition highly for discount factors $\delta = 1.0$, the alternative process can

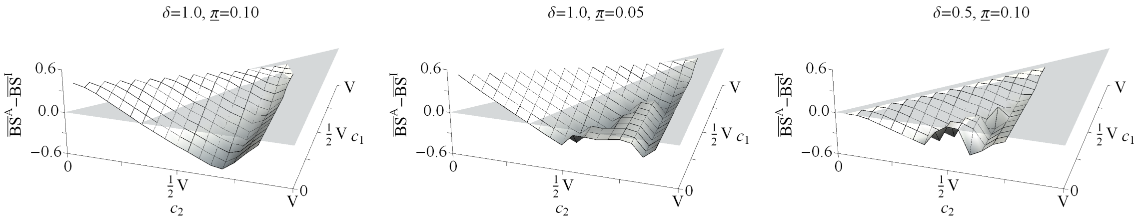

Figure 2.8: Difference of expected buyer surplus between alternative and initial procurement processes for the numerical solution. Thereby $D = 1.0$, $V = 1.0$.

increase the surplus of the buyer for small differences of marginal costs and especially for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L2}}$. While then in the initial process exclusion dominates, for the alternative process there exist equilibria where competition is nearly always sustained and the additional surplus from period 2 overcompensates foregone surplus in period 1. For higher cost differences however, there are equilibria such that exclusionary prices are so low or competition is sustained at prices which are so low that the initial process can be superior to the alternative process.

Also, when $\delta = 0.5$, we found that there is an equilibrium in the alternative process which implements myopic buying by setting $Q^1_{\mathrm{low}} = D$. Accordingly then, in accordance with the finding in section 2.3.3, buyer surplus is never higher than with the initial process for costs in $\mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L2}}$. For the equilibria arising from the calculation this often also holds for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L1}}$. However, there also exist equilibria where competition is sustained and surplus is slightly increased by myopic purchasing as implemented in the equilibrium of the alternative process (cf. figure 2.8). Thus, the overall impact of the alternative procurement process can be described by the next result.

Numerical Result 3. *For the alternative procurement process in a discretized version of the model, there often exist equilibria where the buyer dual sources and competition is sustained with positive probability when the value of sustained competition for the buyer is sufficiently high, including for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}} \cup \mathcal{C}_{\mathrm{L2}}$. Buyer surplus can, but need not, increase compared to the initial process, especially for small cost differences.*

These results are robust for $\Delta_Q = 0.2$ as well as $\Delta_Q = 0.05$. With $\Delta_Q = 0.5$ however, splitting demand in the alternative process guarantees a quantity of $D/2$ to the higher-priced supplier. Accordingly, for $\delta = 1.0$ both suppliers price at V and competition is always sustained but surplus is then never higher than in the initial process.

Hence, even though the alternative procurement process always yields the same outcome as the initial process in a myopic situation, equilibrium outcomes in a strategic context can be quite different. Thus, the choice of the procurement process can substantially influence surplus values for the buyer as well as the structure of the future supplier market. Furthermore, the optimality of the process might critically depend on the exact situation as demonstrated by the results for different marginal cost combinations.

2.5 Conclusion

Within this work we analyze a situation where two suppliers with different costs compete over time and have to exit the market when their profit is insufficient. A single buyer decides strategically from which supplier to source. This is modeled as a two period asymmetric cost Bertrand duopoly with a profit threshold for suppliers and a buyer with inelastic demand. Using backward induction, we solve this model analytically and numerically for subgame-perfect equilibria.

While the buyer benefits from sustained competition in the future, suppliers can increase their surplus by monopolizing the market. Therefore, for high prices in the first period, the buyer strategically dual sources and sustains competition. However, for lower prices myopic single sourcing is optimal and at least one supplier exits. Overall, we find that exclusionary tendencies are strong while exact results depend critically on the costs of suppliers. For small cost differences, the more efficient supplier excludes the other supplier in a unique pure strategy equilibrium, with the buyer purchasing only from the more efficient supplier. The introduction of multiple identical buyers adds coordination challenges but does not change the equilibrium prediction. Also, coarse quantities in a numerical implementation do not yield qualitatively different results. For large cost differences in contrast, there can also exist equilibria where suppliers price accommodatingly and competition is sustained with positive probability.

For the buyer, modifying the procurement process by committing to myopic sourcing never increases surplus when the cost difference between suppliers is small. However, an alternative process which has the buyer announcing the quantities to be sourced first can then lead to a higher probability of sustained competition and an increase in buyer surplus. However, there are also situations where equilibria exist such that expected surplus is reduced.

For firms our results highlight that the choice of the procurement process is of critical importance to optimize sourcing. Not only can a different process change expected surplus but whether this results in an increase or a decrease can also depend on specific details of the market. Conversely, we find that when supplier characteristics are well known, the choice of the process not only allows to optimize surplus but also to impact the future supplier market structure. Generally, committing to myopic sourcing can have a detrimental effect on surplus as the threat to split demand between suppliers and sustain competition forces the more efficient supplier to offer better terms of trade. However, while procurement auctions as modeled by the initial process often induce fierce competition and thus yield lower current prices, they often also reduce future competition. In contrast, committing to a split of a contract often allows to sustain competition. From a supplier perspective, our findings imply that strategic buyers will sustain competition when this is beneficial even if it requires foregoing current surplus. Furthermore, the choice of the procurement process can be instructive regarding the aim of buyers to sustain competition or not.

In the context of antitrust policy, the result of predominant exclusionary pricing for most cost combinations highlights how predatory actions can arise in a procurement auction context and need not require pricing below own costs. However, we also find that indeed, strategic buyers will counter these tendencies by sustaining competition when this is profitable. Also, procurement processes can be employed strategically by powerful buyers to influence expected outcomes, not only with regard to prices but also with regard to the market structure. However, there may well exist contexts where this can also have detrimental effects on competition.

Finally, regarding the analysis of static models in the industrial organization literature our finding that an alternative procurement process which yields identical results in a myopic setting can lead to quite different results in a two period model highlights the importance to account for strategic effects arising from dynamic situations, especially as firm interactions in reality are often dynamic in nature.

Chapter 3

Coordination of Strategic Sourcing to Sustain Supplier Competition in an Experiment

In a situation where strategic buyers source from competing suppliers over time, buyers often have an incentive to sustain competition while suppliers benefit from excluding rival suppliers. We investigate this situation experimentally in a two period duopoly, where in the second period only those suppliers are active whose profitability is sufficient in the first period. Exclusion of competing suppliers is dominant for two independent buyers but pricing becomes more accommodating with improved coordination of buyers. Since sourcing decisions are similar, competition is thus sustained more often when the coordination of buyers improves. There is weak evidence that also buyer surplus increases. Complete rationality of buyers however is not observed to change results substantially. Contrary to the subgame-perfect prediction of no difference, we thus find that coordination confers power to buyers and can be an effective counterweight to exclusionary supplier behavior.

3.1 Introduction

When suppliers who sell to powerful strategic buyers over time are threatened in their survival, both suppliers and buyers have to take into consideration how their decisions influence the future market structure on the supplier side. An example of such a situation is offered by the automotive industry, where only a few relevant car manufacturers[1] source from parts suppliers and thus may account for a large share of the sales of individual suppliers[2]. Meanwhile, numerous car parts firms are in a vulnerable position[3]. Thus, car

[1]In 2008, the top ten car manufacturers produced more than 35% of all cars worldwide (OICA 2009).

[2]For example the former divisions of car manufacturers (e.g., Delphi and Visteon) still make a substantial share of their sales to their previous owners (Babich 2010; Wadecki, Babich, and Wu 2010).

[3]E.g., a third of North American automotive suppliers declared bankruptcy in the downturn of 2008 according to Wadecki, Babich, and Wu (2010).

manufacturers may exercise substantial power vis-à-vis their suppliers. Aspects of this situation are also observed in other markets however, with e.g., only a few powerful retail chains sourcing from food manufacturers and suppliers in the defense industry often selling to a single governmental buyer.

Buyers then face a tradeoff between sourcing from the supplier making the best current offer and sourcing strategically from multiple suppliers to ensure that the future supply situation does not deteriorate. In practice we observe that while in some situations buyers favor single sourcing[4] in other situations multiple sourcing is prevalent[5]. Accordingly, suppliers have to decide whether to engage in aggressive actions to try to exclude competing firms or whether to accommodate to the fact that buyers will sustain competition. The decision to exclude other suppliers is not readily observed since it generally falls foul of antitrust rules[6]. On the other hand there exist markets where suppliers are accused of not competing too fiercely without colluding outright[7].

What is more, decisions can be dependent on how market demand is structured. Buyers may not take sourcing decisions without consulting with other firms purchasing in the same market or may form joint purchasing agencies[8]. This in turn might induce suppliers to compete differently, which may also happen when only a single buyer is active in the market or buyers are especially sophisticated.

This interplay between suppliers and buyers is also acknowledged in antitrust policy. As laid out in the EU Guidelines on Vertical Restraints (EU 2010), "single branding" by suppliers encompasses those tacit agreements which "induce [a buyer] to concentrate its orders... with one supplier". The possible competition risk is "foreclosure of the market to competing suppliers". Nevertheless, the guidelines also state that "powerful buyers will not easily allow themselves to be cut off from the supply of competing goods". However, this leaves open which buyer market structures are especially suited to confer power to buyers in such situations, which we investigate experimentally in this article.

Only a few theoretical works have analyzed strategic buyers and suppliers who are threatened in their survival explicitly. An analytical investigation of the model used in the present article (Wilken 2011b) finds exclusionary outcomes to be often dominant. Also, in a Hotelling model strategic sourcing to sustain supplier competition occurs for exogenously given prices but may not be part of an equilibrium (Clark and Polborn 2006). In the model of Bergès and Chambolle (2009) meanwhile, for sufficiently different discount

[4]The Department of Defense uses single sourcing to procure drugs (Gong, Li, and McAfee 2010), while Beker and Hernando-Vecianaz (2009) provide other public sector examples, e.g., military supplies and waste collection services. Also firms like Sun Microsystems award some contracts to a single supplier as reported by Tunca and Wu (2009).

[5]Multiple sourcing is employed in defense procurement (Anton and Yao 1992) and by, e.g., General Motors, IBM (Anton, Brusco, and Lopomo 2010) and Sun Microsystems (Tunca and Wu 2009).

[6]In recent cases, e.g., France Telecom was found guilty of pricing below cost to eliminate competition for internet access (ECJ C-202/07 P 2009) in the EU, while in the US a subsidiary of AT&T was acquitted in a similar case (SC 555 U.S.__ 2009).

[7]E.g., Airbus and Boeing are sometimes accused of forming a "cosy duopoly" (The Economist 2010).

[8]Pooled purchasing is widespread in the healthcare sector (Marvel and Yang 2008). Also in the automotive industry, e.g., BMW and Daimler purchase selected car parts jointly (Reuters 2010).

factors of the suppliers and the single buyer, the buyer sources strategically in equilibrium but suppliers set prices above the valuation and can thus extract all surplus.

In a broader context, this article adds to the body of work analyzing the power of buyers vis-à-vis suppliers. Overviews are provided by, e.g., Chen (2007) and Inderst and Mazzarotto (2008), while Ruffle (2005) includes also experimental investigations.

Research on the origins of buyer power has focused on the effect of individual buyers' size of demand as in, e.g., Chipty and Snyder (1999) and Inderst and Wey (2003), finding that often a larger size increases the power of buyers. The potential loss of a substantial share of sales when the buyer switches to other suppliers, encourages entry by alternative suppliers or withholds demand can then discipline suppliers. Furthermore, in addition to various other sources, the sophistication of buyers may add power through more professional procurement processes or better information about alternatives (cf. Inderst and Mazzarotto 2008, and references therein).

Sourcing decisions can then be a lever to exercise buyer power. This adds an additional perspective to the literature on the optimality of single vs. multiple sourcing, an overview of which is provided by Elmaghraby (2000). Generally, whether multiple sourcing is optimal or not depends critically on the specific context as demonstrated by, e.g., results for the identical model in Anton and Yao (1989) and Inderst (2008) differing with the number of buyers. More closely related to our model, a commitment to multiple sourcing can increase participation and intensify supplier competition (Klotz and Chatterjee 1995a).

Buyer power can result in better terms of trade. While for a single supplier, buyer size discounts often occur only when the supplier has increasing marginal costs (Chipty and Snyder 1999; Inderst and Wey 2003), for competing suppliers discounts arise, e.g., in the sequential purchasing model of Snyder (1998) and through a commitment to single sourcing in Inderst and Shaffer (2007). Sorensen (2003) and Ellison and Snyder (2010) confirm the existence of buyer size discounts empirically, although the effect is found only for competing suppliers. Groups of buyers who form purchasing agencies can then often be treated as a single buyer commanding the demand of all group members (cf., e.g., Chen 2007, and references therein.). As another consequence of buyer power, foreclosure may occur on the supplier market side. This has been analyzed primarily in the context of "naked exclusion" as discussed below. Also, a single buyer may effectively exclude suppliers by single sourcing from competitors in a learning-by-doing environment as described in Lewis and Yildrim (2002). Conversely, Romano (1991) shows that buyers may consume excessively to avoid foreclosure of a monopolist supplier.

A small number of experiments investigate buyer power explicitly. Ruffle (2000) finds that demand withholding vis-à-vis two suppliers occurs more often and leads to better terms of trade both when buyers are more concentrated and when the share of surplus earned by buyers is lower. Also for a single supplier in Engle-Warnick and Ruffle (2005) prices are lower when the buyer concentration is higher. This is due to the monopolist fearing the loss of more surplus from demand withholding in the presence of fewer buyers.

For a monopolist in a posted-bid market, Normann, Ruffle, and Snyder (2007) find support for the prediction that buyer size discounts arise only for increasing marginal costs. Buyer size discounts are also observed when suppliers compete to supply buyers of different size sequentially in Ruffle (2009). The case of merging suppliers who realize efficiency gains is investigated in Davis and Wilson (2008). Human buyers induce (through demand withholding) lower price levels than automated buyers, both before and after the merger, but lead to large variations of results between individual markets.

Turning to the supplier side of the market, exclusion of suppliers who are threatened in their survival can be achieved through predatory pricing. An overview is offered by, e.g., Bolton, Riordan, and Brodley (2000). In an experimental environment predatory pricing often proves hard to pin down. Nevertheless, Jung, Kagel, and Levin (1994) detect predatory behavior in an abstract framework, while Goeree and Gomez (1998) find clear indications of predatory pricing in a multi-market setup.

Instead of pricing to secure a monopoly, suppliers can also try to "nakedly" exclude a more efficient entrant by offering payments to buyers in exchange for exclusivity contracts. Due to coordination problems between buyers, the monopolist can succeed as the entrant has to cover entry costs. This logic was first formalized by Rasmusen, Ramseyer, and Wiley (1991) and Segal and Whinston (2000) and subsequently modified and extended. In experiments, exclusive dealing arrangements are found to be used frequently (Boone, Müller, and Suetens 2009; Landeo and Spier 2009; Smith 2011). Apart from the impact of discrimination, the rate of exclusion is found to decrease with an increase in the fraction of buyers required (Smith 2011), for a non-human incumbent (Landeo and Spier 2009) and also when buyers can communicate (Landeo and Spier 2009; Smith 2011).

Adding to this literature, we report the first experimental investigation of the interplay of powerful buyers aiming to sustain competition through strategic sourcing and suppliers who have an incentive to engage in exclusionary behavior. Furthermore, we analyze for the first time how buyer coordination and sophistication add power to buyers which is then exercised through sourcing decisions.

Our experiment implements the two period model described in Wilken (2011b). Two buyers source from two suppliers by deciding on the quantity to procure from each supplier. Suppliers have different marginal costs and compete in prices. They are threatened in their survival as they are only active in period 2 when their profit in period 1 is sufficiently high. For the experimental parameters, suppliers then have an incentive to exclude the other supplier, while buyers have an incentive to sustain competition. However, in the subgame-perfect equilibrium, the more efficient supplier excludes the other supplier and enjoys a monopoly in period 2. Although this prediction holds for all experimental treatments, we observe substantial differences in outcomes. While in the baseline, pricing is indeed dominated by exclusionary tendencies as predicted, improving buyer coordination by allowing communication, replacing the two buyers by a single buyer or using rational automated buyers makes pricing more accommodating to the survival of both suppliers.

The impact of complete buyer rationality is by comparison limited. When supplier competition can be sustained and dual sourcing is thus rational, buyers purchase nearly rationally and often sustain competition. No significant change is then observed for improved buyer coordination. When however dual sourcing is not rational, sourcing from both suppliers persists across treatments. While this is found to be partially due to fairness considerations of buyers, the major cause are errors of single buyers. Overall, we find that with improved buyer coordination competition is sustained more often, while rationality of buyers does not induce a significant change. With behavior in period 2 close to the prediction in all treatments, surplus of the more efficient supplier decreases with improved buyer coordination, while there exists weak evidence that buyer surplus increases.

We thus find that the ability to source strategically from one or the other supplier allows buyers to exercise power. The power increases the better buyers can coordinate, which may, but need not be the result of larger buyers. This result is driven primarily by the induced differences in pricing behavior of suppliers.

The present article is organized as follows. We model the situation described above in section 3.2 and deduct predictions for the experimental outcomes from the numerical solution. Treatments are detailed in section 3.3 along with the experimental procedures. Results are presented in section 3.4 while section 3.5 concludes.

3.2 Model and Predictions

3.2.1 Model

The situation described in the introduction is modeled in a two period setting, as visualized in figure 3.1. While period 1 represents the current supply situation, period 2 models the future market. In the first period two suppliers i compete in prices p_i to supply two buyers j with a homogeneous good[9]. Suppliers have different marginal unit costs, $c_1 < c_2$, with supplier 1 being the more efficient supplier throughout this article. Each of the identical buyers has an inelastic demand of d for the good in both periods up to the valuation V, i.e., buyers are assumed not to purchase for prices above their valuation[10]. After prices are posted, each buyer j decides how to source her demand from the two suppliers, $d = q_{1,j} + q_{2,j}$, thereby realizing a surplus of $\mathrm{BS}_j = \sum_i q_{i,j}\,(V - p_i)$. Together, buyers purchase an aggregate quantity $Q_i = q_{i,1} + q_{i,2}$ from supplier i.

To model that suppliers have to exit a market (in the long term) when they are not sufficiently profitable and are thus threatened in their survival, a profit threshold $\underline{\pi}$ is introduced in period 1[11]. Hence, supplier i is only active in period 2 when his profit in period 1

[9] Period 2 variables are indicated by an index throughout this article while period 1 indices are dropped.

[10] This is equivalent to buyers not making losses on individual purchases (cf. also Wilken 2011b). In the experiment this is implemented by restricting prices to $p_i \leq V$ since this allows to exclude the option to withhold demand, thereby placing the focus on strategic sourcing.

[11] Biglaiser and DeGraba (2001) use a similar approach, while Clark and Polborn (2006) employ a profit threshold in a closely related model. Also, Wadecki, Babich, and Wu (2010) model firm exit based on the difference between earnings and liabilities while Babich (2010) uses the ratio of assets to liabilities.

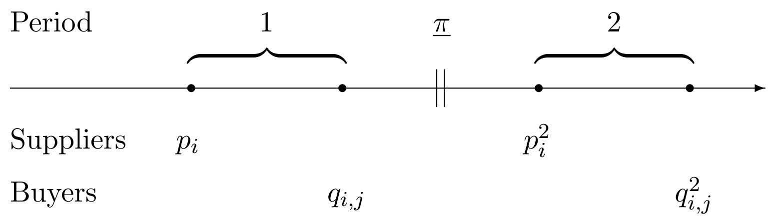

Figure 3.1: Model timing and strategic variables.

attains the threshold, $\pi_i = Q_i(p_i - c_i) \geq \underline{\pi}$. In the second period only the active suppliers compete in a situation otherwise identical to the first period.

In the experiment, a price grid with a smallest unit of account $\Delta_p = 1$ is used. Setting the buyer valuation to $V = 1000$ then ensures a sufficiently fine price space. Accordingly, demand can only be split in single units of $\Delta_q = 1$. Overall demand of each buyer is then set to $d = 4$, large enough not to render the allocation trivial but small enough to be easily comprehensible. The remaining parameters are fixed so as to ensure that an exclusion equilibrium in pure strategies is implemented with a price of supplier 1 in the first period markedly below the cost of the less efficient supplier (cf. section 3.2.2). Simultaneously the range of prices for which a strategic sourcing equilibrium exists is required to be large and expected payoffs for buyers and suppliers to be similar. These conditions are fulfilled by a profit threshold of $\underline{\pi} = 700$ in combination with marginal costs $c_1 = 200$ and $c_2 = 400$.

3.2.2 Theoretical Solution and Predictions

Experimental parameters are used in a numerical implementation of the model to solve for subgame-perfect equilibria through backward induction. This allows to derive predictions for experimental results. Accordingly, the second period is not discounted.

When both suppliers are active in period 2, the equilibria of the discrete one period asymmetric cost Bertrand model with an equal sharing tie-breaking rule arise. We assume that the equilibrium with $p_1^{2\text{D}} = 400$ and $p_2^{2\text{D}} = 401$ is implemented[12]. This choice is uncritical as it translates into a negligible surplus difference in period 2. Both buyers j then purchase only from supplier 1, $\left(q_{1,j}^{2\text{D}}, q_{2,j}^{2\text{D}}\right) = (4, 0)$. When a single supplier i is active, he maximizes surplus by pricing at the buyer valuation $p_i^{2\text{M}} = 1000$ and buyers have to purchase from this supplier, $q_{i,j}^{2\text{M}} = 4$. When no supplier is active, no transactions take place and all market participants realize zero surplus.

Hence, in period 1 buyers have an incentive to sustain competition as each buyer gains additional surplus of $\Delta\text{BS}_j^2 = 2400$ in period 2 from a duopoly compared to a monopoly or

[12] Similar to Deneckere and Kovenock (1996) we include only prices which are weakly undominated as well as their continuous limits, $p_i^{2\text{D}} \geq c_i$. Then two equilibria exist: $\left(p_1^{2\text{D}}, p_2^{2\text{D}}\right) = (399, 400)$ and $\left(p_1^{2\text{D}}, p_2^{2\text{D}}\right) = (400, 401)$. We choose the latter as for $\Delta_p \to 0$ transaction prices converge to $p_1^{2\text{D}} = 400$. In the treatment with automated suppliers the other equilibrium is implemented in the experiment.

no active supplier. Conversely, each supplier has an incentive to exclude the other supplier as this increases surplus by the same amount.

With buyers sourcing in period 1 as described below, supplier 1 always best responds by pricing to exclude the less efficient supplier. Supplier 2 does the same, except for low prices of supplier 1. Then, supplier 2 either accommodates by setting his price equal to the buyer valuation or is indifferent between all prices when competition cannot be sustained. In the subgame-perfect equilibrium, we find that supplier 1 prices at $p_1^* = 316$, so low as to gain exclusivity regardless of the price of the other supplier. This price is thus below the one period equilibrium price of $p_1 = c_2$. Meanwhile, supplier 2 is indifferent between prices $p_2^* \in [750, \ldots, 1000]$. Then, buyers purchase exclusively from supplier 1, $\left(q_{1,j}^*, q_{2,j}^*\right) = (4, 0)$ since they cannot sustain competition and supplier 1 enjoys a monopoly in period 2. As aggregate sourcing behavior is not predicted to change with improved coordination or complete buyer rationality, we have the following prediction.

Prediction 1. *The more efficient supplier always prices below the marginal cost of the less efficient supplier and exclusionary pricing prevails.*

While in the subgame-perfect equilibrium buyers source only from supplier 1, for other prices two types of equilibria of the buyer subgame in period 1 can arise. In a strategic sourcing equilibrium buyers purchase such that both suppliers are active in period 2, whereas in a myopic sourcing equilibrium only one or no supplier is sustained.

For a strategic sourcing equilibrium to arise, it is necessary for aggregate dual sourcing[13] to occur, i.e., $Q_i > 0$ for both suppliers i. Then, for unequal prices the aggregate quantity purchased from the supplier with the higher price is positive, $Q_{\text{high}} > 0$ and chosen as low as possible. Experimental parameters are such that it is always rational for buyers to sustain competition when this is possible, i.e., whenever aggregate demand is sufficient for both suppliers to attain the profit threshold $\underline{\pi}$, then a strategic sourcing equilibrium exists. Meanwhile, in a myopic sourcing equilibrium for unequal prices, buyers purchase only from the supplier with the lower price.

If for a price combination multiple buyer equilibria exist, the numerical solution selects only pareto-optimal ones[14], which is equivalent to always implementing a strategic sourcing equilibrium when one exists. Among these equilibria, buyers minimize the difference of the quantities sold by suppliers. This is relevant only for equal prices and generalizes the equal-sharing tie-breaking rule of period 2. Finally, as buyers are identical they are assumed to purchase as equal as possible a quantity from each supplier. Supplier behavior however is unaffected by the last selection as it depends only on aggregate quantities. Implementing alternative selection rules does not change the overall equilibrium prediction.

There are in turn two types of price combinations. Those for which buyers can sustain competition and thus a strategic sourcing equilibrium exists and those for which sustaining

[13]Throughout this article we refer to dual sourcing when aggregate demand is split between suppliers. This includes instances of both buyers single sourcing their complete demand from different suppliers.

[14]This is a commonly made assumption, cf., e.g., Romano (1991) for this approach in a similar situation.

competition is not possible and therefore only a myopic sourcing equilibrium exists. As depicted in figure 3.4 below, competition can be sustained when both suppliers set high prices. As dual sourcing always occurs in a strategic sourcing equilibrium, we thus have the following prediction regarding aggregate buyer behavior. It is independent of buyer coordination, while rationality is naturally assumed.

Prediction 2. *When competition can be sustained, buyers always dual source and sustain competition.*

When two buyers implement a strategic sourcing equilibrium for unequal prices, sustaining competition is similar to a discrete public good, as it increases the expected buyer surplus[15]. However, for the experimental parameters it is in most cases possible and rational even for a single buyer to sustain competition when the other buyer purchases myopically. Only for a small number of price combinations are both buyers required to source from the higher-priced supplier as $\underline{Q}_{\text{high}} > d$ is necessary to sustain competition and in turn both strategic and myopic sourcing equilibria exist. Thereby, $\underline{Q}_{\text{high}}$ is the minimum quantity required for survival by the supplier with the higher price.

However, when suppliers post prices which allow to sustain competition, buyers still have to coordinate on one of the possibly many strategic sourcing equilibria. As described in section 3.3, we include a treatment with structured one-way communication where buyer 1 can send her (non-binding) intended demand split to buyer 2 prior to the sourcing decision. We use the solution concept of "sensible equilibria" introduced by Farrell (1988), assuming that if buyer 1 prefers to follow her announcement when buyer 2 best responds, then the announcement is believed by buyer 2 (cf. also Cooper et al. 1989). When competition can be sustained[16] and prices are not equal, the only sensible outcome is announcing (and subsequently purchasing) $q_{\text{high},1} = \max\{0, \underline{Q}_{\text{high}} - d\}$ from the supplier with the higher price[17]. Communication thus allows buyer 1 to select the strategic sourcing equilibria most beneficial for her, leading often to only buyer 2 sourcing from both suppliers. In contrast, by assumption maximally symmetric buyer behavior is implemented when no communication is possible. Defining buyer cooperation as both buyers dual sourcing when this is rational, the next prediction follows.

Prediction 3. *Without communication, buyer cooperation in dual sourcing is perfect. When buyers can communicate, cooperation is decreased.*

Now, when suppliers post a price combination which does not allow to sustain competition, buyers are predicted to implement a myopic sourcing equilibrium and therefore not to split demand between suppliers for unequal prices.

Prediction 4. *When competition cannot be sustained, buyers do not dual source.*

[15]The contributions are the quantities Q_{high}, while $\underline{Q}_{\text{high}}$ is the provision point.

[16]When competition cannot be sustained, sensible outcomes and Nash equilibria are identical.

[17]For equal prices the sensible outcomes are $q_{2,1} \in [\max\{0, \underline{Q}_2 - d\}, d]$.

The subgame-perfect prediction is that exclusion is always successful and supplier 1 enjoys a monopoly in period 2. Then, the surplus of supplier 2 is zero as nothing is sold. For buyers all surplus originates from period 1 leading to BS = 5472 while for supplier 1, $\pi_1 = 7328$. Hence, for the overall outcome we have the following prediction.

Prediction 5. *Competition is never sustained and the more efficient supplier monopolizes the market in period 2. Surplus of the more efficient supplier is higher than the surplus of the buyers while the less efficient supplier realizes no surplus.*

3.3 Experimental Implementation

3.3.1 Treatments

Five different treatments are analyzed experimentally as laid out in figure 3.1. The baseline treatment REF implements the model with two human suppliers and buyers. Buyers cannot coordinate explicitly and are by nature not completely rational. In COM, human buyers can communicate with each other. Experimental analyses of the structurally similar "battle-of-the-sexes" game[18] find the most pronounced increase in coordination for structured one-way communication (Cooper et al. 1989; Crawford 1998). Accordingly, buyer 1 can decide whether to communicate and then send her (non-binding) intended demand split to buyer 2 before actual sourcing decisions are taken simultaneously. Coordination is enhanced compared to the baseline as communication allows to coordinate on a specific strategic sourcing equilibrium (cf. section 3.2.2). This treatment models a situation where buyers "talk" about intended sourcing decisions without making binding agreements and this is known to suppliers.

In SIN, suppliers supply a single human buyer. This buyer has a demand of $d = 8$, equal to the aggregate demand of the two buyers in the baseline. This situation can be interpreted either as a single powerful buyer in a specific market or as a buyer group of two buyers with demand of $d = 4$ each. In the latter case sourcing decisions are likely to be implemented among the individual buyers as evenly as possible. As now a single subject takes sourcing decisions, coordination is perfect by definition. The same holds for the two automated buyers in AUB, who follow the optimal behavior as implemented in the numerical solution of section 3.2.2 and are thus completely rational[19]. Hence, they offer a benchmark when both coordination issues are absent and buyers are sophisticated in acting rational[20]. In order to change only the "nature" of buyers from treatment REF, two buyers are kept although clearly a single automated buyer would behave identically from the viewpoint of suppliers.

[18] When competition can be sustained, for most price combinations only strategic sourcing equilibria exist and buyers essentially face an extended "battle-of-the-sexes" game.

[19] In the experiment, for equal prices which allow to sustain competition buyers split "excess demand" not required to sustain competition equally between suppliers.

[20] This stems from the intuition that sophisticated buyers will source more rationally as they have access to more information and sourcing decisions will come under more, and more informed scrutiny.

Buyer rationality	Buyer coordination No	Enhanced	Perfect
Human	REF (Reference)	COM (Communication)	SIN (Single Buyer)
Complete	AUS (Automated Suppliers)		AUB (Automated Buyers)

Table 3.1: Classification of treatments.

In the additional treatment AUS, automated suppliers post a series of prices in period 1 which is randomly generated before the experiment. In period 2, suppliers post rational prices depending on the market structure. With the situation of buyers regarding coordination and rationality being identical to the baseline, this treatment allows to isolate any motivation for dual sourcing in REF stemming from fairness towards the suppliers.

Apart from AUS all treatments yield the same equilibrium prediction (cf. section 3.2.2). Hence, they allow to investigate how improving buyer coordination from REF over COM to SIN and AUB and also complete buyer rationality in AUB impact experimental outcomes.

3.3.2 Procedures

In the experiment, the two period model is repeated for 20 rounds to allow convergence of behavior. Each human subject is assigned either the role of a buyer or a supplier. A group of two suppliers and two buyers forms a market and stays fixed throughout the experiment, except in AUB, where two suppliers form a market and in AUS, where two buyers do so. For each treatment $N = 6$ independent markets are conducted. Before each round, costs are randomly assigned to the supplier subjects. This avoids large differences in payoffs and mitigates fairness considerations of buyer subjects towards the supplier with higher costs (cf. also section 3.4.4). In the communication treatment, also each round one of the buyer subjects is randomly assigned the ability to communicate. The different treatments are implemented in z-tree (Fischbacher 2007), providing subjects with a profit calculator. After each round, profits of all participants in the market are displayed.

Experiments were conducted in the Mannheim experimental laboratory in May 2009 and March 2010. Subjects were recruited using ORSEE (Greiner 2003) and were mostly students. Overall 90 subjects participated and no one participated twice. After being randomly seated in the laboratory, subjects were provided with the instructions (cf. appendix), making all parameters common knowledge. To participate, between five and seven test questions had to be answered, depending on the treatment. Before the first round commenced, subjects were informed about their role on the computer screen. Sessions lasted between 1h10 and 2h00, with the shorter sessions due to the treatments with one automated market side. Firm profits were converted to monetary payouts with a factor of 1/3000, yielding an average payout of EUR 19.85.

3.4 Experimental Results

The analysis of experimental data is limited to rounds 5-19 to allow for learning in the first rounds and to exclude endgame effects in the last. All results are however also valid for rounds 10-19 with exceptions explicitly noted. The mean values of the analysis variables are calculated for the relevant rounds in each market and tested statistically for differences between treatments (Mann-Whitney-U-Test) or within treatments (Wilcoxon-Signed-Ranks-Test). The reported p-values are two-tailed unless otherwise noted and frequencies as well as mean values always refer to the mean of market means. Histograms meanwhile depict the distribution of values from the respective rounds in all markets. Results for the treatment with automated suppliers are included for buyers only.

3.4.1 Incentives for Dual Sourcing and Exclusion

In the theoretical solution, the differences in expected surplus for the possible market structures in period 2 provide an incentive for buyers to sustain competition and for each supplier to exclude the other supplier (cf. section 3.2.2). We first confirm that these incentives are present in the experiment.

For a supplier enjoying a monopoly, the predicted price is $p_i^{2M} = 1000$. Indeed, we observe from figure 3.2 prices $p_i^{2M} \geq 900$ in $\overline{f} = 0.94$ of monopolies in all treatments, with the distribution showing a pronounced peak at the highest prices. For two active buyers, the lowest posted price is predicted to be $p_{\text{low}}^{2D} = 400$. Again, in $\overline{f} = 0.82$ of duopolies the lowest price is $p_{\text{low}}^{2D} \leq 500$, with $\overline{f} = 0.38$ of prices being lower or equal to the predicted value. Hence, the price level is only slightly elevated compared to the prediction. Pairwise comparisons between treatments yield no significant differences of the lowest price in either monopolies ($p \geq 0.214$) or duopolies ($p \geq 0.177$). In the latter case only the difference between the single and automated buyer treatments comes close to significance (cf. section 3.4.2). We thus conclude that pricing in period 2 is close to the prediction and does not differ significantly between treatments.

When only one supplier is active, buyers have to source their demand from this monopolist. In a duopoly, it is optimal to purchase only from the supplier with the lowest price for unequal prices and not to dual source. Nevertheless, dual sourcing is frequently observed as aggregate demand is split in $\overline{f}_{\text{Dual}}^{2D} = 0.28$ of all duopolies in treatments with human buyers (cf. also section 3.4.4). No significant differences are observed between these treatments though with $p \geq 0.206$ pairwise. An additional measure is provided in figure 3.2 by the aggregate quantity purchased from the supplier with the higher price, Q_{high}^{2D}. While we find that in $\overline{f} = 0.67$ of duopolies both buyers purchase at the lowest price only as predicted, residual purchases from the supplier with the higher price are observed across treatments with $\overline{Q}_{\text{high}}^{2D} = 1.08$. Thereby, mean quantities do not differ significantly between treatments with human buyers ($p \geq 0.373$ pairwise). Behavior of buyers is thus close to, but clearly not identical to, rational purchasing.

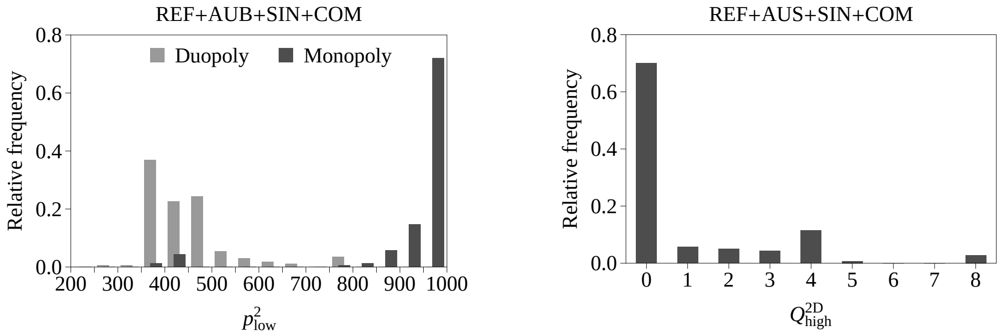

Figure 3.2: Lowest price and aggregate quantity purchased from the supplier with the higher price in duopolies in period 2. Price intervals are $(\,p-50\,,\,p\,]$.

Our findings in the second period are therefore in line with those of Boone, Müller, and Chaudhuri (2008), who observe convergence to the theoretical prediction in an asymmetric cost Bertrand duopoly. They are in contrast however to the experiment of Dugar and Mitra (2009), where for a cost difference similar to ours ($c_2 = 2\,c_1$), prices are substantially elevated, and also to experiments with symmetric Bertrand duopolies which often find prices above the competitive level (cf., e.g., Dufwenberg and Gneezy 2000)[21]. An important factor in our results is that sustaining collusion is complicated by interruptive and structurally different period 1 interactions as well as the fact that there is generally not always a duopoly in the second period.

Across treatments, in markets where both duopolies and monopolies occur in period 2, we find mean buyer surplus to be higher when competition is sustained and supplier profits to be higher when the market is monopolized. Pooling the relevant treatments these differences are significant with $p = 0.000$ one-tailed for buyers and supplier 1 ($N \geq 16$) and $p = 0.008$ one-tailed for supplier 2 ($N = 7$). Mean buyer surplus is $\overline{\text{BS}}^{2\text{D}} = 4473$ in duopolies but only $\overline{\text{BS}}^{2\text{M}} = 306$ in monopolies. Conversely, for supplier 1, $\overline{\pi}_1^{2\text{M}} = 6024$ when exclusion is successful as opposed to $\overline{\pi}_1^{2\text{D}} = 1454$ when competition is sustained. The difference between mean values is similar for supplier 2. With suppliers and buyers behaving close to the prediction, the surplus gains are not quite as large as in theory but sufficient for opposing incentives of suppliers and buyers to be intact in the experiment.

3.4.2 Pricing

We now analyze how the opposing incentives regarding the market structure in the second period change behavior in the first period. Time series of the market mean of posted prices are depicted in figure 3.3, showing that across treatments, pricing behavior is relatively stable in the rounds 5-19 used for analysis.

We find that prices of supplier 1 are significantly higher in the experiment than the common prediction of $p_1^* = 316$ with $p = 0.031$ in a Wilcoxon test for all treatments. In the

[21] Also in Cournot markets, suppliers in duopolies often collude, while a larger number of suppliers do not (Huck, Normann, and Oechssler 2004).

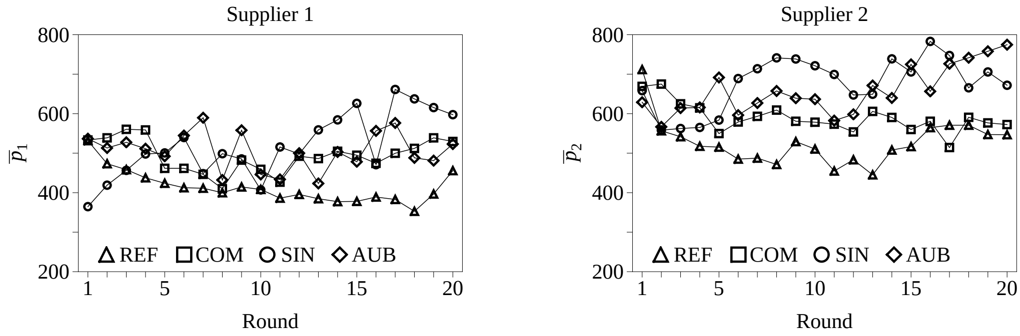

Figure 3.3: Mean prices in period 1.

baseline, prices are close to the marginal cost of the less efficient supplier with $\overline{p}_1 = 394$. Meanwhile, mean prices are elevated to $\overline{p}_1 \geq 477$ in all treatments with improved buyer coordination (cf. figure 3.3). However, as reported in table 3.2, only for a single buyer is the increase clearly significant, while when buyers are automated, this is only the case in rounds 5-19. With no significant pairwise differences ($p \geq 0.394$), we pool treatments with improved coordination COM, SIN and AUB as CSA and with perfect coordination SIN and AUB as SA. In both cases clear evidence of significantly increased prices compared to the baseline is found ($p = 0.104$ only just fails to be significant for CSA in rounds 10-19).

For the less efficient supplier 2, we find that prices in the baseline and communications treatment are lower than the prediction of $p_2^* \geq 750$ in equilibrium ($p = 0.031$), although in the latter case not significantly so for the second segment of rounds. In contrast, for a single and automated buyers, observed mean prices are compatible with the lower bound of the equilibrium price interval with $p \geq 0.219$. Accordingly, comparing between treatments, mean prices with communication are only slightly higher than $\overline{p}_2 = 511$ in the baseline (cf. table 3.2). However, in both treatments with perfect coordination prices increase significantly in the first segment of rounds, while only coming close to significance with $p \leq 0.180$ in rounds 10-19. Pairwise comparison ($p \geq 0.240$) again allows us to pool treatments as CSA and SA. While in the former case, the difference to the baseline just fails to be significant, when pooling only treatments with perfect coordination the price increase for supplier 2 is easily significant.

Hence, although predicted prices are the same in all four treatments and although buyer behavior is found to be similar in sections 3.4.3 and 3.4.4, experimentally we find that prices of both suppliers increase when coordination is improved. Meanwhile, rational automated buyers are not observed to induce a change compared to the perfectly coordinated single human buyer.

We now investigate how these differences affect whether competition can be sustained by analyzing the combination of simultaneously posted prices of both suppliers. These are depicted in figure 3.4, with the differences in price levels easily discernible. For buyers to be able to sustain competition, price combinations need to allow both suppliers to attain the profit threshold. In the baseline treatment price combinations are concentrated for

Treatment	H_0	N	$\overline{p}_1$	MW p	$\overline{p}_2$	MW p
REF		6	394		511	
COM	E(REF) = E(COM)	6	477	0.310	576	0.818
SIN	E(REF) = E(SIN)	6	537	**0.065**	702	**0.093**$^+$
AUB	E(REF) = E(AUB)	6	500	**0.041**$^+$	663	**0.093**$^+$
CSA	E(REF) = E(CSA)	18	504	**0.033**$^+$	647	0.119
SA	E(REF) = E(SA)	12	518	**0.018**	683	**0.041**

Table 3.2: Prices in period 1. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

both suppliers at prices close to the marginal cost of supplier 2. Accordingly it is possible to sustain competition in less than a third of rounds (cf. table 3.3). With the introduction of communication, a single and automated buyers, the concentration of price combinations close to the marginal cost of supplier 2 becomes less pronounced while more instances of both suppliers posting high prices are observed. The frequency of price combinations which allow to sustain competition thus increases from the baseline to around a half with communication and more than $\overline{f}_{\mathrm{C}} \geq 0.61$ for a single and automated buyers. However, this increase is found not to be significant with communication, in line with the finding for the underlying changes in prices. Also, only for rounds 5-19 in AUB is the increase significant, while coming close for the other segment and a single buyer ($p \leq 0.171$). Overall, we observe a high variation between individual markets. While in the baseline for all markets the frequency is $f_{\mathrm{C}} \leq 0.67$, with communication and a single buyer there are markets where it is never possible to sustain competition but also ones where it is always possible. Testing for pairwise differences, we can again pool treatments according to their level of coordination as CSA and SA ($p \geq 0.426$). Competition can then be sustained significantly more frequently for both pooled treatments than for REF, except for CSA in rounds 10-19, where with $p = 0.154$ it comes close however.

For those prices where competition cannot be sustained, at least one supplier has to exit the market. Hence, the frequency f_{C} offers a direct measure of whether pricing is exclusionary or accommodating by allowing survival of both suppliers. While thus in the baseline exclusionary pricing is prevalent, we find that improved buyer coordination decreases the aggressiveness of pricing and suppliers become more accommodating to sustained competition. The additional introduction of sophisticated, completely rational buyers does not increase this tendency significantly further compared to a single human buyer. Combined with the results for the price levels we can thus state the first finding.

Finding 1. *With independent buyers the more efficient supplier prices close to the marginal cost of the less efficient supplier and exclusionary pricing is dominant. Improved buyer coordination leads to an increase in the price level of both suppliers. Thereby pricing becomes more accommodating to the survival of both suppliers. Complete rationality of buyers is not observed to substantially change pricing.*

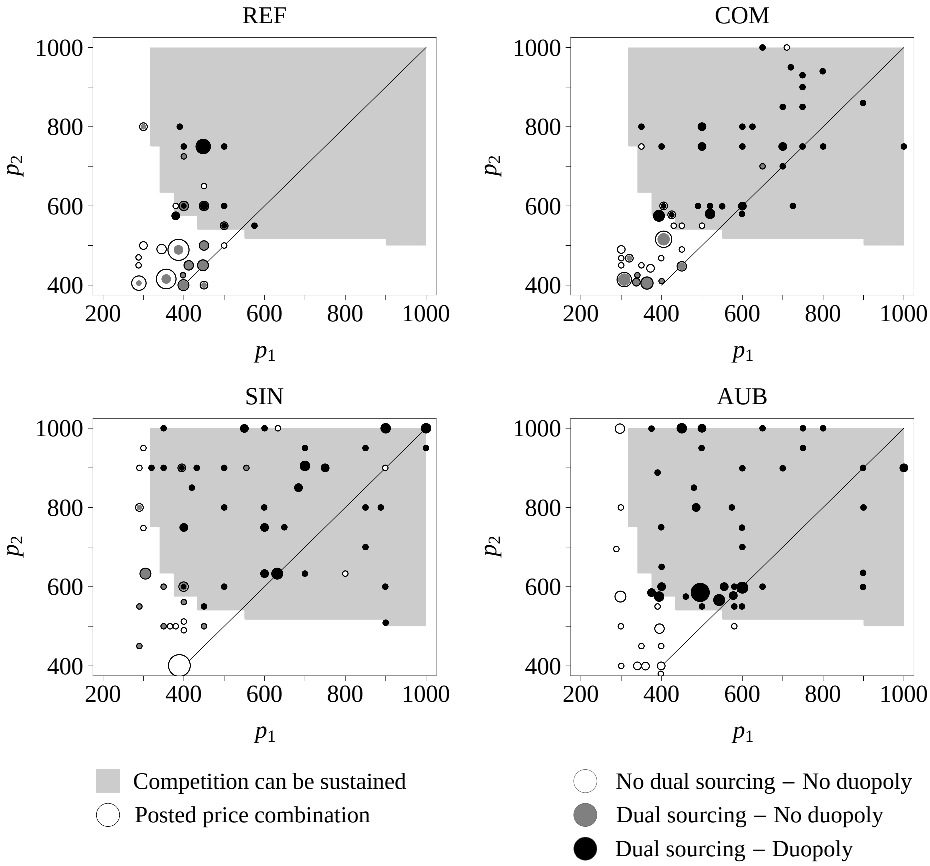

Figure 3.4: Posted price combinations in period 1, ensuing buyer behavior and market structure in period 2. Area of symbols is proportional to the observed frequency.

Since non-exclusionary prices in period 1 benefit buyers by allowing to sustain competition (cf. section 3.4.5), we thus find that buyer power increases with an improved ability to coordinate sourcing decisions. Although not predicted by theory, this is compatible with intuition, as the more efficient supplier will refrain from trying to exclude supplier 2 when he perceives the coordinated buyers to be able to source to sustain competition and to be able to respond to exclusionary pricing by sourcing from the other supplier only.

Pricing in duopolies in period 2 as analyzed in section 3.4.1 does not differ between treatments, except for the weakest evidence that rational non-human buyers might induce slightly higher prices (cf. also below). Hence, we can conclude that indeed the improved coordination of sourcing decisions induces the observed differences in pricing, as other potential sources like the size of the buyer (for a single buyer) or non-human buyers (for automated buyers) are unchangedly present in the second period as well. Accordingly, improved coordination increases the power of buyers only in situations where the consequences of better coordination can be relevant as in period 1 but not in period 2.

Various experiments find that prices with human buyers are lower than with automated buyers (Brown-Kruse 1991; Davis and Williams 1991; Davis and Wilson 2008). In our experiment we do not detect such a change when excluding the influence of im-

Treatment	H_0	N	$\overline{f}_{\mathrm{C}}$	MW p
REF		6	0.28	
COM	E(REF) = E(COM)	6	0.51	0.457
SIN	E(REF) = E(SIN)	6	0.61	0.171
AUB	E(REF) = E(AUB)	6	0.71	**0.076**$^{+}$
CSA	E(REF) = E(CSA)	18	0.61	**0.088**$^{+}$
SA	E(REF) = E(SA)	12	0.66	**0.051**

Table 3.3: Frequency of price combinations which allow to sustain competition. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

proved coordination and comparing the treatments with perfect coordination SIN and AUB ($p = 0.937$ for both supplier 1 and 2 prices). Also, prices in the myopic situation of period 2 do not differ significantly ($p = 0.177$ for the lowest price in duopolies and $p = 0.524$ in monopolies), although they come close to exhibit the reported change in duopolies. This absence of a substantial impact is most likely due to strategic sourcing being inherent in our model. Thus, also automated buyers source strategically. Accordingly, the reported differences in the literature have more to do with the fact that human buyers can strategically withhold demand in a repeated game while automated buyers are implemented to purchase myopically, than with the nature of buyers.

Another finding in the existing experimental literature is that an increased concentration of strategic buyers yields lower prices (Ruffle 2000; Engle-Warnick and Ruffle 2005). This is attributed to the increased power wielded by more concentrated individual human buyers through their ability to more drastically reduce supplier profits by withholding demand. This bears some similarity to the situation in the first period in our model, where we find that more "concentrated" decision making in the form of improved coordination of buyers leads to more favorable conditions for buyers. However, the mechanism of exercising power through sourcing decisions is quite different here. Also, we find that the ability to extract better terms of trade in our setting stems not from the mere size of individual buyers but from the additional power conferred by improved coordination of sourcing decisions.

3.4.3 Rational Dual Sourcing

When suppliers post prices in period 1 which allow to sustain competition, it is always rational for buyers to dual source and keep both suppliers active (cf. section 3.2.2). To investigate this situation, all analyses in this section are based on only those rounds where competition can be sustained (cf. section 3.4.2). This limits analysis to those markets where such rounds exist. This is the case in $N = 6$ markets in AUB and AUS but only in $N = 5$ (REF, SIN) or $N = 4$ (COM) markets with human suppliers and buyers.

To sustain both suppliers it is necessary for dual sourcing to occur in aggregate. While the automated buyers dual source always by construction when competition can be sus-

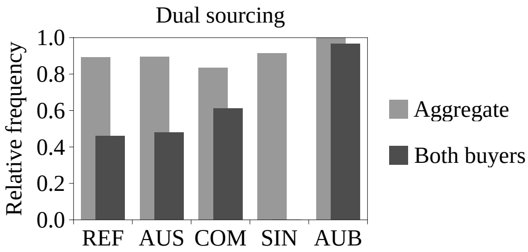

Figure 3.5: Frequency of dual sourcing in period 1 when competition can be sustained.

tained, we find that also across the other treatments, with $\overline{f}_{\text{Dual}} \geq 0.83$ dual sourcing occurs nearly always when it is rational as depicted in figures 3.4 and 3.5. For the treatments with human suppliers and buyers, we find no significant differences in pairwise comparisons with $p \geq 0.524$. Thus, improved coordination is not observed to change the frequency of dual sourcing and we therefore pool treatments REF, COM and SIN as RCS in table 3.4. Then, no significant difference arises when suppliers are automated and also mean values are nearly identical. Hence, the absence of potential fairness considerations due to the automation of suppliers does not impact the frequency of dual sourcing here. However, the frequency with human buyers is found to be significantly lower than the rational benchmark implemented by the automated buyers, but only in rounds 5-19. Although dual sourcing thus occurs slightly less often than for completely rational buyers, we find that when it is rational to dual source, nearly always human buyers do so and accordingly behavior is rather close to rational behavior.

To complement this analysis we investigate next the aggregate quantities which are sourced from the supplier with the higher price[22] in period 1, Q_{high}. This quantity offers a measure of the amount of strategic sourcing as a positive value implies that buyers forego surplus in period 1. For the treatments with human suppliers and buyers mean values $2.38 \leq \overline{Q}_{\text{high}} \leq 3.04$ are close together and no significant difference exists for any treatment compared to the baseline (cf. table 3.4). We again pool these treatments as RCS, although some caution is due as the pairwise difference between the single buyer and communications treatment comes close to being significant ($p = 0.190$). Then, for the pooled treatments we do not observe a significant difference to either the treatment with automated suppliers or with automated buyers.

As for different prices different values of Q_{high} are optimal to ensure both suppliers make a profit of at least $\underline{\pi}$, we analyze also the deviation of experimentally observed from optimal quantities[23] $\Delta Q_{\text{high}} = Q^{\text{Exp}}_{\text{high}} - Q^{\text{Theo}}_{\text{high}}$. Thereby, the optimal quantities are calculated numerically using the algorithm of section 3.2.2. The distributions in figure 3.6 show central peaks at zero deviations for all treatments. For automated buyers the distribution consists of a single peak at a deviation of zero and is thus not included. Optimal aggregate quantities are sourced often, ranging from $\overline{f} = 0.51$ (REF) to $\overline{f} = 0.70$ (COM).

[22]Tied rounds are not included in Q_{high}. However, in all treatments only $\overline{f} \leq 0.14$ of rounds are tied.
[23]Experimental quantities are indicated by a superscript to distinguish them from theoretical quantities.

Treatment	H_0	N	$\overline{f}_{\text{Dual}}$	MW p	$\overline{Q}_{\text{high}}$	MW p
REF		5	0.89		3.04	
COM	E(REF) = E(COM)	4	0.83	0.524	2.38	0.452
SIN	E(REF) = E(SIN)	5	0.91	1.000	2.92	0.841
RCS		14	0.88		2.81	
AUS	E(RCS) = E(AUS)	6	0.90	0.687	2.13	0.231
AUB	E(RCS) = E(AUB)	6	1.00	**0.037**$^+$	3.08	0.585

Table 3.4: Frequency of dual sourcing and quantity sourced from the supplier with the higher price in period 1 when competition can be sustained. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

As expected the treatments with improved coordination exhibit higher peaks and only minor deviations, while distributions for REF and AUS are rather similar. The frequency of no deviation is nearly identical with communication and a single buyer. Results are thus in line with those from one-way communication in the related but simpler "battle-of-the-sexes" game, where Cooper et al. (1989) find coordination on one of the equilibria in $f = 0.95$ of cases. Comparing experimental and optimal quantities for each treatment, we find only small mean deviations $|\overline{\Delta Q}_{\text{high}}| \leq 0.56$. Accordingly, with $p \geq 0.250$ sourced quantities are compatible with the quantities from optimal rational behavior in all treatments.

From figure 3.6 we find that for automated suppliers the experimental quantity tends to deviate to positive values, while for REF the opposite holds. Although not significant, this difference is opposed to what would be observed if human buyers purchased more from the higher-priced supplier out of fairness motivations in the baseline. We thus find again that buyers in aggregate source close to the optimal quantities, with fairness playing no discernible role. The evidence that improved coordination leads to better sourcing decisions is only very weak, while complete rationality is not found to substantially impact results. We can thus state the following finding.

Finding 2.1. *When competition can be sustained, buyers nearly always dual source. Buyer behavior is close to rational behavior and not influenced by fairness motivations. It does not change substantially with improved coordination or complete buyer rationality.*

The finding that human buyers frequently act strategically mirrors results from those experiments in posted-offer markets which are most closely related to ours (Ruffle 2000; Engle-Warnick and Ruffle 2005; Davis and Wilson 2008). In these articles buyers frequently use strategic demand withholding while in our experiment buyers employ strategic sourcing as a lever to exercise buyer power.

The success of dual sourcing is given by the frequency with which both suppliers are actually active in a duopoly in period 2 when competition can be sustained, f_{DC}. This value is included in figure 3.4 as the share of price combinations where competition can be and actually is sustained. An alternative perspective is offered by figure 3.6, where non-

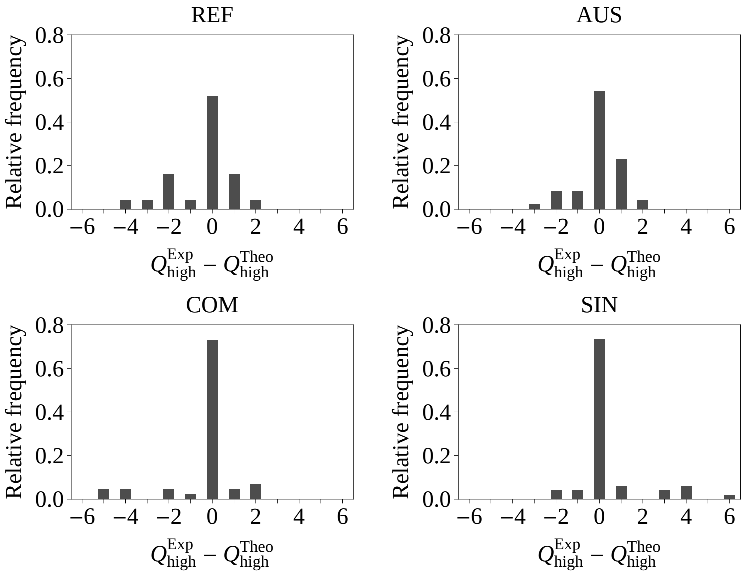

Figure 3.6: Quantity sourced from the supplier with the higher price: Deviation of experimental from optimal quantities in period 1 when competition can be sustained.

negative deviations of the experimental quantity from the optimal quantity purchased at the higher-priced supplier generally imply that competition is sustained[24].

As reported in table 3.3, we find that in the baseline treatment buyers are only in about two thirds of cases successful in sustaining supplier competition in rounds 5-19. In the three other treatments with human buyers, mean frequencies of dual sourcing success are nearly identical with $0.81 \leq \overline{f}_{\mathrm{DC}} \leq 0.84$. These values are significantly higher (or just fail to be) than in the baseline in rounds 5-19. However, for rounds 10-19 the mean value in the baseline also rises to $\overline{f}_{\mathrm{DC}} = 0.79$ and is thus no longer significantly different from any of the other three treatments with $p \geq 0.524$. Due to the differences, we cannot pool treatments as RCS as above. Instead, we pool the other three treatments with human buyers ($p \geq 0.623$ pairwise) and find a persistent significant increase compared to REF for rounds 5-19 but none for rounds 10-19 ($p = 0.710$).

These inconsistent results are caused by differences for the baseline treatment between the two segments of rounds. Due to the low frequency of rounds where competition can be sustained of only $\overline{f}_{\mathrm{C}} = 0.28$ (cf. section 3.4.2), the low value of $\overline{f}_{\mathrm{DC}}$ originates from failure to keep both suppliers active in only a single round for three of the five relevant markets in rounds 5-19. The low frequency of success is thus in all likelihood the result of single buyer errors in dual sourcing which are "amplified" by the low number of rounds where competition can be sustained. This is corroborated by the treatment with automated suppliers. Then, the buyer side of the market is identical to the baseline and we found compelling evidence above that when competition can be sustained, fairness motivations do not change buying behavior. Since by construction competition can now be sustained

[24]This does not include tied prices and cases where in turn the quantity sourced from the lower-priced supplier is so low that this supplier exits, which happens in one round in REF and in three rounds in SIN.

Treatment	H_0	N	$\overline{f}_{\mathrm{DC}}$	MW p
REF		5	0.64	
COM	E(REF) = E(COM)	4	0.82	0.119
SIN	E(REF) = E(SIN)	5	0.84	**0.056**$^{+}$
AUS	E(REF) = E(AUS)	6	0.81	**0.093**$^{+}$
AUB	E(REF) = E(AUB)	6	1.00	**0.002**$^{+}$

Table 3.5: Frequency of a duopoly in period 2 when competition can be sustained. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

in $\overline{f}_{\mathrm{C}} = 0.53$ of rounds, results are more robust and thus a better guide to dual sourcing success than values in the baseline treatment. Since frequencies for AUS do not differ significantly from those for COM and SIN, we conclude that improved coordination does not necessarily improve the frequency of success in sustaining competition.

Automated buyers are completely rational and therefore always succeed in sustaining competition. Although they are thus significantly more successful than in the baseline in rounds 5-19, they just fail to be so in rounds 10-19 with $p = 0.167$. Also, when pooling treatments with human buyers as either COM, SIN and AUS or RCS (in the latter case ignoring the differences in rounds 5-19), the frequency of dual sourcing success is significantly lower than with the perfectly rational buyers ($p \leq 0.001$). We can thus state the following addition to the previous finding.

Finding 2.2. *Human buyers succeed often but not always in sustaining competition when this is rational. Weak evidence implies that improved coordination does not change the frequency of success, while complete buyer rationality increases it.*

Sustaining competition is a slightly untypical discrete public good game because for nearly all price combinations which allow to sustain competition it is rational for even a single buyer to do so alone[25] (cf. section 3.2.2). Nevertheless a “free riding” problem in sharing the costs of purchases from the higher-priced supplier continues to exist. The rates of sustained supplier competition of around $\overline{f}_{\mathrm{DC}} \approx 0.8$ are compatible with the upper bound of observed provision rates in public good experiments with similar characteristics as reported in the meta analysis of Croson and Marks (2000). Furthermore, they report that communication significantly increases the rate of provision. The negligible effect in our case meanwhile can be attributed to the fact that buyers do not necessarily need to cooperate for successful provision.

The situation of buyers in the experiments on “naked exclusion” described in section 3.1 is most closely related to that in our model in rounds where competition can be sustained. Both free-form (Smith 2011) as well as structured two-way communication (Landeo and Spier 2009) are found to increase the frequency of entry of a second supplier. Again, the lack of a substantial impact of communication in our experiment is most likely due to the

[25] In all treatments both buyers are required to source non-myopically to sustain competition in only $\overline{f} \leq 0.13$ of rounds where this is possible.

rationality for a single buyer to sustain competition. This is consistent with the finding of Smith (2011) that the rate of ensuing competition decreases with a higher proportion of buyers required to cooperate. Landeo and Spier (2009) find that rates of competitive entry significantly increase due to the absence of fairness considerations of buyers when the incumbent supplier is automated. In contrast, in our experiment fairness motivations do not to have a substantial influence on buyer behavior when competition can be sustained. This arises because of a less drastic reduction in supplier profits with future competition and the fact that in our case both suppliers are human. We find however that fairness does play a role when competition cannot be sustained in section 3.4.4.

So far we have focused on aggregate buyer behavior. Now we analyze if and how buyers cooperate when competition can be sustained, therefore decomposing the frequency of aggregate dual sourcing as $f_{\text{Dual}} = f_{\text{Co}} + f_{\text{NoCo}}$: Either both buyers dual source and thus cooperate or only a single buyer purchases strategically.

The frequency of both buyers dual sourcing is shown in figure 3.5. In the baseline and automated supplier treatments, buyers cannot explicitly coordinate and we find $\overline{f}_{\text{Co}} = 0.46$ and $\overline{f}_{\text{Co}} = 0.48$ respectively. These frequencies do not differ significantly ($p = 0.833$), allowing us to pool both treatments as RA. Thus, without explicit coordination, only in about half of the rounds do both buyers cooperate. When buyers can communicate, the mean value increases to $\overline{f}_{\text{Co}} = 0.61$ although this increase is not significant ($p = 0.829$). Automated buyers are implemented to split demand as evenly as possible among each other and thus offer an upper reference point for cooperation[26] with $\overline{f}_{\text{Co}} = 0.97$, which is significantly higher than for the pooled treatments without coordination ($p = 0.010$). Interpreting the single buyer in SIN as a purchasing group of two buyers (cf. section 3.3.1), aggregate demand can be assumed to be split as evenly as possible between buyers, yielding $\overline{f}_{\text{Co}} = 0.89$ which is significantly higher than in RA ($p = 0.091$).

We focus now on how evenly buyers share the cost of strategic sourcing as indicated by the quantity sourced from the higher-priced supplier. In both treatments without explicit coordination there are numerous instances where quantities differ quite substantially, which is borne out by differences of $\overline{\Delta q}_{\text{high}} = \overline{|q_{\text{high},2} - q_{\text{high},1}|} = 1.66$ in REF and $\overline{\Delta q}_{\text{high}} = 0.96$ in AUS. These values do not differ significantly with $p = 0.355$ and accordingly we again pool both treatments as RA. The perfectly coordinated automated buyers yield a significantly lower mean difference of only $\overline{\Delta q}_{\text{high}} = 0.13$ ($p = 0.002$). The non-zero value originates from situations where the optimal Q_{high} is uneven and thus cannot be split evenly between buyers. Interpreting SIN again as a purchasing agency of two buyers results in $\overline{\Delta q}_{\text{high}} = 0.21$, which is also significantly lower than in RA with $p = 0.010$.

In the treatment with communication, buyer 1 always announces her intended demand split and in $\overline{f} = 0.93$ of situations follows her announcement. This is quite close to the predicted value of one. Nevertheless, contrary to the prediction of maximum asymmetry, in $\overline{f} = 0.63$ of cases both buyers source the same quantity from the supplier with the

[26]The remaining rounds require $Q_{\text{high}} = 1$ and therefore only a single buyer dual sources.

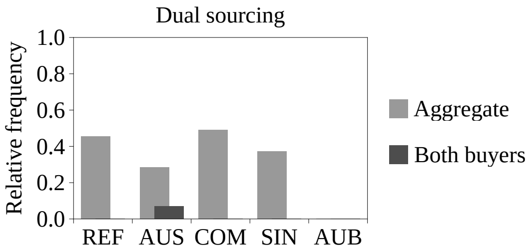

Figure 3.7: Frequency of dual sourcing in period 1 when competition cannot be sustained.

higher price, while $q_{\text{high},1}$ is lower in less than one third of cases. Hence there is at most a weak tendency for buyer 1 to purchase less from the higher-priced supplier than buyer 2. This yields a high degree of cooperation with $\overline{\Delta q}_{\text{high}} = 0.86$, which does however not differ significantly from the value in the treatments without coordination ($p = 0.829$).

Therefore, corroborating the finding from the frequency of both buyers dual sourcing, a clear increase in buyer cooperation is found (by construction) when coordination is perfect, while the increase when buyers can communicate is not significant.

Finding 3. *Without communication, human buyers cooperate in dual sourcing in only around half of the cases. When buyers can communicate, there is only the weakest evidence that this increases buyer cooperation.*

3.4.4 Non-Rational Dual Sourcing

Now we analyze those situations where for non-tied prices it is not rational to dual source, $f_{\text{Dual}} = 0$. Accordingly, all demand is purchased from the supplier with the lower price and therefore also $Q_{\text{high}} = 0$. This is the case in the first period in those rounds where competition cannot be sustained and also in period 2 duopolies. Non-rational dual sourcing can then arise due to inadvertent random errors by human buyers. Furthermore, when human buyers face human suppliers, they might be motivated to dual source by fairness considerations since the less efficient supplier cannot compete on the same terms as the efficient supplier[27].

Figure 3.4 includes the frequency of aggregate dual sourcing in rounds where competition cannot be sustained in period 1 while mean values[28] are shown in figure 3.7. In the baseline, communication and single buyer treatments, dual sourcing occurs in slightly less than half of the rounds as reported in table 3.6 and values are not significantly different pairwise ($p \geq 0.762$). Accordingly, as in section 3.4.3 we pool the treatments with human buyers and suppliers as RCS with $\overline{f}_{\text{Dual}} = 0.44$. Compared to the rational automated buyers who never split demand, the frequency is found to be significantly higher. The

[27]To minimize fairness motivations, as described in section 3.3.2 costs are randomly allocated to subjects in each round and subject identifiers of the suppliers are not disclosed to buyers.

[28]Rounds with tied prices are included in $\overline{f}_{\text{Dual}}$ to complement the analysis in section 3.4.3. In all treatments, they account however for only $\overline{f} \leq 0.13$ of rounds in both period 1 and 2.

Treatment	H_0	N	$\overline{f}_{\text{Dual}}$	MW p	$\overline{Q}_{\text{high}}$	MW p
REF		6	0.46		1.62	
COM	E(REF) = E(COM)	4	0.49	0.967	1.49	1.000
SIN	E(REF) = E(SIN)	4	0.37	0.762	1.36	0.610
RCS		14	0.44		1.51	
AUS	E(RCS) = E(AUS)	6	0.29	0.433^x	0.62	0.108^x
AUB	E(RCS) = E(AUB)	3	0.00	**0.009**	0.00	**0.003**

Table 3.6: Frequency of dual sourcing and quantity sourced from the supplier with the higher price in period 1 when competition cannot be sustained. Mann-Whitney test, p-values two-tailed. (x) significant for rounds 10-19.

respective mean value with automated suppliers is lower than in RCS at less than one third of rounds, although the difference is significant only for rounds 10-19 ($p = 0.058$).

We now focus on the volume of dual sourcing as given by the aggregate quantity purchased from the supplier with the higher price, Q_{high}. When competition cannot be sustained, quantities in the three treatments with human buyers and suppliers are between $1.36 \leq \overline{Q}_{\text{high}} \leq 1.62$ and do not differ significantly pairwise ($p \geq 0.610$). Pooling these as RCS, the quantity is significantly higher than with automated buyers (cf. table 3.6). When in turn suppliers are automated and fairness motivations are absent, the mean quantity is markedly lower with $\overline{Q}_{\text{high}} = 0.62$. The difference just fails to be significant with $p = 0.108$ in rounds 5-19, while being easily so in rounds 10-19 ($p = 0.008$).

Complementing the analysis with the duopoly rounds in period 2, RCS treatments can again be pooled, yielding $\overline{f}^{\text{2D}}_{\text{Dual}} = 0.28$ and $\overline{Q}^{\text{2D}}_{\text{high}} = 0.84$ (cf. also figure 3.2). Both values are somewhat lower than in period 1, but not significantly so with $p \geq 0.322$ in the $N = 14$ markets available for analysis. No significant difference in either the dual sourcing frequency or the quantity purchased from the supplier with the higher price ($p \geq 0.637$) is found compared to the automated suppliers, where $\overline{f}^{\text{2D}}_{\text{Dual}} = 0.29$ and $\overline{Q}^{\text{2D}}_{\text{high}} = 1.66$. This result contrasts with the finding for period 1. The likely reason is that automated suppliers post equilibrium prices in period 2, reducing the surplus foregone by buyers when purchasing from the higher-priced supplier to only $\Delta\text{BS} \leq 8$, which translates into a payoff difference of less than EUR 0.01, leading many subjects to be (nearly) indifferent.

Thus the observed differences in strategic sourcing between the treatments with human and automated suppliers in period 1 provide weak evidence that fairness partially motivates non-rational dual sourcing, although it appears to be of only minor importance compared to the impact of errors made by human buyers. This interpretation is backed up by the finding that sourcing behavior in the first period is roughly in line with behavior in the second period[29]. Furthermore, the frequency that both buyers cooperate in dual sourcing is now $\overline{f}_{\text{Co}} \leq 0.07$ in period 1 (cf. figure 3.7) and even identical to zero in treatments REF

[29]This is also confirmed by an additional treatment with $\underline{\pi} = 0$, where dual sourcing is never rational for unequal prices. Then $\overline{f}_{\text{Dual}}$ and Q_{high} do not differ significantly from RCS in both periods, although mean values are slightly lower in period 1.

Treatment	H_0	N	$\overline{f}_D$	MW p
REF		6	0.19	
COM	E(REF) = E(COM)	6	0.43	0.461
SIN	E(REF) = E(SIN)	6	0.53	0.128
AUB	E(REF) = E(AUB)	6	0.71	**0.022**$^+$
CSA	E(REF) = E(CSA)	18	0.56	**0.052**$^+$
SA	E(REF) = E(SA)	12	0.62	**0.024**

Table 3.7: Frequency of a duopoly in period 2. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

and COM, while in period 2 also $\overline{f}_{Co} \leq 0.10$. Hence, dual sourcing in cases where it is not rational stems more from individual errors than from a strategy shared by buyers. This is especially evident when comparing to the frequency of cooperation when competition can be sustained, which is close to one half (cf. section 3.4.3). Overall, we can thus draw the following conclusion.

Finding 4. *Even when competition cannot be sustained, human buyers dual source frequently. There is weak evidence that fairness motivations are responsible for a small part of this, while the rest can be attributed to buyer errors.*

The relevance of fairness motivations marks a notable difference to situations where competition can be sustained in section 3.4.3 and rational dual sourcing dominates.

3.4.5 Overall Results

As discussed in sections 3.4.2 and 3.4.3, both supplier and buyer behavior in period 1 have an impact on how often competition is sustained. The frequency of a duopoly in period 2 is then given by the product of the frequency of prices which allow to sustain competition and successful dual sourcing by buyers, $f_D = f_C \times f_{DC}$.

Figure 3.4 depicts the frequency of sustained competition as the share of price combinations which are colored in black. While in the baseline treatment competition is sustained in only one fifth of cases as reported in table 3.7, the mean value is doubled when buyers can communicate. A further increase is observed with a single buyer and for automated buyers competition is sustained in more than two-thirds of cases.

The statistical analysis reflects the high variation of prices between individual markets as discussed in section 3.4.2. As a result, the frequency of sustained competition varies between $f_D = 0$ and $f_D \geq 0.53$ in individual markets for all treatments with human buyers. Accordingly, the increase in the frequency of sustained competition with communication is not significant (cf. table 3.7), while for a single buyer it only just fails to be so for both segments of rounds ($p \leq 0.128$). In the case of automated buyers, the increase is significant in the first segment of rounds but in the second it falls just short with $p = 0.134$. We find no pairwise differences between the treatments with improved coordination ($p \geq 0.180$) and

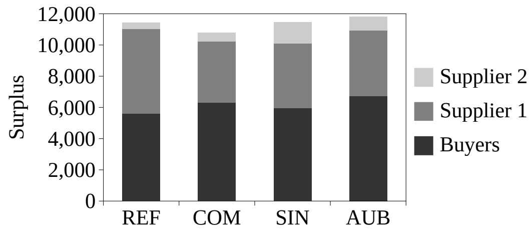

Figure 3.8: Surplus distribution.

with perfect coordination ($p = 0.290$). This allows us to again pool the treatments as CSA and SA respectively, although the low p value for CSA advises some caution. Thereby, the result for SA implies that complete rationality of buyers does not increase the frequency significantly further when coordination is perfect. We find that the frequency of sustained competition is significantly higher than in the baseline treatment both for perfect coordination (SA) and also for improved coordination (CSA) in rounds 5-19, while only just failing to be significant with $p = 0.160$ in rounds 10-19.

For the rational automated buyers in AUB, the frequency of sustained competition is determined only by the frequency of suppliers setting prices which allow to sustain competition as then buyers are programmed to purchase accordingly. However, also for the treatments with human buyers, pricing in period 1 is the decisive factor in determining whether competition is sustained. In section 3.4.3 we found that the frequency of successful dual sourcing does not differ significantly between treatments with human buyers regardless of the level of coordination[30] and is always close to $\overline{f}_{\mathrm{DC}} \approx 0.80$. In contrast, in section 3.4.2 the frequency of price combinations which allow to sustain competition was found to differ substantially. Accordingly, for the frequency of sustained competition we observe the same significance of differences between treatments as for the frequency of prices which allow to sustain competition. Furthermore, estimating $\overline{f}_{\mathrm{D}}$ from $\overline{f}_{\mathrm{C}}$ by using a fixed value $f_{\mathrm{DC}} = 0.8$ in all treatments with human buyers and $f_{\mathrm{DC}} = 1.0$ in AUB yields mean frequencies which differ by less than $\Delta\overline{f}_{\mathrm{D}} \leq 0.05$ from the observed frequencies and exhibit the same significance of differences. Therefore we can draw the following conclusion.

Finding 5.1. *With independent buyers, competition is only rarely sustained. With improved coordination the frequency of sustained competition increases, mainly due to more accommodating pricing. No additional increase is observed for completely rational buyers.*

While for buyers the frequency of sustained competition is decisive, for suppliers the frequency of a monopoly in period 2 offers a measure of the success of exclusion. We find that the order of mean frequencies of exclusion is roughly reversed compared to the frequency of sustained competition. Improved coordination significantly decreases the frequency of $\overline{f}_{\mathrm{M}} = 0.70$ in REF with $p = 0.015$ for CSA and $p = 0.022$ for SA.

[30]Regarding the low value of $\overline{f}_{\mathrm{DC}} = 0.64$ for REF in rounds 5-19 see the discussion in section 3.4.3.

Treatment	H_0	N	$\overline{BS}$	MW p	$\overline{\pi}_1$	MW p	$\overline{\pi}_2$	MW p
REF		6	5614		5436		387	
COM	E(REF) = E(COM)	6	6320	0.240	3894	**0.009**$^+$	569	0.699
SIN	E(REF) = E(SIN)	6	5956	0.310	4139	**0.065**$^+$	1358	**0.041**$^+$
AUB	E(REF) = E(AUB)	6	6720	0.240	4214	0.240	890	**0.065**$^+$
CSA	E(REF) = E(CSA)	18	6332	0.137	4421	**0.015**	939	**0.066**$^+$
SA	E(REF) = E(SA)	12	6338	0.180	4177	**0.067**$^+$	1124	**0.018**$^+$

Table 3.8: Surplus of buyers, supplier 1 and supplier 2. Mann-Whitney test, p-values two-tailed. (+) not significant for rounds 10-19.

The differences between treatments in the frequency of period 2 market structures and the preceding behavior in period 1 induce differences in the surplus distribution. As depicted in figure 3.8, due to the inelastic demand the total surplus is similar in all treatments. However, since purchases at the supplier with the higher cost are made and in some cases no supplier is active in period 2, the surplus is slightly lower than the prediction of $12,800$. Pooling all treatments, we find that buyer surplus is significantly higher in rounds where competition is sustained than when a monopoly follows. Accordingly, supplier 1 surplus is higher when exclusion is successful than when it is not, while the profit of supplier 2 increases when he is sustained ($p = 0.000$ in all cases, $N \geq 16$).

In line with the prevalence of exclusionary pricing, the baseline treatment yields surplus values not significantly different from the prediction of BS = 5472 ($p = 0.688$). Although mean values of buyer surplus in the treatments with improved coordination are higher than in the baseline, none of these increases is significant as reported in table 3.8. The absence of pairwise differences ($p \geq 0.240$) allows us to again pool treatments with improved and perfect buyer coordination. Then, the increase of buyer surplus compared to the baseline only just fails to be significant for CSA and SA ($p \leq 0.180$ for both segments of rounds). However, surplus is clearly higher than predicted in both cases ($p \geq 0.009$). The variation between individual markets continues to be pronounced.

In the baseline, surplus of supplier 1 is found to be $\overline{\pi}_1 = 5436$, which is significantly lower ($p = 0.031$) than the predicted value of BS = 7328 and comparable to buyer surplus ($p = 0.844$). This is mostly due to the (few) cases where competition is sustained or both suppliers exit. For the treatments with improved coordination, mean surplus is lower still with $\overline{\pi}_1 \leq 4214$ as evidenced by figure 3.8. The decrease compared to the baseline is significant in rounds 5-19 for both SIN and COM as reported in table 3.8, while just failing to be so in the second segment of rounds ($p \leq 0.180$) and in both segments for automated buyers ($p = 0.240$). However, due to the lack of pairwise differences ($p \geq 0.699$) we can again pool treatments as CSA and SA. Then the decrease in supplier 1 profit is easily significant except for SA in rounds 10-19 where however it comes close with $p = 0.125$. Accordingly, the profit is lower than predicted ($p \leq 0.005$) and thus also significantly lower than the surplus of buyers ($p = 0.000$).

Although the less efficient supplier 2 is not predicted to realize any surplus, in all experimental treatments the mean profit of supplier 2 is positive. In the baseline treatment we find $\overline{\pi}_2 = 387$, a value which increases with improved coordination as the frequency of sustained competition is higher. However, the difference is significant only for a single buyer and automated buyers and then only in the first segment of rounds. Pooling is not unproblematic as for both CSA ($p = 0.132$) and SA ($p = 0.180$) pairwise differences are close to significance. Also, while in rounds 5-19 an increase compared to the baseline is observed in both cases, this fails to be significant for the second segment of rounds, providing only weak evidence that profits increase with improved coordination.

With no significant difference between SIN and AUB in surplus for both buyers and supplier 1, we can conclude that the complete rationality of buyers has only a limited impact on the surplus distribution. Hence, we can state the following addition to the previous finding.

Finding 5.2. *With independent buyers, no difference in the surplus of the more efficient supplier and buyers is observed, while the less efficient supplier realizes positive surplus. With improved coordination, the surplus of the more efficient supplier decreases. Conversely, there is weak evidence that the surplus of buyers and the less efficient supplier increases. Complete rationality of buyers is not observed to change results substantially.*

3.5 Conclusion

We experimentally investigate the dynamic sourcing decisions of powerful buyers vis-à-vis suppliers which are threatened in their survival. A two period asymmetric cost Bertrand duopoly with two buyers is implemented, where suppliers are only active in the second period when their profit in period 1 is sufficiently high. Buyers then have an incentive to sustain competition while suppliers have an incentive to exclude the other supplier. For all experimental treatments the subgame-perfect prediction is that the more efficient supplier successfully excludes the other supplier and enjoys a monopoly in the second period. This is roughly observed in the baseline treatment. When however buyer coordination is improved through communication and especially when it is perfect with a single or two automated buyers, pricing becomes more accommodating and often competition is sustained. The surplus of supplier 1 is depressed while there are weak indications that buyer surplus increases. Sophisticated, completely rational buyers are not found to improve significantly upon this. Notably, sourcing decisions do not change substantially with improved coordination. Strategic dual sourcing is regularly used and very often succeeds in sustaining competition when this is rational. Dual sourcing persists however even when competition cannot be sustained, mainly due to errors but to a small degree also due to fairness motivations. Overall, the observed changes are mainly caused by suppliers pricing less aggressively when facing better coordinated buyers. Thus, coordination improves the power of buyers.

Regarding firm interactions in situations similar to the one modeled here, our results have noticeable implications. Buyers who communicate with other buyers, who form a purchasing agency or who act as a monopsonist are perceived to be more powerful by suppliers since their sourcing decisions can have a decisive impact on the survival of suppliers. Hence suppliers behave accordingly, increasing the surplus of buyers through less exclusionary pricing and allowing competition to be sustained. Our results thus indicate that aside from any effects caused by buyer size alone, improved buyer coordination adds power to buyers. On the supplier side, results are more subtle. Notably, in our model we do not find evidence that sourcing decisions change substantially with better coordination, cautioning about the danger to suppliers of facing buyers who command a large part of market demand.

In the realm of antitrust policy, our findings add an important insight. The formation of better coordinated buyers adds power to these buyers, especially vis-à-vis suppliers who are threatened in their survival. This undermines exclusionary tendencies of suppliers as buyers will often benefit from sustained competition. Hence, our experiment adds further credence to the finding that powerful buyers will not allow their supply to be monopolized, thereby limiting exclusionary tendencies as included in the EU Guidelines on Vertical Restraints. Indeed, we not only find that strategic sourcing to sustain upstream competition is pervasive, we also find that the more powerful buyers, the more successful this becomes as suppliers are coerced into pricing more accommodatingly. Nevertheless it is important to take into account that in other settings the additional power arising from being able to "single-handedly" decide on the survival of a supplier through the sourcing decision can also have effects which are detrimental to competition. Finally, our findings are also a reminder of the importance of validating theoretical results in experimental settings as they are not predicted by game theory.

Chapter 4

The Role of the Procurement Process in Sustaining Supplier Competition - An Experiment

Strategic buyers who source from competing suppliers over time often aim to sustain competition among the suppliers. We investigate experimentally the role the procurement process plays in achieving this, by implementing different processes in a two period posted-offer duopoly with two buyers. Suppliers exit when profitability in the first period is insufficient. In the second period, all processes yield comparable outcomes which are close to the rational prediction. In the first period exclusionary pricing dominates for the baseline procurement auction process and effectively also for split-award auctions, leading often to a monopolistic supply situation in the second period. However, in line with the subgame-perfect prediction, allowing subsidies or announcing sourcing before suppliers bid induces more accommodating pricing and increases the probability of competition being sustained. We thus find that the procurement process can have a major impact on supplier behavior and thereby also on the future structure of the supplier market.

4.1 Introduction

When a firm is a large buyer in a market and needs to procure a good now and in the future from competing suppliers, it faces a strategic decision between sourcing from a single or multiple suppliers.

In reality, evidence is found for both approaches. Retail chains often use "winner-takes-all" auctions to procure goods from suppliers, awarding the contract only to the bidder making the best offer. The same holds for procurement processes by public bodies requiring explicitly that the lowest offer be accepted[1]. In contrast, many airlines operate

[1]This is how the Department of Defense procures drugs (Gong, Li, and McAfee 2010). Also, defense projects like the Joint Strike Fighter (after competing prototypes were built) are often awarded to a single supplier. Beker and Hernando-Vecianaz (2009) provide further examples from the public and private sector.

fleets of large commercial aircraft from both Airbus and Boeing, the sole providers, despite operational benefits of sourcing from only one company[2].

Understanding future consequences of current sourcing decisions becomes especially important when buyers are large and suppliers are at risk of survival[3]. When a buyer commands a large share of the overall demand, her sourcing decision will have a profound impact on the sales of a single supplier. Thus, if the supplier is threatened in survival, it may be decisive for staying active or not. Accordingly, with the exit of individual suppliers, the upstream market structure is changed and competitiveness may decrease in the future. This prospect in turn may induce superior suppliers to engage in predatory behavior and try to exclude weaker rivals by inducing buyers to single source, thus monopolizing the market in the future. With predatory conduct generally violating antitrust laws[4] but powerful buyers recognized to exercise a countervailing influence (EU 2010), such situations are also of interest to antitrust policy.

Buyers can thereby generally determine the timing and format in which the procurement competition takes place and the sourcing decision is being made by implementing a specific procurement process. Increasingly, various auction formats are employed[5]. Characterizing and understanding the impact of basic differences in these formats is thus important to allow the selection of procurement processes which optimally support sourcing decisions and thus also further strategic procurement goals such as sustaining competition among suppliers[6].

To investigate the impact of different procurement processes, a two period model is employed, representing the current and future sourcing situations. Two suppliers with different efficiencies compete in prices to supply two buyers. Exit is modeled by requiring a minimum profit in the first period for suppliers to be active in the second period. We implement the model experimentally for four different procurement processes.

In the second period, we find pricing and purchasing decisions not to differ for any procurement process from the baseline Bertrand competition which corresponds to a procurement auction. Accordingly, for all procurement processes buyers benefit from sustaining both suppliers. However, in the first period exclusionary pricing is predominant in the baseline process, resulting often in the more efficient supplier enjoying a monopoly in the second period. Exclusion also dominates when suppliers can post nonlinear prices

[2]Among the largest 25 customers of all delivered Airbus and Boeing aircraft in the years 1974-2009, just two purchased from a single company only (Airbus 2009; Boeing 2009). Multiple sourcing is also used in defense procurement (Anton and Yao 1992) and, e.g., by Motorola (Metty et al. 2005), General Motors and IBM (Anton, Brusco, and Lopomo 2010).

[3]Car manufacturers and their suppliers offer an example of such a situation. Single manufacturers often account for a large share of the sales of car parts suppliers (cf. examples in Babich 2010; Wadecki, Babich, and Wu 2010), many of which are in a weak position. E.g., in the economic downturn of 2008 a third of suppliers in North America declared bankruptcy according to Wadecki, Babich, and Wu (2010).

[4]Examples are thus taken mainly from actual cases. Recently, France Telecom (ECJ C-202/07 P 2009) was found guilty, while a subsidiary of AT&T (SC 555 U.S.___ 2009) was acquitted of charges of predatory pricing for internet access.

[5]Cf., e.g., Metty et al. (2005) and examples in Tunca and Wu (2009).

[6]E.g., Sun Microsystems is reported to use processes with different complexity depending on the procurement situation (Tunca and Wu 2009).

in split-award auctions. Both suppliers demand premia for small quantities. These often allow to sustain competition, an option buyers however frequently do not use.

When buyers can pay subsidies to suppliers or announce their quantity split before suppliers bid, price levels increase and pricing is more conducive to the survival of both suppliers. Buyers then often keep both suppliers active by dual sourcing and the frequency of sustained competition increases accordingly. Across procurement processes, the less efficient supplier often prices more aggressively than optimal.

Behavior of buyers is relatively close to rational behavior for all procurement processes, although the success of sustaining both suppliers when this is optimal is often lower than predicted. Hence, contrary to the prediction, no significant increase in total buyer surplus is observed for processes with subsidies and pre-announced sourcing, although surplus is shifted from the more to the less efficient supplier. Nevertheless, the marked impact of the procurement processes on the behavior of suppliers in a strategic situation and thus on the future structure of the supplier market is close to the subgame-perfect prediction.

This article is organized as follows. An overview of related work is given in section 4.2. Then, in section 4.3 the model as well as the procurement processes are specified. Numerical solutions for subgame-perfect equilibria are provided in section 4.4 and predictions are deducted. Experimental procedures are summarized in section 4.5, while results are discussed in section 4.6. Section 4.7 concludes.

4.2 Related Literature

Since we investigate the strategic interplay of suppliers and buyers, our work is related to different strands of literature. The first is the literature on buyer power. Although the concept of countervailing power dates back to Galbraith (1952), only recently has the strategic behavior of buyers received considerable attention. Overviews of the theoretical work are provided, e.g., by Inderst and Mazzarotto (2008) in the context of retailing and Inderst and Shaffer (2008) with a focus on mergers, while Ruffle (2005) encompasses the related experimental literature.

Buyer power is found to arise from a large size of demand of a buyer (cf., e.g., Chipty and Snyder 1999), a threat to integrate backwards into the supplier market (Katz 1987) but also, e.g., from the control of access to downstream markets (Mazzarotto 2004). Accordingly, in the model employed in this article, buyers are powerful since each buyer controls a sizable share of aggregate demand.

Powerful buyers can extract better terms of trade, as formalized for a single supplier by, e.g., Chipty and Snyder (1999) and Inderst and Wey (2003), in a dynamic model with competing suppliers in Snyder (1998) and as a consequence of single-sourcing in Inderst and Shaffer (2007). In experiments, lower prices are observed in posted-offer markets when buyer concentration increases for both a single supplier (Engle-Warnick and Ruffle 2005) and multiple suppliers (Ruffle 2000). The work of Normann, Ruffle, and Snyder (2007) finds buyer-size discounts for a single supplier to arise only for increasing marginal costs as predicted, while for competing suppliers large buyer discounts are pervasive (Ruffle 2009). Finally, Davis and Wilson (2008) investigate the impact of supplier mergers in the presence of powerful buyers and find human buyers to generally induce lower prices.

In addition to other consequences, buyer power may however also lead to foreclosure of suppliers as addressed in our investigation. Discussion has focused on exclusive supply contracts with compensation payments, employed by an incumbent monopolist to exclude a more efficient entrant. Due to coordination problems among buyers, exclusion can be profitable as demonstrated in the "naked exclusion" literature originating from Rasmusen, Ramseyer, and Wiley (1991) and Segal and Whinston (2000). Exclusive dealing is also found to occur frequently in experimental markets in Landeo and Spier (2009), Boone, Müller, and Suetens (2009) and Smith (2011). Increasing the fraction of buyers required for exclusion and allowing communication generally decreases the rate of exclusion (Landeo and Spier 2009; Smith 2011). Meanwhile, price discrimination can lead to increased exclusion as reported in Boone, Müller, and Suetens (2009).

When suppliers cannot exclude rivals explicitly through contracts as in our model, predatory pricing might arise to induce exit of competing suppliers and recoup foregone profits through monopoly prices in the future. An overview of the related literature is given by, e.g., Bolton, Riordan, and Brodley (2000). In experiments, predatory pricing has proven challenging to detect (Isaac and Smith 1985; Harrison 1988). While in an abstract setting Jung, Kagel, and Levin (1994) find indications for predatory behavior, it is also observed reliably in the multi-market setup of Goeree and Gomez (1998).

As buyer power is exercised through sourcing in our work, this article is also related to the literature on optimal sourcing decisions of firms, an overview of which is provided by, e.g., Elmaghraby (2000). Generally, the optimality of single vs. multiple sourcing is found to depend critically on details of the situation, e.g., the number and size of buyers (cf. Anton and Yao 1989; Inderst 2008). Also, with split-award auctions in equilibrium the contract is often split (Anton and Yao 1992), which however need no longer hold with scale economies (Anton, Brusco, and Lopomo 2010). Committing to multiple sourcing by guaranteeing a share of the contract to each bidder is found to be able to increase participation and reduce procurement costs (Klotz and Chatterjee 1995a; Klotz and Chatterjee 1995b). In addition, the works of Clark and Polborn (2006) and Bergès and Chambolle (2009) investigate explicitly how sourcing decisions of strategic buyers impact supplier foreclosure. In Clark and Polborn (2006), buyers may not source strategically in equilibrium but prices can be altered by the threat to do so. Meanwhile, Bergès and Chambolle (2009) find that there can exist equilibria where suppliers price so high that they extract all surplus, exploiting the buyer who sustains them.

The present work follows our analytical investigation of the model employed here, finding exclusionary behavior to be dominant in a procurement auction, while also showing how guaranteeing a quantity to suppliers by announcing the sourcing decision first can

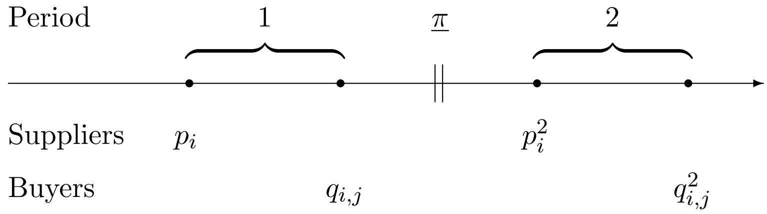

Figure 4.1: Model timing and strategic variables.

lead to more accommodating outcomes (Wilken 2011b). Meanwhile, in a closely related experiment with this model, we find improved coordination of buyers to increase both the probability of competition being sustained and the buyer surplus (Wilken 2011a).

The present work thus adds to the investigation of buyer sourcing decisions as a source of countervailing power by analyzing the role the procurement process plays in determining supplier pricing and the future structure of the supplier market. To the best of our knowledge, this work is the first to experimentally investigate the impact of different procurement processes and after the preceding article (Wilken 2011a) only the second to address explicitly strategic sourcing decisions of buyers in an experiment.

4.3 Model and Procurement Processes

4.3.1 Model

To investigate the impact of different procurement processes in a situation as described in the introduction, we employ an asymmetric cost Bertrand model. This is repeated in two periods as depicted in figure 4.1, with period 1 representing the current and period 2 the future market situation. In the first period, two suppliers i set prices p_i for a homogeneous good[7]. Suppliers are identical except for their different constant marginal costs, with supplier 1 being the more efficient supplier throughout this work, $c_1 < c_2$.

Two buyers j purchase the good from the suppliers. Each demands a quantity of exactly d in every period and decides how to source this demand from the suppliers, $d = q_{1,j} + q_{2,j}$. Using an inelastic demand thereby allows us to exclude the option to withhold demand in the experiment. The good is valued at V by buyers, who are assumed not to purchase for prices above their valuation, i.e., they do not make losses on individual purchases (cf. also Wilken 2011b). The surplus of a buyer is then $\mathrm{BS}_j = \sum_i q_{i,j}\,(V - p_i)$. Together, buyers purchase an aggregate quantity $Q_i = q_{i,1} + q_{i,2}$ from supplier i.

In order to be active in period 2, the profit of a supplier in period 1 has to be at least as high as $\underline{\pi}$, i.e., $\pi_i = Q_i\,(p_i - c_i) \geq \underline{\pi}$. This profit threshold models in a straightforward way that suppliers are threatened in their survival and that to remain active in a

[7]Period 1 indices are dropped throughout this work while period 2 indices are carried.

Process	Change to REF
REF - Baseline	-
SPA - Split-award auctions	Suppliers set prices for small and large quantity
SUB - Subsidies	Buyers can pay subsidies to suppliers
PRE - Pre-announced sourcing	Buyers announce demand split first

Table 4.1: Procurement processes.

market, firms in the long run have to be profitable[8]. In period 2 then, only the active suppliers compete to supply buyers.

In the experiment, prices can be chosen in steps of $\Delta_p = 1$ and are limited to $p_i \leq V$ to implement that buyers do not purchase above their valuation and to avoid buyer losses. Allowing for a large range of possible prices, we set $V = 1000$. To facilitate understanding without rendering the sourcing decision trivial, $d = 4$ and an increment $\Delta_q = 1$ are chosen, i.e., quantities can be split in integer values between suppliers. The remaining parameters are set to allow survival of both suppliers for a large range of price combinations, to yield a pure strategy equilibrium prediction with a price of supplier 1 in period 1 below the price of the one period model and to implement similar expected payoffs of suppliers and buyers. This is achieved by choosing $c_1 = 200$, $c_2 = 400$ and $\underline{\pi} = 700$.

4.3.2 Procurement Processes

In addition to the baseline procurement process REF which corresponds to the model in section 4.3.1, we analyze three modifications as experimental treatments, with the respective process being used in both periods. An overview is provided in table 4.1.

In REF, buyers essentially put up their demand for tender in a procurement auction. Suppliers bid to supply the buyers, who however keep the discretion to award the contract to a single supplier or split it between suppliers.

The first modification is the use of split-award auctions in SPA. Suppliers now post two prices. One holds when an individual buyer sources at most half the demand from the supplier, $p_i(q \leq d/2)$. The other, $p_i(q > d/2)$, holds when the supplier is awarded more than half of the contract. Buyers then decide how to split the award between suppliers as in the baseline. This is a simplified version of step ladder bids as modeled in Anton and Yao (1992), where suppliers post prices for specific contract splits[9]. The process is thus equivalent to suppliers setting nonlinear prices.

Subsidies can be paid to suppliers by buyers in SUB. In both periods, each buyer j can thus make direct transfer payments to each supplier i, $s_{i,j} \geq 0$, in addition to or instead of sourcing a positive quantity from this supplier. Using subsidies to sustain suppliers at

[8]Using measures of performance to model firm exit is not uncommon. Biglaiser and DeGraba (2001) as well as Clark and Polborn (2006) use similar profit thresholds, while Babich (2010) and Wadecki, Babich, and Wu (2010) model firm exit dependent on the ratio of assets to liabilities in the former and the difference between earnings and liabilities in the latter case.

[9]This process is employed, e.g., in defense procurement (cf. Anton, Brusco, and Lopomo 2010).

risk of exit is not uncommon as evidenced by the examples from the automotive industry in Babich (2010) and Wadecki, Babich, and Wu (2010)[10].

Buyers decide ahead of the actual procurement competition how to source demand from the supplier with the lower and the higher price in PRE, $d = q_{\text{low},j} + q_{\text{high},j}$. At identical prices demand is split equally. Suppliers then post prices and are awarded the respective quantity depending on the relative price. This allows buyers to commit to dual sourcing by guaranteeing a positive quantity to the higher-priced supplier. The procurement process is thus similar to the model used by Klotz and Chatterjee (1995b)[11].

4.4 Theoretical Solution and Predictions

For each of the different procurement processes, we solve the model numerically for subgame-perfect equilibria using backward induction. These then serve as predictions for experimental outcomes. In the calculations, experimental parameters are used and the second period is not discounted. While the experimental step size $\Delta_p = 1$ of the price grid can be implemented for calculations of REF and SUB, for split-award auctions the size of the price grid limits the numerically feasible analysis to $\Delta_p = 20$. Also, as discussed below with pre-announced sourcing mixed strategy equilibria arise, requiring $\Delta_p = 10$. In both cases however, calculations with even coarser grids yield structurally similar outcomes, pointing to the robustness of results to changes in Δ_p.

Three different market structures can arise in period 2 with two, one or no active supplier. As it is the last period, suppliers as well as buyers behave myopically. Thus, the situation in a duopoly for REF and SUB corresponds to a standard asymmetric cost Bertrand market, since it is not rational to pay any subsidies, $\left(s_{1,j}^{2D}, s_{2,j}^{2D}\right) = (0,0)$. Using equal-sharing tie-breaking, the subgame has two equilibria[12], $\left(p_1^{2\text{D}}, p_2^{2\text{D}}\right) = (399, 400)$ and $\left(p_1^{2\text{D}}, p_2^{2\text{D}}\right) = (400, 401)$ with $\left(q_{1,j}^{2\text{D}}, q_{2,j}^{2\text{D}}\right) = (4, 0)$ for each buyer. Since both equilibria converge to the unique transaction price $p_1^{2\text{D}} = 400$ for $\Delta_p \to 0$, we assume the second equilibrium to arise. Similarly, we find two equilibrium types in split-award auctions, one with $p_1^{2\text{D}}(q > 2) = 390$ and the other with $p_1^{2\text{D}}(q > 2) = 400$, while buyers again purchase only from supplier 1. For consistency, one of the latter equilibria is selected. With pre-announced sourcing, buyers maximize period 2 surplus by setting $\left(q_{\text{low},j}^{2\text{D}}, q_{\text{high},j}^{2\text{D}}\right) = (4, 0)$. Then, suppliers price as in an asymmetric cost Bertrand duopoly, with again $\left(p_1^{2\text{D}}, p_2^{2\text{D}}\right) = (400, 410)$ being chosen for further calculations.

When only a single supplier i is active, buyers have to source their complete demand from this supplier for all procurement processes, $q_{i,j}^{2\text{M}} = 4$ and the supplier maximizes his profit by setting $p_i^{2\text{M}} = 1000$ and $p_i^{2\text{M}}(q > 2) = 1000$ for split-award auctions. With trans-

[10] Also, e.g., Daimler supported suppliers financially in the downturn of 2008 (Fischer 2010).

[11] There, as in Klotz and Chatterjee (1995a), this mechanism is used to allow suppliers to cover entry costs and thus increase participation, whereas in our model always both suppliers bid in period 1. As pointed out in Elmaghraby (2000), guaranteeing a production quantity is observed, e.g., in defense procurement.

[12] We assume suppliers to post only weakly undominated prices (cf. Deneckere and Kovenock 1996) as well as their limits for $\Delta_p \to 0$: $p_i^{2\text{D}} \in [c_i, V]$.

action prices and sourced quantities being identical for the respective market structures in period 2 for all procurement processes, the following prediction can be made.

Prediction 1. *In the second period, outcomes are not changed by any modified procurement process compared to the baseline process.*

When competition is sustained, each buyer thus gains surplus of $\text{BS}_j^{2\text{D}} = 2400$ compared to the zero surplus with a single or no active supplier. Accordingly, buyers have an incentive to sustain competition, while conversely each supplier has an incentive to monopolize the market and realize the corresponding additional profit of $\pi_i^{2\text{M}} - \pi_i^{2\text{D}} = 2400$.

For given prices in period 1, two types of equilibria of the buyer subgame exist. In a strategic sourcing equilibrium, buyers source such that competition is sustained and thus in the second period two suppliers are active. Meanwhile, in a myopic sourcing equilibrium only a single or no supplier is active in period 2. For competition to be sustained, aggregate demand has to be dual sourced[13] in period 1, i.e., $Q_i > 0$ for both suppliers. Since positive subsidies $S_i > 0$ increase supplier surplus accordingly, they are treated as equivalent to dual sourcing throughout this work. In a strategic sourcing equilibrium buyers then generally (e.g., at unequal linear prices) forego surplus in period 1 compared to myopically optimal sourcing, $\Delta\text{BS} > 0$. Accordingly, buyers source such that ΔBS is as low as possible. Meanwhile, in a myopic sourcing equilibrium, buyers maximize period 1 surplus only and with linear prices they then single source from the supplier with the lower price[14].

Experimental parameters are chosen such that when it is possible to sustain competition, it is also rational for buyers to do so. Therefore, whenever suppliers post prices which allow to sustain competition, a strategic sourcing equilibrium exists. This is the case for high prices in REF and SPA but for all prices in SUB with the respective ranges being depicted in figure 4.6 alongside experimental results, although for SPA this applies only to effective prices weighted by sourced quantities. The situation for PRE is discussed below. Accordingly, when suppliers post prices for which competition cannot be sustained, a myopic sourcing equilibrium exists. This is the case for low prices in REF and SPA but for none with subsidies. A myopic sourcing equilibrium can exist alongside strategic sourcing equilibria for a small range of prices but it can be shown that even then the latter are weakly pareto-superior for buyers. Thus, when only strategic sourcing equilibria exist, a single buyer can sustain competition by profitably deviating from myopic sourcing.

When a strategic sourcing equilibrium exists and when positive surplus has to be foregone to sustain competition, the buyer situation is similar to a discrete public good game. Increased expected surplus from sustained competition is provided in period 2 if the contributions of quantities sourced from the myopically non-optimal supplier are sufficient for his survival. The situation is somewhat untypical though, because for the experimental

[13]We refer to dual sourcing throughout this article as aggregate demand being sourced from both suppliers. This can include both buyers single sourcing their complete demand from different suppliers.

[14]In split-award auctions, myopic sourcing can entail dual sourcing. However, for the prices in the experiment this plays a negligible role.

Process	Δ_p	p_1^*	p_2^*	$(q_{1,j}^*, q_{2,j}^*)$	Period 2 market
REF	1	316	$\{750, \ldots, 1000\}$	$(4, 0)$	M1
SPA	20	$p_1^*(q \leq 2) \in \{200, \ldots, 340\}$	$p_2^*(q \leq 2) \in \{760, \ldots, 1000\}$	$(4, 0)$	M1
		$p_1^*(q > 2) = 300$	$p_2^*(q > 2) \in \{400, \ldots, 1000\}$		
SUB	1	399	$\{400, \ldots, 598\}$	$(q_{1,j}^*, q_{2,j}^*) = (4, 0)$	D
				$(s_{1,j}^*, s_{2,j}^*) = (0, 350)$	
PRE	10	$\overline{p}_1^* = 729$	$\overline{p}_2^* = 895$	$(q_{\text{low},j}^*, q_{\text{high},j}^*) = (3, 1)$	D/M1

Table 4.2: Subgame-perfect equilibria. M1 indicates a monopoly of supplier 1, D a duopoly.

parameters it is for many price combinations rational and possible for a single buyer to sustain competition alone.

In the numerical implementation, we select a single equilibrium of the buyer subgame to allow calculation of equilibrium prices. Thereby, only equilibria which are pareto-optimal for the buyers are considered. Assuming buyers to also prefer sustaining competition in cases of indifference, a strategic sourcing equilibrium is thus selected whenever one exists. Then, the equilibria minimizing the difference of aggregate quantities being sourced from each supplier are chosen, generalizing the equal-sharing tie-breaking rule. Finally, due to the identical nature of buyers, we assume equilibria to arise where buyer behavior is as symmetric as possible, although this does not impact supplier behavior.

With the behavior of buyers thus given, equilibrium prices are calculated as mutual best responses of suppliers, yielding the subgame-perfect equilibria of the model in table 4.2. For the baseline process, supplier 1 prices at $p_1^* = 316$, so low that buyers just cannot keep both suppliers active. Similarly, in split-award auctions supplier 1 sets prices at $p_1^*(q \leq 2) \in \{200, \ldots, 340\}$ and $p_1^*(q > 2) = 300$, ensuring that no option exists for the buyers to sustain competition[15]. For both processes, supplier 2 is then indifferent between a range of (high) prices. Buyers single source from supplier 1, who thus enjoys a monopoly in the second period. With subsidies, supplier 1 prices at $p_1^* = 399$ in order to secure all demand in period 1. Supplier 2 is then again indifferent between a range of prices but kept in the market by buyers through subsidies.

For pre-announced sourcing, first equilibrium prices of the supplier subgames are calculated for each aggregate demand split $(Q_{\text{low}}, Q_{\text{high}})$ of the buyers. Then, pure strategy equilibria exist when $Q_{\text{high}} = 0$ and $Q_{\text{high}} \geq 4$, while in the other cases only mixed strategy equilibria exist. These are calculated using the linear-complementarity algorithm[16] Lcp (Lemke and Howson 1964) as implemented in Gambit (McKelvey, McLennan, and Turocy 2007). The buyer equilibrium is then found from the different demand splits with buyers again assumed to purchase as symmetrically as possible. In the subgame-perfect

[15] Applying this for $\Delta_p = 1$ yields $p_1(q \leq 2) \leq 317$ and $p_1(q > 2) = 316$ as in REF, while for $\Delta_p \to 0$ the upper limit for $p_1(q \leq 2)$ converges to the respective $p_1(q > 2)$.

[16] This algorithm is not guaranteed to yield all equilibria (Shapley 1974). For $\Delta_p = 40$ however, the Enummixed algorithm (Mangasarian 1964) which has this property, identifies only the equilibria found by Lcp, which are also structurally similar to those for $\Delta_p = 10$.

equilibrium, each buyer then sources a quantity of one from the higher-priced supplier, $(q^*_{\text{low},j}, q^*_{\text{high},j}) = (3,1)$. Supplier 1 mixes over $p_1 \in [600, 990]$, while supplier 2 mixes over $p_2 \in [610, 1000]$ with a probability $f^* \geq 0.4$ of setting $p_2 = 1000$. The resulting mean prices of $\overline{p}^*_1 = 729$ and $\overline{p}^*_2 = 895$ are listed in table 4.2. Competition is thus sustained with a probability of $f^*_{\text{D}} = 0.96$, while in the remaining cases supplier 1 enjoys a monopoly in period 2. From the calculated equilibria we can directly deduct predictions of pricing in the experiment.

Prediction 2. *For the baseline and split-award processes, the more efficient supplier prices below the marginal cost of the less efficient supplier and exclusionary pricing is predominant. For subsidies and pre-announced sourcing, prices of the more efficient supplier increase. Prices are thus more accommodating to the survival of both suppliers.*

The last prediction for SUB follows from the observation that for some equilibrium prices competition can even be sustained by dual sourcing alone.

As discussed above, when suppliers post prices which allow competition to be sustained or when in SUB and PRE this is in principle always possible, buyers purchase according to a strategic sourcing equilibrium. This is summed up by the following prediction. Thereby, buyer cooperation is defined as both buyers dual sourcing whenever this is rational as in the numerical implementation.

Prediction 3. *When competition can be sustained, buyers always dual source and sustain competition. Buyer cooperation in dual sourcing is perfect.*

The subgame-perfect equilibria allow us to predict the overall surplus distribution. For REF this yields $\text{BS}^* = 5472$ for buyers and $\pi^*_1 = 7328$ for supplier 1 but $\pi^*_2 = 0$ for supplier 2. Values for SPA are only slightly different due to the numerical implementation with a larger Δ_p. However, buyer surplus is markedly higher for SUB (BS = 8908) and PRE (BS = 6490). It is decreased in the first period due to strategic sourcing and accordingly increased in the second period. Also, surplus of supplier 1 is set to decrease to $\pi^*_1 \leq 4585$, while supplier 2 surplus increases to $\pi^*_2 \geq 700$. Combined with the equilibrium market structure in period 2, we can state the following prediction describing the overall impact of the different procurement processes.

Prediction 4. *Competition is never sustained for the baseline and split-award processes, while it is (nearly) always sustained for subsidies and pre-announced sourcing. Then, also total buyer surplus increases compared to the baseline and split-award processes.*

4.5 Experimental Procedures

In the experiment, the two period model is repeated for 20 rounds to allow convergence of market outcomes. Groups of four subjects, two suppliers and two buyers, form a market. These groups stay fixed throughout the experiment, as do supplier and buyer roles. However, each round the two supplier subjects are randomly assigned to be the low- or high-cost supplier. This limits expected payout differences and mitigates fairness considerations of buyers, which might motivate sourcing from the supplier with the higher cost. The model and all its parameters are common knowledge for subjects. We conduct $N = 6$ markets for each procurement process. The model is implemented in z-Tree (Fischbacher 2007) and provides a profit calculator. After each period the earnings of all market participants in the respective group are displayed.

The markets were conducted in the experimental laboratory in Mannheim in May 2009 and March 2010. Subjects were recruited using ORSEE (Greiner 2003). Overall 96 subjects participated, most of them students and no one participated twice. Upon arrival, subjects were seated randomly and provided with written instructions (cf. appendix) and five or six test questions (depending on the procurement process) had to be answered. Before the experiment commenced, subjects were randomly assigned to their role of either supplier or buyer. Sessions lasted between 1h30 and 2h00. Converting total firm profits at a rate of 1/3000 then yielded an average payout to subjects of EUR 19.27.

4.6 Experimental Results

Results of the experiment are analyzed for rounds 5-19. This allows for learning by subjects in the first rounds and excludes any endgame behavior in the last round. However, all results are also valid for rounds 10-19 unless otherwise noted. For the respective rounds, mean values of the analysis variables are calculated for each experimental market. Accordingly, reported frequencies and mean values are always means of market means. Histograms however depict the distribution of values from the respective rounds in all markets[17]. To test for differences between procurement processes, we use a Mann-Whitney-U-Test and for differences within a procurement process a Wilcoxon-Signed-Ranks-Test. Thereby p-values are generally two-tailed with exceptions explicitly noted.

4.6.1 A Non-Strategic Situation

The incentive for buyers to sustain competition and for suppliers to monopolize the market is given by the difference in expected surplus between a duopoly and a single active supplier in period 2. For this difference to be present in the experiment, the behavior of both suppliers and buyers has to be close to rational behavior in this non-strategic situation. We analyze this in turn.

Figure 4.2 shows the posted prices for all procurement processes when a single supplier i enjoys a monopoly, with $p_i^{2\mathrm{M}}(q > 2)$ included for SPA as buyers have to purchase at this price. We find that posted prices are close to the rational price of $p_i^{2\mathrm{M}} = 1000$ across procurement processes, with $p_i^{2\mathrm{M}} \geq 900$ in $\overline{f} = 0.91$ of monopoly rounds. Accordingly, no significant difference in mean prices $\overline{p}_i^{2\mathrm{M}} \geq 938$ is introduced by any of the modified

[17]In histograms of prices the k-th interval is $\left(p^k, p^{k+1}\right]$, while for forgone surplus it is $\left[\Delta\mathrm{BS}^k, \Delta\mathrm{BS}^{k+1}\right)$.

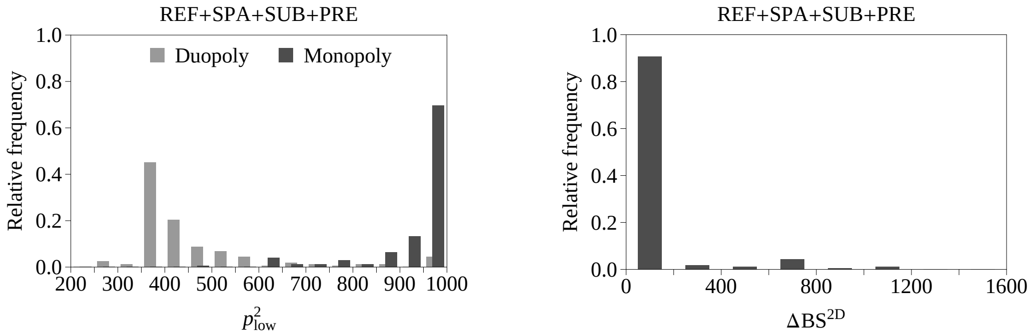

Figure 4.2: Lowest price and surplus foregone by buyers in duopolies in period 2.

procurement processes compared to the baseline with $p \geq 0.177$, although values for both SPA and PRE come relatively close to significance, though only in rounds 5-19. Since buyers have to purchase all demand from the single active supplier, with split-award auctions we find prices for the purchase of a small and a large quantity not to be significantly different ($p = 0.625$).

For duopolies, figure 4.2 again depicts the lowest price at which buyers can source their demand. We find that prices are close to the theoretical prediction of $p^{\text{2D}}_{\text{low}} = 400$ with $\overline{f} = 0.90$ of duopoly rounds yielding $p^{\text{2D}}_{\text{low}} \leq 600$ and the price being equal to or lower than the prediction in $\overline{f} = 0.44$ of cases. Again, we observe no significant difference of the lowest mean price $\overline{p}^{\text{2D}}_{\text{low}} \leq 503$ for any procurement process compared to REF with $p \geq 0.190$, and only the difference in SPA is close to significance. Suppliers are not found to set significantly different prices for small and large quantities ($p \geq 0.250$), although only $N = 4$ markets yield duopolies and are thus available for analysis. Overall, we thus find pricing in period 2 to be close to the prediction.

When a single supplier is active in period 2, buyers have to source all demand from this supplier. For two active suppliers it is rational to purchase the complete demand from the supplier with the lower price in non-tied rounds for all procurement processes[18], thereby foregoing no surplus $\Delta\text{BS}^{\text{2D}} = 0$. However, we find that although ties occur in only $\overline{f} \leq 0.13$ of duopoly rounds, aggregate dual sourcing is observed quite often with $\overline{f}^{\text{2D}}_{\text{Dual}} \geq 0.35$, except for pre-announced sourcing where $\overline{f}^{\text{2D}}_{\text{Dual}} = 0.07$. Nevertheless, compared to REF none of the procurement processes induces a significant change in the frequency ($p \geq 0.452$). The corresponding foregone surplus is depicted in figure 4.2, where for PRE the difference between the hypothetical surplus from sourcing only at the lowest posted price and actual surplus is shown. We find that across processes, in $\overline{f} = 0.90$ of duopoly rounds the foregone surplus is small with $\Delta\text{BS}^{\text{2D}} < 200$. Indeed, in more than two-thirds of rounds it is exactly zero, i.e., buyers realize all available surplus. Comparing the foregone surplus for the modified processes to the baseline ($\overline{\Delta\text{BS}}^{\text{2D}} \leq 132$), we observe no significant changes with $p \geq 0.238$. The low values of foregone surplus therefore indicate

[18]With split-award auctions, splitting demand maximizes surplus in only $\overline{f} = 0.03$ of duopolies and is thus not explicitly considered.

that buyers split demand primarily when the price difference is small. Hence, buyers source relatively close to the prediction, although some deviations remain.

Our finding of prices in duopolies being close to equilibrium behavior is in contrast to that of Dugar and Mitra (2009) in an asymmetric cost Bertrand setting. They find the lowest price to be substantially higher than predicted for a relative cost difference corresponding to our model. Similar results are also obtained for symmetric Bertrand competition (cf., e.g., Dufwenberg and Gneezy 2000). With the analysis from Wilken (2011a), we can conclude however that our deviating findings are not an effect of the presence of human buyers but originate from the interruption of supplier interaction by pricing in period 1 and by rounds without a duopoly in period 2, making collusion harder to sustain[19].

Turning to the predicted differences in surplus values, we find that for all procurement processes mean buyer surplus in rounds with duopolies $\overline{\mathrm{BS}}^{2\mathrm{D}} \geq 3909$ is significantly higher than $\overline{\mathrm{BS}}^{2\mathrm{M}} \leq 564$ in monopoly rounds ($p \leq 0.063$). The difference is slightly smaller than predicted since supplier and buyer behavior is close to but does not always match rational behavior. Accordingly, for supplier 1 the profit when competing in a duopoly of $\overline{\pi}_1^{2\mathrm{D}} \leq 1519$ is significantly smaller than $\overline{\pi}_1^{2\mathrm{M}} \geq 5691$ in a monopoly with $p \leq 0.063$. Meanwhile, the profit of supplier 2 is higher in all markets where monopolies occur than in the corresponding duopolies. Incentives for buyers to sustain competition and for suppliers to exclude the other supplier are thus intact in the experiment for all procurement processes. Also, with no significant differences detected in supplier and buyer behavior between processes in this non-strategic situation, we find broad support for the first prediction.

Finding 1. *In the second period, behavior of suppliers and buyers is close to the rational prediction and no changes in outcomes compared to the baseline process are observed for any of the modified procurement processes.*

4.6.2 Pricing

With none of the modified procurement processes inducing a significant change in the non-strategic situation of the second period, we now analyze how pricing in period 1 is affected. Figures 4.3 and 4.4 depict the evolution of the posted mean prices over all rounds for the different procurement processes. Pricing stabilizes after the first rounds and remains so for the analyzed rounds 5-19, with pre-announced sourcing inducing a higher variability compared to the other processes.

For the baseline process REF, the mean posted price of supplier 1 is close to the marginal cost of supplier 2 with $\overline{p}_1 = 394$. As depicted in figure 4.3, in split-award auctions supplier 1 sets prices for the purchase of a large quantity which are not significantly different from the prices in the baseline (cf. table 4.3). However, the mean price for a small quantity, $\overline{p}_1(q \leq 2) = 532$ is significantly increased compared to REF. Therefore, contrary to the prediction, prices are consistently higher for the purchase of a small than for a large

[19] In line with our findings, Boone, Müller, and Chaudhuri (2008) observe asymmetric cost Bertrand markets converging to the marginal cost of the less efficient supplier.

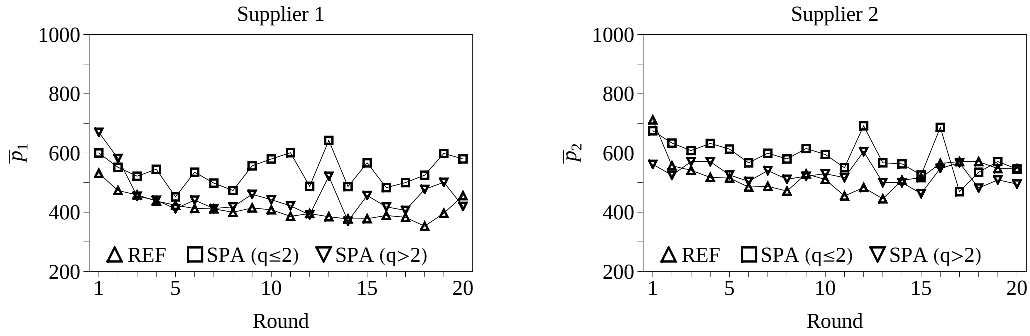

Figure 4.3: Mean prices in period 1 for processes REF and SPA.

quantity ($p = 0.063$), which in effect constitutes quantity discounts. With prices for a large quantity not being different from the baseline however, we interpret them as small quantity premia instead. These aim to deter buyers from dual sourcing by making a split of demand unattractive through higher prices. This interpretation is substantiated by the absence of small quantity premia in period 2 where in general it is rational for buyers to source only from a single supplier (cf. section 4.6.1). When however subsidies are allowed or sourcing is pre-announced, in line with the prediction the mean price of supplier 1 is significantly higher than in REF with $\overline{p}_1 \geq 533$, as also evidenced by figure 4.4.

For the less efficient supplier, no significant change in mean prices compared to the baseline value of $\overline{p}_2 = 511$ is observed for SPA and SUB, although in the latter case the mean is $\overline{p}_2 = 609$. However, also supplier 2 demands small quantity premia in split-award auctions by setting a higher price for a smaller quantity ($p = 0.031$). Meanwhile, with pre-announced sourcing the mean price of supplier 2 increases significantly to $\overline{p}_2 = 828$.

While we thus find relatively aggressive pricing in REF and SPA as predicted, for SUB and PRE supplier behavior is more accommodating without being outright collusive. Nevertheless, in one market in SUB suppliers collude nearly perfectly at $p_1 = p_2 \approx 1000$ in the last ten rounds. Meanwhile, with pre-announced sourcing, instances of perfect collusion are observed in five markets, which however always break down after a single round. This points to potential detrimental effects for buyers of procurement processes which induce more passive pricing.

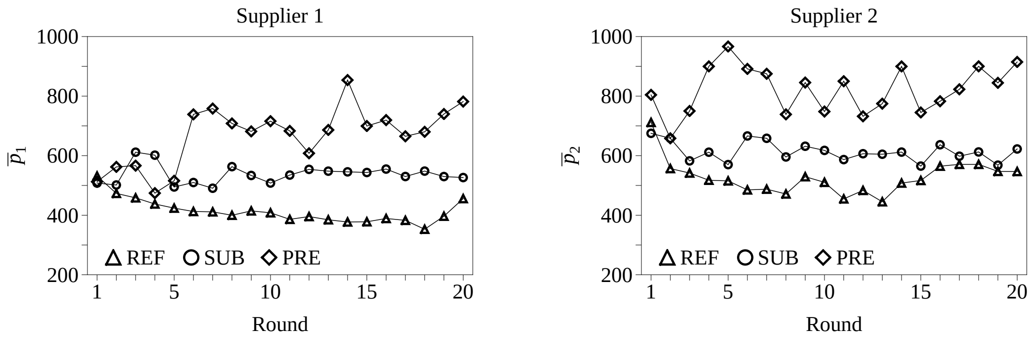

Figure 4.4: Mean prices in period 1 for processes REF, SUB and PRE.

Process	H_0	N	$\overline{p}_1$	MW p	H_0	N	$\overline{p}_2$	MW p
REF		6	394			6	511	
SPA ($q \leq 2$)	E(REF) = E(SPA)	6	532	**0.002**	E(REF) = E(SPA)	6	582	0.240
SPA ($q > 2$)	E(REF) = E(SPA)	6	437	0.310	E(REF) = E(SPA)	6	522	0.589
SUB	E(REF) $\geq$ E(SUB)	6	533	**0.066**	E(REF) = E(SUB)	6	609	0.240
PRE	E(REF) $\geq$ E(PRE)	6	697	**0.001**	E(REF) = E(PRE)	6	828	**0.002**

Table 4.3: Prices in period 1. Mann-Whitney test, p-values two-tailed for H_0 an equality, one-tailed for H_0 an inequality.

Observed prices of supplier 1 are thus significantly higher than predicted with $p = 0.031$ for all processes except for PRE, where they are compatible with the predicted mean price ($p = 0.563$). For supplier 2, compatibility with the predicted price levels is meanwhile found for all treatments ($p \geq 0.219$) except for significantly lower prices in REF and $p_2(q \leq 2)$ in SPA ($p = 0.031$).

We now analyze how these differences to the predicted values arise by deducting the deviations of posted prices[20] p_i^{Exp} from rational best responses to the price of the other supplier p_i^{BR}. The best responses are calculated using the numerical approach of section 4.4, with $\Delta_p = 1$ for SPA and PRE now being feasible. Accordingly, this assumes buyers purchase rationally, which is however a good approximation given the results of section 4.6.3 below except for SPA. Also, although suppliers do not know the price of the other supplier in the experiment, due to relatively stable prices (cf. above) they can be assumed to be able to infer it to a good degree. Figure 4.5 displays the deviations for all procurement processes, with the best response yielding the minimum absolute deviation chosen in cases of supplier indifference between prices.

In the baseline process we find that prices of supplier 1 deviate only slightly from the best responses and accordingly no significant difference is observed in table 4.4. Meanwhile, for supplier 2 the majority of posted prices are substantially lower than optimal, with the difference between $\overline{p}_2^{\text{Exp}} = 511$ and $\overline{p}_2^{\text{BR}} = 893$ being easily significant. This is due to supplier 2 pricing too aggressively in response to low prices, when the best response of $p_2^{\text{BR}} = 1000$ would often allow buyers to sustain him. Supplier 1 can then exclude supplier 2 with prices close to c_2 and not substantially below it as predicted.

In the case of split-award auctions, best responses consist of prices for purchase of a small and a large quantity. Supplier 1 then sets prices which are significantly skewed to too high values for small quantities but compatible with best responses for large quantities. This deviation is caused by the small quantity premia in the experiment, since optimal behavior has supplier 1 often posting prices which are so low as to make sustaining both suppliers impossible. Our analysis is based on buyers always sustaining competition when this is equilibrium behavior. Since buyers however often do not use this option in the experiment (cf. section 4.6.3), exclusion frequently prevails despite the premia for small

[20] Experimentally observed values are indicated by "Exp" whenever this makes it easier to distinguish from theoretical values.

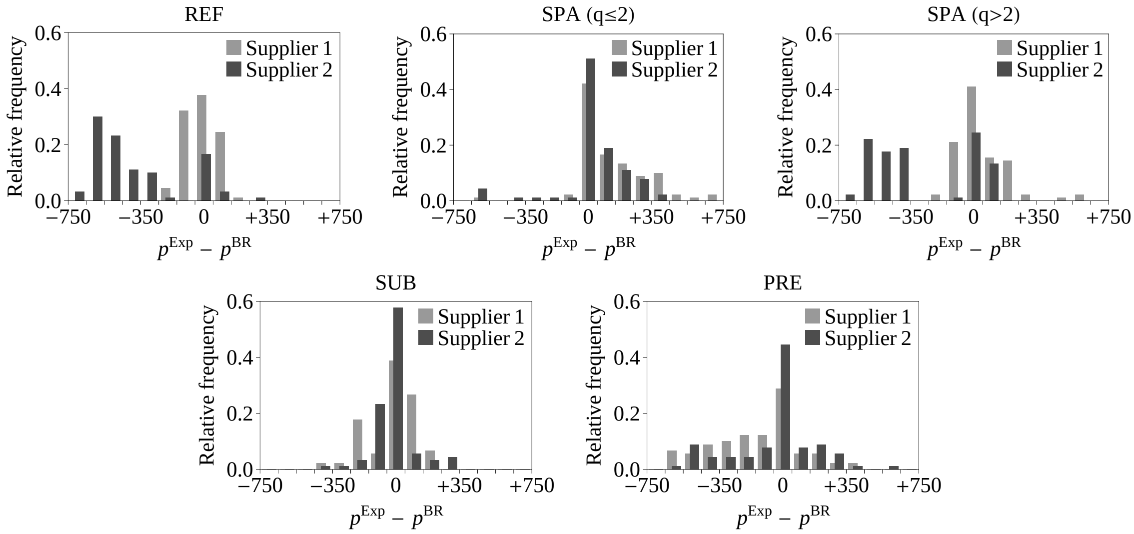

Figure 4.5: Deviation of posted prices from best responses to the price of the other supplier in period 1.

quantities of supplier 1. The less efficient supplier meanwhile is found to set prices which are lower than optimal for high quantities, while small quantity prices are compatible with rational behavior. The best response would then often force at least one buyer to purchase a quantity higher than two from the less efficient supplier to sustain him as this is not possible at the low prices by splitting contracts.

When buyers can pay subsidies to suppliers in SUB, we find that pricing in the experiment is compatible with best responses for both suppliers in table 4.4 and accordingly the distributions exhibit pronounced peaks at small deviations. Also for pre-announced sourcing, small deviations from the best responses dominate for both suppliers. For supplier 2, no significant deviation from the best response is observed. Now, in contrast to the baseline process, in many cases supplier 2 does set a price of $p_2 = 1000$ when this is optimal, as a consequence of being guaranteed a non-zero quantity even when posting a very high price. For the more efficient supplier, the distribution is slightly skewed to the left, leading to prices which are significantly lower than the best response. Analyzing different values of Q_{high} separately where this is feasible[21], for supplier 1 the deviation to lower prices remains significant ($p = 0.063$) for $Q_{\text{high}} = 2$ but not for $Q_{\text{high}} = 1$. Conversely, for supplier 2, no significant difference is observed when $Q_{\text{high}} = 2$, but when $Q_{\text{high}} = 1$, deviations to lower prices come close with $p = 0.125$. In this case, the less efficient supplier cannot guarantee his survival by setting $p_2 = 1000$ and thus tries to underbid instead of pocketing the period 1 profit at a high price and exiting. In contrast, for $Q_{\text{high}} = 2$, supplier 2 sets high prices and the more efficient supplier underbids too aggressively.

We thus find that often supplier 2 prices more aggressively than optimal, namely for the baseline process, for large quantities in split-award auctions and when $Q_{\text{high}} = 1$ is

[21] This is possible only for $Q_{\text{high}} = 1$ and $Q_{\text{high}} = 2$ as other quantities do not occur sufficiently often in the experiment.

Process	H_0	N	$\overline{p}_1^{\mathrm{Exp}}$	$\overline{p}_1^{\mathrm{BR}}$	WC p	$\overline{p}_2^{\mathrm{Exp}}$	$\overline{p}_2^{\mathrm{BR}}$	WC p
REF	E(Exp) = E(BR)	6	394	414	0.438	511	893	**0.031**
SPA ($q \leq 2$)	E(Exp) = E(BR)	6	532	397	**0.031**	582	541	0.313
SPA ($q > 2$)	E(Exp) = E(BR)	6	437	394	0.563	522	815	**0.031**
SUB	E(Exp) = E(BR)	6	533	555	0.688	609	625	0.438
PRE	E(Exp) = E(BR)	6	697	837	**0.063**	828	878	0.438

Table 4.4: Posted prices and best responses to the price of the other supplier in period 1. Wilcoxon test, p-values two-tailed.

pre-announced. Behavior of supplier 1 is in comparison closer to best responses, although some deviations persist. The following finding then summarizes the above results regarding pricing in the first period.

Finding 2.1. *For the baseline process, the more efficient supplier prices close to the marginal cost of the less efficient supplier. This is also observed for large quantities in split-award auctions, while premia are demanded for small quantities. For subsidies and pre-announced sourcing, prices of the more efficient supplier increase. Across processes, the less efficient supplier often prices more aggressively than optimal.*

The persistent premia for small quantities in split-award auctions are in line with the experimental finding of widespread large buyer discounts of Ruffle (2009) in a model where two suppliers supply differently sized buyers sequentially. However, as discussed above, we attribute premia mainly to suppliers trying to deter strategic dual sourcing and accordingly no premia are observed in the non-strategic setting of period 2.

As discussed in section 4.4, buyers can sustain competition only for certain combinations of prices in period 1, as depicted in figure 4.6. For the baseline process, price combinations in the experiment are concentrated close to the marginal cost of supplier 2 for both suppliers, making sustaining competition possible in only $\overline{f}_{\mathrm{C}} = 0.28$ of cases as reported in table 4.5. Exclusionary pricing is thus predominant as predicted by the subgame-perfect equilibrium. This outcome is also predicted for split-award auctions. Now however, we find that it is possible to sustain competition in $\overline{f}_{\mathrm{C}} = 0.62$ of rounds and thus significantly more often than in the baseline process, although for rounds 10-19 this relation just fails to be significant with $p = 0.102$. This increase is a direct consequence of the premia for small quantities demanded by both suppliers. Instead of making dual sourcing unattractive, the higher prices often allow buyers to keep both suppliers active by splitting the contract. This is only partially reflected in figure 4.6 since the displayed prices are weighted by the purchased quantities and buyers often do not sustain competition although this is possible as discussed in section 4.6.3 below.

In SUB it is always possible to sustain competition by paying subsidies and thus $\overline{f}_{\mathrm{C}} = 1.00$, which marks a significant increase compared to the baseline process REF. In addition, with prices of supplier 1 increasing, the level of posted prices is shifted to higher values in figure 4.6. Therefore, even without using subsidies buyers can sustain a

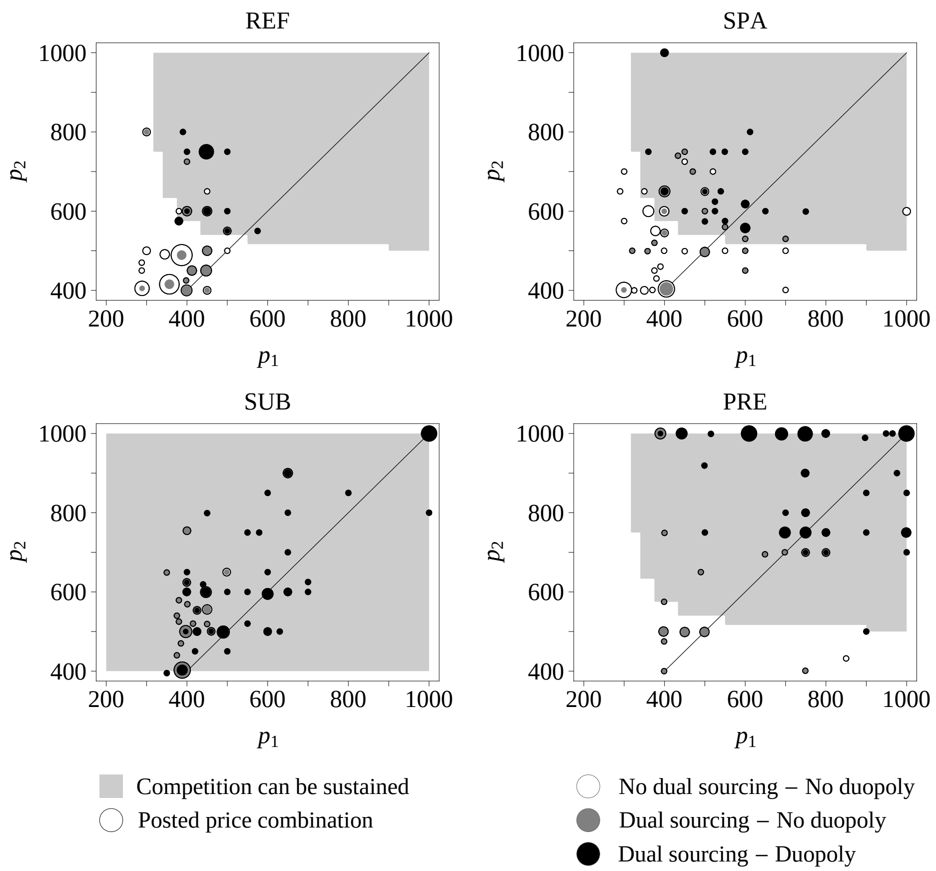

Figure 4.6: Posted price combinations in period 1, ensuing buyer behavior and market structure in period 2. Area of symbols is proportional to the observed frequency.

duopoly in $\overline{f}_C = 0.56$ of rounds by dual sourcing alone. This only just fails to be significantly higher than in REF with $p = 0.102$.

For pre-announced sourcing the situation is not directly comparable since prices now immediately determine the market structure in the second period as the quantity split has already been set. Accordingly, in figure 4.6 competition is shown as being possible to sustain for all prices for which there exists a quantity split implementing this. In a strict sense, it is always possible for suppliers to ensure joint survival by coordinating on a high price as this leads to equal sharing of the contract. It is found in section 4.6.3 below however that buyers set quantities such that even at different prices competition can be

Process	H_0	N	$\overline{f}_C$	MW p
REF		6	0.28	
SPA	E(REF) = E(SPA)	6	0.62	**0.061**$^{+}$
SUB	E(REF) $\geq$ E(SUB)	6	1.00	**0.001**

Table 4.5: Frequency of price combinations which allow to sustain competition. Mann-Whitney test, p-values two-tailed for H_0 an equality, one-tailed for H_0 an inequality. (+) not significant for rounds 10-19.

sustained in $\overline{f}_{\text{DC}} = 0.99$ of cases. Then suppliers price such that both survive in $\overline{f}_{\text{C}} = 0.74$ of cases, which is significantly higher than $\overline{f}_{\text{C}} = 0.28$ in REF with $p = 0.005$ one-tailed. Limiting the analysis to $Q_{\text{high}} \geq 2$, which allows supplier 2 to be sustained by posting a price higher than supplier 1, we even attain $\overline{f}_{\text{C}} = 0.93$ ($p = 0.001$ one-tailed). This is then also close to the corresponding subgame-perfect prediction of $f_{\text{C}}^{*} = 0.96$. Pricing in PRE is thus in any case more conducive to the survival of both suppliers than in the baseline process. We summarize these results as an addition to the previous finding.

Finding 2.2. *For the baseline process exclusionary pricing is predominant, while prices are more accommodating to the survival of both suppliers for all modified processes.*

4.6.3 Dual Sourcing

Given the posted prices both buyers decide how to source their demand from the suppliers in period 1, except in PRE where they move first. To sustain competition, it is necessary that in aggregate buyers dual source from both suppliers. Thereby, we treat positive subsidies as equivalent to dual sourcing unless otherwise noted (cf. section 4.4).

Figure 4.7 depicts the frequency of dual sourcing across all rounds, with posted quantities for unequal prices being analyzed for PRE. The high value of $\overline{f}_{\text{Dual}} = 0.51$ for the baseline process REF is notable, given that in section 4.6.2 we found that it is possible to sustain competition in only $\overline{f}_{\text{C}} = 0.28$ of rounds. Also ties occur in only $\overline{f} = 0.04$ of rounds, which render dual sourcing rational as well. Meanwhile, for split-award auctions no significant change compared to the baseline process is detected in table 4.6 and even the mean value $\overline{f}_{\text{Dual}} = 0.53$ is very close to the one for the baseline process. Since we found above that both suppliers can be sustained in $\overline{f}_{\text{C}} = 0.62$ of rounds, this is a first indication that buyers often do not act upon the option to sustain competition. For subsidies and pre-announced sourcing, significant increases in the frequency of dual sourcing compared to the baseline process are observed. Demand is being split (or subsidies are being paid) nearly always with $\overline{f}_{\text{Dual}} \geq 0.97$, in line with the predicted equilibrium behavior from section 4.4. Even when subsidies are excluded, $\overline{f}_{\text{Dual}} = 0.80$ in SUB is still significantly higher than the value in REF for rounds 5-19 ($p = 0.067$), though not for rounds 10-19.

The overall picture changes however when we restrict the analysis to those rounds where it is possible to sustain competition and thus dual sourcing is always rational. For SUB and PRE, it is always possible to sustain competition in the former case and buyers move first in the latter case, leaving the frequencies unchanged. Figure 4.7 highlights that in REF however the frequency of dual sourcing then increases to $\overline{f}_{\text{Dual}} = 0.89$ for the $N = 5$ markets where rounds exist which allow to sustain competition. Accordingly, differences to the processes SUB and PRE are no longer significant with $p \geq 0.303$. Thus, in all procurement processes with linear prices the frequency of dual sourcing is close to the rational prediction of $\overline{f}_{\text{Dual}} = 1$ when competition can be sustained and therefore the overall differences arise mainly from the exclusionary prices in REF. Meanwhile, for

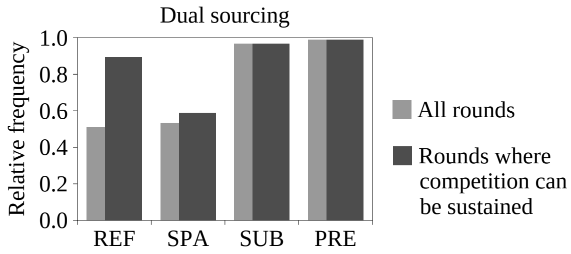

Figure 4.7: Frequency of dual sourcing in period 1.

split-award auctions the mean frequency increases only slightly to $\overline{f}_{\text{Dual}} = 0.59$ when competition can be sustained. This is now significantly lower than in REF with $p = 0.087$ for rounds 5-19 while just failing to be so in the second segment of rounds ($p = 0.157$).

In SUB, buyers can either dual source or pay subsidies to ensure survival. We find that in about half of all rounds, buyers both split demand and pay subsidies to suppliers, while in $\overline{f} = 0.17$ of rounds only subsidies are paid and in $\overline{f} = 0.28$ of rounds only purchases are split. When buyers pay only subsidies, these are often tailored to allow to reach the profit threshold and are therefore close to $\underline{\pi}$. Positive subsidies are thus observed in more than two-thirds of rounds and often splitting demand and subsidies are combined, as is rational for many price combinations.

An additional measure of strategic sourcing is provided by the surplus foregone by buyers in the first period, i.e., the difference between maximum possible and realized surplus in period 1. To sustain competition at unequal linear prices[22] some surplus has to be foregone. In the case of pre-announced sourcing, buyers cannot actively forego surplus as prices are unknown when deciding on the demand split. However, setting $Q_{\text{high}} > 0$ is a commitment by buyers to purchase a positive quantity at myopically non-optimal prices and therefore in the following we analyze the difference between the surplus from purchasing solely at the lowest posted price and the realized buyer surplus in period 1.

For the baseline procurement process, in more than half of all rounds buyers forego exactly zero surplus and also the mean aggregate value is rather small with $\overline{\Delta\text{BS}} = 196$ as reported in table 4.6. Since competition can be sustained in only about a third of rounds, this points again to rather rational buyer behavior. For split-award auctions, no significant change in foregone surplus compared to REF is found although the mean value is somewhat higher. Again, in about half of all rounds no surplus is foregone at all by buyers, which contrasts with the finding that competition can be sustained in $\overline{f}_{\text{C}} = 0.62$ of rounds. When subsidies are possible, the surplus foregone by buyers is significantly higher than in the baseline process with $\overline{\text{BS}} = 480$, since now buyers can always sustain competition. Also for pre-announced sourcing, the equilibrium solution of section 4.4 predicts positive values of foregone surplus and indeed in $\overline{f} = 0.94$ of rounds foregone surplus is positive, increasing the mean value significantly from the baseline process in rounds 5-19, while $p = 0.197$ one-tailed for rounds 10-19. The foregone surplus stems from

[22] Ties occur in only $\overline{f} \leq 0.14$ of rounds in all procurement processes and are thus not explicitly analyzed.

Process	H_0	N	$\overline{f}_{\text{Dual}}$	MW p	$\overline{\Delta\text{BS}}$	MW p
REF		6	0.51		196	
SPA	E(REF) = E(SPA)	6	0.53	0.985	291	0.589
SUB	E(REF) $\geq$ E(SUB)	6	0.97	**0.001**	480	**0.008**
PRE	E(REF) $\geq$ E(PRE)	6	0.99	**0.001**	411	**0.032**$^{+}$

Table 4.6: Frequency of dual sourcing and surplus foregone by buyers in period 1. Mann-Whitney test, p-values two-tailed for H_0 an equality, one-tailed for H_0 an inequality. (+) not significant for rounds 10-19.

the commitment to purchase a positive quantity from the supplier with the higher price. This is nearly always made by buyers in aggregate with $Q_{\text{high}} = 2$ in $\overline{f} = 0.62$ of rounds and $Q_{\text{high}} = 1$ in $\overline{f} = 0.22$ of rounds.

Again, we restrict analyses to the rounds where it is possible to sustain competition and thus it is rational to forego surplus in non-tied rounds. For the baseline process we then find an increased value of $\overline{\Delta\text{BS}} = 597$, which is no longer significantly different from the foregone surplus in SUB or PRE ($p \geq 0.537$) in rounds 5-19, while in the second segment of rounds it is even higher than for PRE with $p = 0.038$. Now, $\overline{\Delta\text{BS}} = 411$ for split-award auctions is not found to be significantly different from REF ($p = 0.328$).

Hence, we find that except for split-award auctions, buyer behavior is less influenced by the modified procurement processes than by the differences in pricing these induce, yielding the following finding.

Finding 3.1. *When competition can be sustained, buyers nearly always dual source for all procurement processes except for split-award auctions. Overall, the frequency of dual sourcing is higher for subsidies and pre-announced sourcing than for the baseline process since competition can be sustained more often. For split-award auctions it is close to the baseline.*

To test how close buyer behavior is to rationality, equilibria of the buyer subgames for the experimental prices are calculated numerically using the algorithms from section 4.4. To allow a comparison between procurement processes, the resulting deviation of experimentally observed foregone surplus $\Delta\text{BS}^{\text{Exp}}$ from the optimal foregone surplus $\Delta\text{BS}^{\text{Theo}}$ is analyzed. This assumes that buyers expect rational market outcomes in period 2, which are approximately observed in the experiment (cf. section 4.6.1). From figure 4.8 we find that across procurement processes the distribution of deviations has a pronounced peak at small absolute differences.

Deviations in the baseline process are slightly skewed to positive values but the difference between observed and optimal foregone surplus is not significant ($p = 0.563$). For split-award auctions meanwhile, the distribution exhibits a central peak similar to the baseline process, while the frequency of large deviations is substantially more pronounced than in all other processes. Accordingly, foregone surplus in the experiment of $\overline{\Delta\text{BS}}^{\text{Exp}} = 291$ is found to be significantly lower than the optimal value of $\overline{\Delta\text{BS}}^{\text{Theo}} = 443$ with $p = 0.093$ in rounds 5-19, although it just fails to be so in rounds 10-19 with $p = 0.156$. However,

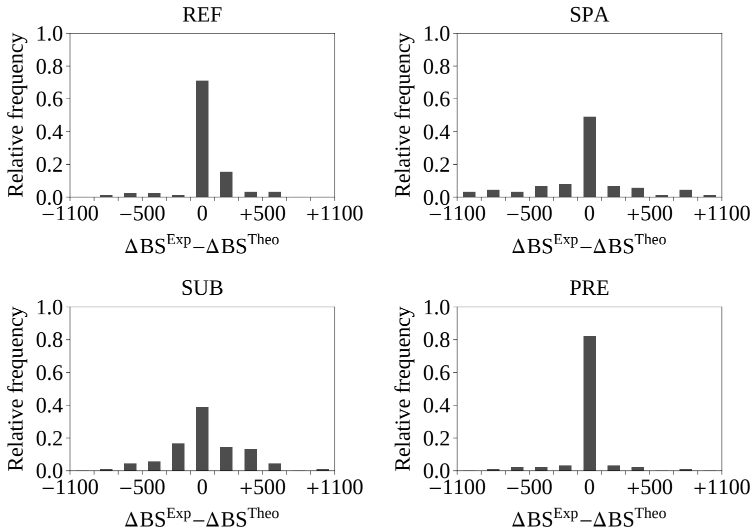

Figure 4.8: Foregone surplus: Deviation of experimental from optimal values in period 1.

this analysis uses numerical results for buyers implementing strategic sourcing equilibria whenever they exist. The split-award process is unique though in that for $\overline{f} = 0.23$ of posted prices both strategic and myopic sourcing equilibria of the buyer subgame exist (cf. section 4.4). When alternatively we calculate foregone surplus for buyers who always coordinate on a myopic sourcing equilibrium when one exists, the picture is reversed. The distribution has an increased central peak and is skewed to too high values of foregone surplus, in line with the finding that now experimentally foregone surplus is significantly higher than the optimal $\overline{\Delta \mathrm{BS}}^{\mathrm{Theo}} = 211$ with $p = 0.094$ (although $p = 0.156$ in rounds 10-19). With experimental values of foregone surplus in between these extremes, also buyer behavior in split-award auctions is broadly compatible with rational behavior, although buyers often do not act upon the option to sustain suppliers, i.e., they often do not succeed in implementing a generally pareto-superior strategic sourcing equilibrium (cf. section 4.6.3). This is most likely due to the more complex situation with nonlinear prices, which is further complicated by some strategic sourcing equilibria requiring relatively intricate quantity allocations with different demand splits for each buyer.

When buyers can pay subsidies to suppliers, the peak for small deviations is lower and the distribution visibly broader than for the baseline process. Nevertheless, as deviations are nearly symmetric, the mean foregone surplus in the experiment does not differ significantly from the optimal value of $\overline{\Delta \mathrm{BS}}^{\mathrm{Theo}} = 460$ ($p = 0.688$). The broader distribution stems most likely from a combination of dual sourcing being always optimal since competition can always be sustained and the additional coordination challenges introduced by a second strategic buyer variable. Too little foregone surplus thereby implies that competition is not sustained and therefore buyers are in a number of cases not successful in sustaining competition as discussed below.

For pre-announced sourcing, figure 4.8 includes the corresponding deviation from the surplus foregone when buyers always set $Q_{\mathrm{high}} = 2$ according to the subgame-perfect equilibrium. Only few deviations are observed and accordingly we find that the surplus foregone by buyers does not differ significantly from the value for the "optimal" solution of $\overline{\Delta\mathrm{BS}}^{\mathrm{Theo}} = 397$. Testing instead sourced quantities directly, we can corroborate this result as the experimental mean value of $\overline{Q}_{\mathrm{high}} = 2.0$ does not differ significantly from the predicted $Q^*_{\mathrm{high}} = 2.0$ with $p = 0.875$.

Summarizing these results, the following qualifying finding can be stated.

Finding 3.2. *For all procurement processes buyer behavior is close to rational sourcing decisions. However, buyers often fail to implement surplus-maximizing behavior for split-award auctions.*

While so far analyses have focused on aggregate buyer behavior we now investigate when buyers cooperate in strategic sourcing. As discussed in section 4.4, only when for a price combination both strategic and myopic sourcing equilibria exist, is it not possible for a single buyer to profitably sustain competition by deviating from myopic sourcing. Accordingly, only then does sustaining competition require buyer cooperation. However, this holds for only $\overline{f} = 0.02$ of rounds in REF and by construction in none of the rounds for subsidies and pre-announced sourcing. Only for split-award auctions is cooperation required in $\overline{f} = 0.23$ of rounds to sustain competition. Compared to $\overline{f}_{\mathrm{C}} = 0.62$, this implies that the participation of both buyers is then necessary in more than one third of cases where competition can be sustained. This is due to the posted price structures which often allow to sustain both suppliers only when both buyers split demand.

In the experiment, individual buyers may however still be unwilling to forego surplus and sustain a supplier alone even when it is rational. Since buyer cooperation is only relevant when competition can be sustained, we restrict analysis to these rounds, decomposing the corresponding frequency of dual sourcing into $\overline{f}_{\mathrm{Dual}} = \overline{f}_{\mathrm{Co}} + \overline{f}_{\mathrm{NoCo}}$. Both buyers dual source and thus cooperate in the first case, while in the second case at most a single buyer dual sources.

For the baseline process REF then, both buyers cooperate in $\overline{f}_{\mathrm{Co}} = 0.46$ of cases. With $\overline{f}_{\mathrm{Dual}} = 0.89$, this implies that only in around half of the cases where aggregate demand is dual sourced do both buyers do so. For split-award auctions, the frequency is even lower with $\overline{f}_{\mathrm{Co}} = 0.16$, which is however partly due to the lower value of $\overline{f}_{\mathrm{Dual}} = 0.59$. The mean value is close to the baseline process for SUB ($\overline{f}_{\mathrm{Co}} = 0.51$) but somewhat higher for PRE with $\overline{f}_{\mathrm{Co}} = 0.70$ where in both cases $\overline{f}_{\mathrm{Dual}} \geq 0.97$. Accordingly, none of these differences is observed to be significant with $p \geq 0.353$.

Therefore, we observe some indications for "free riding", which corresponds to large differences in foregone surplus between individual buyers when competition can be sustained, $\overline{\Delta\mathrm{BS}_{1-2}} = \overline{|\Delta\mathrm{BS}_1 - \Delta\mathrm{BS}_2|}$. We analyze the absolute value of the mean differences in each market due to the arbitrary buyer assignment. Again, we find cooperation to be rather low with $\overline{\Delta\mathrm{BS}_{1-2}} = 341$ in the baseline process, compared to the respective value of aggregate foregone surplus of $\overline{\Delta\mathrm{BS}} = 597$. While the mean value decreases somewhat for SPA to $\overline{\Delta\mathrm{BS}_{1-2}} = 189$ since now often both buyers do not forego any surplus, it is similar to the baseline with subsidies ($\overline{\Delta \text{BS}}_{1-2} = 316$). Accordingly, in both cases the difference to REF is not significant with $p \geq 0.429$. The amount of foregone surplus for pre-announced sourcing is often identical for both buyers due to both setting the same demand split and paying identical prices. Hence, the absolute foregone surplus difference is only $\overline{\Delta \text{BS}}_{1-2} = 115$, a significant decrease compared to REF with $p = 0.082$. This is in line with the above (albeit non-significant) increase in the frequency of cooperation and therefore the following addition to the previous finding can be stated.

Finding 3.3. *For all procurement processes buyers cooperate only infrequently in dual sourcing, except for weak evidence that cooperation increases for pre-announced sourcing.*

We now analyze how successful buyers are in sustaining competition as given by the frequency of a duopoly being sustained when this is possible for buyers, f_{DC}. In turn, this measure can be decomposed as the product of the frequency of dual sourcing when competition can be sustained and both suppliers being sustained when buyers dual source, $f_{\text{DC}} = f_{\text{Dual}} \times f_{\text{DDual}}$. These are then measures of buyers attempting to sustain both suppliers and actually succeeding respectively.

From table 4.7 we find that in the baseline process buyers succeed in only about two-thirds of cases in sustaining supplier competition. However, in rounds 10-19 this increases to $\overline{f}_{\text{DC}} = 0.79$. The low value in the first segment of rounds follows from the failure to sustain competition in only a single round in three markets, due to the low frequency of sustaining competition being possible. In our closely related work (Wilken 2011a), we find in a comparable situation with automated suppliers $\overline{f}_{\text{DC}} = 0.81$ and conclude this value to be a superior guide to buyer behavior.

In the case of split-award auctions, buyers succeed only in about one-third of cases in sustaining competition. With $p = 0.121$ this only just fails to be significantly lower than for the baseline process. This low value is a combination of buyers not attempting to sustain competition when this is possible as evidenced by $\overline{f}_{\text{Dual}} = 0.59$ and if they do, in not succeeding ($\overline{f}_{\text{DDual}} = 0.56$). As described above, this follows because often myopic sourcing is also equilibrium behavior. Furthermore, sustaining both suppliers also often requires complex demand split patterns, increasing the probability of failure. In addition, subjects in the experiment may have an aversion to split demand and purchase from a supplier at a high price when a low price is available, as is often the case due to premia for small quantities.

Modifying the procurement process by allowing subsidies does not lead to significantly different values of f_{DC} and even the mean value is close to the baseline with $\overline{f}_{\text{DC}} = 0.62$. We observe that buyers dual source nearly always, $\overline{f}_{\text{Dual}} = 0.97$ but then competition is actually sustained in only $\overline{f}_{\text{DDual}} = 0.64$ of cases. This rather low rate is most likely due to the more complex sourcing situation with the option to split demand and pay subsidies. As discussed in section 4.4, sustaining the supplier with the higher linear price can be regarded as a discrete public good game, with f_{DC} corresponding to the provision rate. The success rates of $\overline{f}_{\text{DC}} \geq 0.62$ for REF and SUB are thereby well within the range

Process	H_0	N	$\overline{f}_{DC}$	MW p
REF		5	0.64	
SPA	E(REF) = E(SPA)	6	0.36	0.121
SUB	E(REF) = E(SUB)	6	0.62	0.887

Table 4.7: Frequency of a duopoly in period 2 when competition can be sustained. Mann-Whitney test, p-values two-tailed.

of experimentally observed rates in comparable public good experiments (cf. Croson and Marks 2000, and references therein), although as discussed above, in our experiment often a single buyer can sustain competition.

With pre-announced sourcing, no measure exists which is directly comparable to f_{DC}. However, for competition to be sustained, buyers have to source aggregate demand such that this allows suppliers to post different prices which sustain them[23]. This is observed in $\overline{f}_{DC} = 0.99$ of rounds, which is significantly higher than $\overline{f}_{DC} = 0.64$ for the baseline process with $p = 0.004$, and only just fails to be so in the second segment of rounds with $p = 0.133$. However, this includes demand splits with $Q_{high} = 1$, which can sustain suppliers only for $p_1^1 > p_2^1$, a situation not likely to occur given the difference in marginal costs. Requiring $Q_{high} \geq 2$, both suppliers can be sustained in $\overline{f}_{DC} = 0.73$ of rounds with supplier 2 setting the higher price. This is then no longer significantly different from REF with $p = 0.195$. Thus, we can state the next finding regarding buyer behavior.

Finding 3.4. *When competition can be sustained, buyers succeed often, but not always, in sustaining competition for all procurement processes, except for split-award auctions where they are only infrequently successful.*

4.6.4 Overall Results

We now analyze how the frequency of a duopoly in period 2, f_D differs between procurement processes. Thereby, f_D is the product of suppliers posting non-exclusionary prices and buyers successfully sustaining competition, $f_D = f_C \times f_{DC}$.

For the baseline process, the low frequency of $\overline{f}_D = 0.19$ reported in table 4.8 is primarily a result of suppliers posting exclusionary prices, allowing survival of both suppliers in only $\overline{f}_C = 0.28$ of rounds. In addition, buyers are not always successful in sustaining competition when this is possible ($\overline{f}_{DC} = 0.64$). Accordingly, the observed frequency is not too far from the prediction of exclusion always occurring. No significant change compared to the baseline process follows for split-award auctions, where only in about a quarter of rounds competition is sustained. While this is again comparably close to the predicted outcome, the underlying behavior is quite different. Suppliers demand premia for small quantities and thereby often allow buyers to sustain competition ($\overline{f}_C = 0.62$) but then buyers often do not use this option ($\overline{f}_{DC} = 0.36$).

[23] In principle, suppliers can ensure joint survival by setting the same high price as then demand is split.

Process	H_0	N	$\overline{f}_D$	MW p
REF		6	0.19	
SPA	E(REF) = E(SPA)	6	0.26	0.784
SUB	E(REF) $\geq$ E(SUB)	6	0.62	**0.025**
PRE	E(REF) $\geq$ E(PRE)	6	0.73	**0.003**

Table 4.8: Frequency of a duopoly in period 2. Mann-Whitney test, p-values two-tailed for H_0 an equality, one-tailed for H_0 an inequality.

When buyers can pay subsidies, as predicted the frequency of sustained competition increases significantly compared to the baseline process to a mean value of $\overline{f}_D = 0.62$. This is primarily due to subsidies always allowing buyers to sustain competition regardless of the posted prices. The frequency of sustained competition thus corresponds to the success of buyers in keeping both suppliers active and is therefore lower than the theoretical prediction of one. For pre-announced sourcing, with $\overline{f}_D = 0.73$ competition is sustained significantly more often than with the baseline process and the frequency is thus relatively close to the prediction of $f^*_D = 0.96$. The difference stems from buyers sourcing such that survival of both suppliers at different prices is possible in $\overline{f}_{DC} = 0.99$ of rounds but suppliers posting accommodating prices which yield a duopoly in only $\overline{f}_C = 0.74$ of all rounds. However, as discussed in section 4.6.2, when we assume that generally prices of supplier 2 are higher than those of supplier 1 and thus $Q_{\text{high}} \geq 2$ is required to sustain competition, these values change to $\overline{f}_{DC} = 0.73$ and $\overline{f}_C = 0.93$. This points to buyers not always being successful in guaranteeing a sufficiently large quantity to the supplier with the higher price. The following finding summarizes these results.

Finding 4.1. *Competition is only rarely sustained for the baseline and split-award processes, while it is sustained often for subsidies and pre-announcing sourcing.*

With the frequency of no active supplier in period 2 being $\overline{f}_N \leq 0.11$ in all procurement processes, the occurrence of monopolies in the second period mirrors the findings for sustained competition. Accordingly, the frequency of a monopoly is significantly lower for procurement processes SUB and PRE ($\overline{f}_M \leq 0.34$, $p \leq 0.050$) than for the baseline process, where $\overline{f}_M = 0.70$. Meanwhile, no significant difference to REF is observed for split-award auctions. Accordingly, a monopoly in period 2 is the predominant outcome in the baseline and split-award auction procurement processes, while for subsidies and pre-announced sourcing it is a duopoly.

We now analyze how these differences influence the distribution of surplus. We find that aggregate surplus of all market participants in the experiment is somewhat lower than predicted due to situations where both suppliers exit and positive quantities are sourced from the less efficient supplier. With demand being inelastic, it is however not altered by any procurement process compared to the baseline ($p \geq 0.485$).

For all procurement processes, total surplus of buyers from both periods is significantly higher in those rounds where competition is sustained than in those where a monopoly

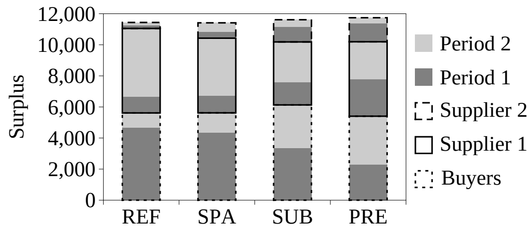

Figure 4.9: Surplus distribution.

follows ($p \leq 0.063$ one-tailed), with mean values of the processes being $\overline{\text{BS}}^{\text{D}} \geq 6023$ and $\overline{\text{BS}}^{\text{M}} \leq 4939$ respectively. This finding underlines the theoretical prediction of section 4.4 that for the experimental parameters buyers are better off with procurement processes which sustain competition. Nevertheless, we find the total surplus $\overline{\text{BS}} = 6130$ for SUB and $\overline{\text{BS}} = 5404$ for PRE not to be significantly different from $\overline{\text{BS}} = 5614$ in the baseline process with $p = 0.242$ one-tailed for SUB and $p = 1.000$ two-tailed for PRE. However, the corresponding changes of surplus for the suppliers are compatible with the prediction as the surplus of supplier 1 decreases from $\overline{\pi}_1 = 5436$ to $\overline{\pi}_1 \leq 4791$ ($p \leq 0.090$ one-tailed), although for PRE the difference is not significant for rounds 10-19. Accordingly, the total surplus of supplier 2 is significantly increased from $\overline{\pi}_2 = 387$ in REF to $\overline{\pi}_2 \geq 1429$ for SUB and PRE ($p \leq 0.008$ one-tailed), except for the second segment of rounds in SUB. Also, as predicted, no significant change in the surplus compared to the baseline is observed for any market participant for SPA ($p \geq 0.310$). Furthermore, in line with the prediction and as apparent from figure 4.9, the surplus of the buyers is shifted to the second period for SUB and PRE through foregoing of period 1 surplus and increased surplus in period 2. The corresponding changes compared to REF are all easily significant ($p \leq 0.013$), while for SPA no shift is detected ($p \geq 0.394$).

Comparing experimental buyer surplus values to predicted ones, we find that the total surplus in REF and SPA is compatible with the prediction ($p \geq 0.500$), while it is significantly lower for processes SUB and PRE ($p \leq 0.063$). Accordingly, the failure of the latter processes to increase buyer surplus stems mainly from a lower mean surplus in period 2, where $\overline{\text{BS}}^2 \leq 3120$ is observed but $\overline{\text{BS}}^2 \geq 4594$ predicted ($p = 0.031$). With both suppliers and buyers behaving close to the rational prediction in period 2 (cf. section 4.6.1), the low surplus is due to the frequency of sustained competition being close to two-thirds in SUB and PRE rather than the predicted values of (close to) one. This in turn is caused mainly by buyers not being as successful as predicted in sustaining competition in SUB and at times failing to guarantee a sufficiently high quantity to the higher-priced supplier in PRE (cf. section 4.6.3). Therefore, we can state an addition to the previous finding.

Finding 4.2. *No change in the total surplus of buyers compared to the baseline process is observed for any of the modified procurement processes. However, for subsidies and pre-announced sourcing, surplus is shifted from the more to the less efficient supplier.*

4.7 Conclusion

This work analyzes the impact of different procurement processes on the future supplier market structure in a situation where survival of suppliers is threatened and powerful buyers source strategically. We implement a two period asymmetric cost Bertrand duopoly in an experiment where supplier survival requires sufficient first period profits.

In the second period all procurement processes yield similar outcomes which are close to the predicted solutions. Thus, in a non-strategic situation none of the modified processes is observed to induce behavior different from that in the baseline procurement auction. Accordingly, buyers benefit from sustaining competition while suppliers benefit from monopolizing the market. For the baseline process and when suppliers bid in split-award auctions, we find supplier exclusion to be the predominant overall outcome. In line with the subgame-perfect prediction, allowing subsidies to suppliers or announcing sourcing before suppliers bid leads to competition among suppliers being sustained significantly more often. Across procurement processes, buyer sourcing decisions are relatively close to rational behavior, although buyers do not always succeed in sustaining competition when this is possible. The differences in overall outcomes are thus primarily the result of suppliers acting differently aggressive dependent on the procurement process and also of the feasibility of exclusion varying between processes. Thereby, the less efficient supplier often prices more aggressively than optimal, enabling exclusion.

We therefore find that changes in the procurement process which do not yield discernible differences in a non-strategic setting can have a profound impact on the behavior of suppliers in a strategic situation. The procurement process thus plays a major role in determining the future structure of the supplier market. These results therefore hold notable implications for both firms in supplier-buyer relationships as well as antitrust policy.

For powerful buyers our findings highlight the option to strategically employ sourcing not only through specific purchasing decisions but also by implementing different procurement formats. The predicted importance of this decision with respect to the supplier market structure is demonstrated to hold also in an experiment. When supplier competition in the future is to be sustained, being willing to pay subsidies to suppliers or committing to multiple sourcing by guaranteeing a fraction of the overall contract to each bidder can increase the probability that both suppliers remain active. However, the findings also show that some caution is due as an increase in the frequency of sustained competition is often accompanied by a loss in current surplus through less aggressive pricing.

The frequent failure of the less efficient supplier to price passively enough and thereby allow buyers to sustain him highlights that the willingness of buyers to sustain competition has to be considered when bidding for a contract. A passive approach can thus at times be rational, enticing buyers to split contracts. On the other hand superior suppliers might adjust bidding behavior to take account of the fact that under specific procurement formats buyers are aiming to sustain competition.

In the realm of antitrust policy, the experiment offers additional insight into the interplay between suppliers aiming to exclude rivals and buyers addressing the foreclosure risk through strategic purchases. Results highlight that the format under which this interplay takes place as defined by the procurement process, is of high importance for the outcome. This in turn implies that powerful buyers possess an important tool of countervailing power in the form of the choice of the procurement process, influencing whether vertical restraints can be successfully implemented by suppliers or not. On the other hand, the experiment highlights that depending on the procurement process, a supplier might well succeed in predatorily establishing single branding without offering compensation to buyers and without pricing below his own cost.

Appendix A

Proofs of Chapter 2

A.1 Proof of Proposition 1

A) Let $p_1^1 \neq p_2^1$ and $p_i^1 > p_{-i}^1$. With $Q_i^1 + Q_{-i}^1 = D$, the surplus of the buyer is $\mathrm{BS} = Q_i^1 \left(V - p_i^1\right) + \left(D - Q_i^1\right)\left(V - p_{-i}^1\right) + \mathrm{BS}^2$. Thereby $\mathrm{BS}^2 = \delta\, D\,(V - c_2)$ if competition is sustained and $\mathrm{BS}^2 = 0$ otherwise. As $\partial_{Q_i^1}\mathrm{BS} < 0$ regardless of BS^2, the surplus is maximized for the minimum Q_i^1 compatible with the respective constraints. Sustaining competition requires $\pi_i^1 \geq \underline{\pi}$, and therefore the minimum quantity to be purchased at supplier i is uniquely determined as $\underline{Q}_i = \underline{\pi} / \left(p_i^1 - c_i\right)$. This also uniquely determines $Q_{-i}^1 = D - \underline{Q}_i$. Then, competition is sustained if $\underline{Q}_i \leq D$ and $\left(D - \underline{Q}_i\right)\left(p_{-i}^1 - c_{-i}\right) \geq \underline{\pi}$. Solving for p_{-i}^1 and using that $p_{-i}^1 < p_i^1 \leq V$, we find that sustaining competition is possible if and only if $P_i(p_i^1) \leq p_{-i}^1 < p_i^1$ and $\mu_i < p_i^1 \leq V$. Not sustaining competition is always possible and therefore uniquely $Q_i^1 = 0$. Comparing the surplus in both cases we find that sustaining competition is superior for $R_i(p_i^1) \leq p_{-i}^1$, where we used assumption 3.

Hence, the buyer sustains competition only if $p_{-i}^1 \in \left[\max\left\{P_i(p_i^1), R_i(p_i^1)\right\}, p_i^1\right)$. The lower bound of prices p_i^1 is the minimum p_i^1 for which a price p_{-i}^1 exists which sustains competition. With P_i continuous as well as $\partial_{p_i^1} P_i(p_i^1) < 0$ for the relevant p_i^1 and $R_i(p_i^1) < p_i^1$ for all p_i^1 when $p_i^1 > \mu_i$ as required above, the lower bound of p_i^1 follows from $P_i(p_i^1) = p_i^1$ as $p_i^1 > \eta$. The negative solution of the quadratic equation is discarded as it is lower than μ_i. Due to the symmetry, explicit indices are entered in η and we find $\eta > \mu_i$. Thus $p_i^1 \in (\eta, V]$ has to hold, thereby yielding $\mathcal{S}_{\mathrm{U}}^i$.

Making indices explicit and generalizing $\mathcal{S} = \mathcal{S}_{\mathrm{U}}^1 \cup \mathcal{S}_{\mathrm{U}}^2$, the buyer sustains competition and thus implements a strategic sourcing equilibrium if and only if $(p_1^1, p_2^1) \in \mathcal{S}_{\mathrm{U}}$. Then, $\left(Q_1^{1\mathrm{S}}, Q_2^{1\mathrm{S}}\right)$ is the unique equilibrium. For all other prices, competition is not sustained and the buyer purchases $\left(Q_1^{1\mathrm{M}}, Q_2^{1\mathrm{M}}\right)$ in the unique myopic sourcing equilibrium.

B) Now let $p_1^1 = p_2^1$. With $\mathrm{BS} = D\left(V - p_2^1\right) + \mathrm{BS}^2$, the surplus from different quantity allocations differs only by the surplus from period 2. As $\mathrm{BS}^{2\mathrm{D}} > \mathrm{BS}^{2\mathrm{M}} = \mathrm{BS}^{2\mathrm{No}} = 0$, the buyer sustains competition whenever this is possible. Apart from this she is indifferent between all demand allocations.

The logic from A) yields that sustaining competition requires both $Q_2^1\left(p_2^1 - c_2\right) \geq \underline{\pi}$ and $\left(D - Q_2^1\right)\left(p_2^1 - c_1\right) \geq \underline{\pi}$, which in turn simplifies to $p_2^1 \geq \eta$, using that $\eta > \mu_2$. Hence, a strategic sourcing equilibrium is implemented if and only if $p_2^1 \in [\eta, V]$. Then $\left(Q_1^1, Q_2^1\right) = \left(D - \underline{Q}_2, \underline{Q}_2\right)$ is a strategic sourcing equilibrium, as it keeps both suppliers active. For lower equal prices, competition cannot be sustained and $\left(Q_1^1, Q_2^1\right) = (D, 0)$ is a myopic sourcing equilibrium. □

A.2 Proof of Lemma 2

For prices $p_i^1 \geq p_{-i}^1$ to lead to sustained competition, they have to be in $\mathcal{S}$. This requires $p_i^1 \in [\eta, V]$, which is non-empty by assumption 4 and thus $\eta \leq V$. We first observe that with assumption 1, both $P_i(p_i^1)$ and $R_i(p_i^1)$ are continuous and $\partial_{p_i^1} P_i(p_i^1) < 0$ as well as $\partial_{p_i^1} R_i(p_i^1) < 0$ everywhere in $p_i^1 \in [\eta, V]$.

For every $p_{-i}^1 \in \left[\underline{p}_{-i}, V\right)$ there exists a p_i^1 such that competition is sustained. $p_i^1 = V$ always implements this, as then $\left(p_{-i}^1, V\right) \in \mathcal{S}_{\mathrm{U}}^i$. Also for $p_{-i}^1 = V$, by proposition 1 the price combination $(V, V) \in \mathcal{S}_{\mathrm{E}}$. Conversely, for $p_{-i}^1 \in \left[c_{-i}, \underline{p}_{-i}\right)$ there exists no $p_i^1 > p_{-i}^1$ such that competition is sustained: We have $p_{-i}^1 < \max\{P_i(V), R_i(V)\}$ and due to P_i and R_i falling in p_i^1, also $p_{-i}^1 < \max\left\{P_i(p_i^1), R_i(p_i^1)\right\}$ for all $p_i^1 \in [\eta, V]$. Thus there exists no p_i^1 which can yield a $(p_{-i}^1, p_i^1) \in \mathcal{S}_{\mathrm{U}}^i$. With $\eta \geq \underline{p}_{-i}$ as shown below, also $p_i^1 = p_{-i}^1$ does not yield $(p_{-i}^1, p_{-i}^1) \in \mathcal{S}_{\mathrm{E}}$.

With P_i strictly falling in p_i^1 and $P_i(\eta) = \eta$ from the proof of proposition 1 we have $\eta = P_i(\eta) \geq P_i(V)$. Furthermore, $R_i(p_i^1) < p_i^1$ and thus with R_i also strictly falling, $\eta > R_i(\eta) \geq R_i(V)$. Therefore, $\eta \geq \underline{p}_{-i}$ follows directly. Next, we rewrite $P_i(V) = c_{-i} + \underline{\pi}/\left[D - \underline{\pi}/\left(V - c_i\right)\right]$. Since $D\left(V - c_1\right) > D\left(V - c_2\right) \geq \delta\, D\left(V - c_2\right) > \underline{\pi}$ by assumption 1, the denominator is larger than zero but smaller than D and hence $P_i(V) > c_{-i} + \underline{\pi}/D = \mu_{-i}$, which shows that also $\underline{p}_{-i} > \mu_{-i}$. □

A.3 Proof of Lemma 3

First, we assume that $R_2(V)$ binds in $\underline{p}_1 = \max\{P_2(V), R_2(V)\}$. From the proof of lemma 2 we know that R_2 is continuous and $\partial_{p_2^1} R_2(p_2^1) < 0$. As $R_2(c_2) = c_2$ we have with $c_2 < V$ that $R_2(V) < R_2(c_2) = c_2$ always. Now, we assume $P_2(V)$ binds. Then, simple algebra yields that $P_2(V) > c_2$ if and only if $c_1 > \underline{c}_1$ for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$. Conversely, $P_2(V) \leq c_2$ if and only if $c_1 \leq \underline{c}_1$ for $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$.

When $P_2(V) \leq c_2$, then with $R_2(V) < c_2$ always $\underline{p}_1 \leq c_2$ follows. Accordingly, for $P_2(V) > c_2$, we have $\underline{p}_1 = P_2(V)$ and thus also $\underline{p}_1 > c_2$. Now, we find $\underline{p}_1 > \mu_2$ if and only if $c_1 > \underline{c}_1 + \underline{\pi}/D$ for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H2}}$. It follows then that $c_2 < \underline{p}_1 \leq \mu_2$ if and only if $(c_1, c_2) \in \mathcal{C}_{\mathrm{H1}} = \mathcal{C}_{\mathrm{H}} \setminus \mathcal{C}_{\mathrm{H2}}$. □

A.4 Proof of Lemma 4

The profit of supplier i is specified in A) for a price p^1_{-i} of the other supplier. The range of prices p^1_{-i} is then in B) divided into intervals according to the possible responses. In C) the best response of supplier $i = 1$ is calculated.

A) The profit $\pi_i(p^1_i)$ depends on the relative size of prices and the ensuing market structure in period 2.

UE) Underbidding and Exclusion. Setting $p^1_{i,\mathrm{UE}} < p^1_{-i}$ such that no strategic sourcing follows excludes supplier $-i$ and yields

$$\pi_{i,\mathrm{UE}} = D\left(p^1_{i,\mathrm{UE}} - c_i\right) + \begin{cases} \pi^{2\mathrm{M}}_i & \text{for } \mu_i \leq p^1_{i,\mathrm{UE}} \leq V \\ 0 & \text{for } p^1_{i,\mathrm{UE}} < \mu_i \end{cases} .$$

UD) Underbidding and Duopoly. Supplier i posts $p^1_{i,\mathrm{UD}} < p^1_{-i}$ such that strategic sourcing sustains competition. The profit is then $\pi_{i,\mathrm{UD}} = \left(D - \underline{Q}_{-i}\right)\left(p^1_{i,\mathrm{UD}} - c_i\right) + \pi^{2\mathrm{D}}_i$.

MA) Match. If supplier i sets $p^1_{i,\mathrm{MA}} = p^1_{-i}$, for supplier $i = 1$ this entails a profit of

$$\pi_{1,\mathrm{MA}} = \begin{cases} \left(D - \underline{Q}_2\right)\left(p^1_{1,\mathrm{MA}} - c_1\right) + \pi^{2\mathrm{D}}_1 & \text{for } \eta \leq p^1_{1,\mathrm{MA}} \leq V \\ D\left(p^1_{1,\mathrm{MA}} - c_1\right) + \pi^{2\mathrm{M}}_1 & \text{for } \mu_1 \leq p^1_{1,\mathrm{MA}} < \eta \\ D\left(p^1_{1,\mathrm{MA}} - c_1\right) & \text{for } p^1_{1,\mathrm{MA}} < \mu_1 \end{cases} ,$$

while the profit for supplier $i = 2$ is

$$\pi_{2,\mathrm{MA}} = \begin{cases} \underline{\pi} & \text{for } \eta \leq p^1_{2,\mathrm{MA}} \leq V \\ 0 & \text{for } p^1_{2,\mathrm{MA}} < \eta \end{cases} .$$

OD) Overbidding and Duopoly. Supplier i posts $p^1_{i,\mathrm{OD}}$ in excess of p^1_{-i} such that strategic sourcing sustains both suppliers. The profit is then $\pi_{i,\mathrm{OD}} = \underline{\pi} + \pi^{2\mathrm{D}}_i$.

OE) Overbidding and Exit. When supplier i sets $p^1_{i,\mathrm{OE}} > p^1_{-i}$ such that no strategic sourcing follows, he will be excluded from the market and the profit is $\pi_{i,\mathrm{OE}} = 0$.

With $\partial_{p^1_{i,\mathrm{UE}}} \pi_{i,\mathrm{UE}} > 0$ and $\partial_{p^1_{i,\mathrm{UD}}} \pi_{i,\mathrm{UD}} > 0$, the respective maximum prices compatible with UE and UD dominate all other $p^1_i < p^1_{-i}$ with the same outcome. $\pi_{i,\mathrm{OD}}$ and $\pi_{i,\mathrm{OE}}$ are independent of p^1_i, so supplier i is indifferent between all relevant prices.

B) We define $a = \left[c_{-i}, \underline{p}_{-i}\right)$, $b = \left[\underline{p}_{-i}, \eta\right]$ and $c = (\eta, V]$, which divide the prices of supplier $-i$ into intervals according to the relevant profit functions of A). Supplier i can always set $p^1_i > p^1_{-i}$ such that he has to exit (OE). Matching the price (MA) is possible as long as $p^1_{-i} \geq c_i$ since $p^1_i \in [c_i, V]$. Similarly, excluding the other supplier (UE) is feasible for all prices $p^1_{-i} > c_i$. Setting a higher price which sustains a duopoly (OD) is possible for $p^1_{-i} \in b \cup c$ and $p^1_{-i} < V$ by lemma 2. Accordingly, underbidding such that a duopoly arises is possible only for $p^1_{-i} \in c$ as this is just the condition from $\mathcal{S}^{-i}_{\mathrm{U}}$.

C) The best response $p^1_{1,\mathrm{r}}$ of supplier $i = 1$ is now deducted for each of the intervals of prices p^1_2. With $p^1_2 \geq c_2 > c_1$, MA is feasible for all p^1_2. Then, matching the price always yields $\pi_1 > 0$ and thus OE is strictly dominated.

C).a For $p^1_2 \in \left[c_2, \underline{p}_2\right)$, the profit from underbidding (UE) is maximized by $p^1_{1,\mathrm{UE},a} = p^1_2 - \epsilon$. This leads to a lower π_1 than matching the price as long as $p^1_1 < \eta$, which always holds in a.

C).b As above, $p^1_{1,\mathrm{UE},b} = p^1_2 - \epsilon$ for $p^1_2 \in b$ and thus for $p^1_2 < \eta$, matching again dominates underbidding to exclude supplier 2. It is also superior to overbidding for a duopoly to arise, as with $p^1_2 \geq \underline{p}_2 > \mu_2 > \mu_1$, both first and second period profit is higher for matching.

For $p^1_2 = \eta$, $\pi_{1,\mathrm{MA}} = \pi_{1,\mathrm{OD}} = \underline{\pi} + \pi^{2\mathrm{D}}_1$. Then, the profit-maximizing price to underbid and exclude supplier 2 (UE) is $p^1_{1,\mathrm{UE},b} = \max\{P_2(\eta), R_2(\eta)\} - \epsilon = \eta - \epsilon$ as $P(\eta) = \eta$ and $R(\eta) < \eta$ from the proof of proposition 1. Then, in period 2, $\pi^2_{1,\mathrm{UE},b} = \delta\, D\,(V - c_1) > \delta\, D\,(V - c_2) > \underline{\pi} = \pi^1_{1,\mathrm{MA}}$ by assumption 1. Furthermore, $\pi^1_{1,\mathrm{UE},b} = D\,(\eta - \epsilon - c_1) > \delta\, D\,(c_2 - c_1) = \pi^{2\mathrm{D}}_1 = \pi^2_{1,\mathrm{MA}}$ as $\delta \leq 1$ and $\eta > \mu_2 > c_2$.

C).c For $p^1_2 \in c$, profits from underbidding for a duopoly are lower than those from matching due to marginal underbidding by ϵ, $\pi_{1,\mathrm{MA}} > \pi_{1,\mathrm{UD}}$. While also $\pi^2_{1,\mathrm{OD},c} = \pi^2_{1,\mathrm{MA},c}$, as $p^1_2 > \eta$ first period profits when matching exceed $\pi^1_{1,\mathrm{OD},c} = \underline{\pi}$. Maximizing the profit from excluding supplier 2 now requires $p^1_{1,\mathrm{UE},c} = \max\left\{P_2(p^1_2), R_2(p^1_2)\right\} - \epsilon$. Then, $\pi_{1,\mathrm{UE},c}$ may or may not be higher than $\pi_{1,\mathrm{MA},c}$. The only case where the equilibrium outcome is influenced is treated explicitly in lemma 6.

Consolidating the results, we find that for $p^1_2 \in [c_2, \eta\,)$ matching is the best response, $p_{1,\mathrm{r}}(p^1_2) = p^1_2$, while for $p^1_2 \in [\eta, V]$ it is optimal to either match the price or underbid drastically, $p^1_{1,\mathrm{r}}(p^1_2) = \mathrm{argmax}_{p^1_1 \in \left\{p^1_2\,,\, \max\{P_2(p^1_2), R_2(p^1_2)\} - \epsilon\right\}}\, \pi_1(p^1_1)$. Therefore, we always have $p^1_{1,\mathrm{r}}(p^1_2) \leq p^1_2$. $\square$

A.5 Proof of Lemma 5

We use parts A) and B) of the proof of lemma 4 and introduce an additional lemma.

Lemma A.5.1. *The set of price combinations $\mathcal{S}^i_{\mathrm{U}}$ can be equivalently expressed as*

$$\mathcal{S}^i_{\mathrm{U}} = \left\{\left(p^1_1, p^1_2\right) \mid p^1_i \in \left[\max\left\{P^{-1}_i(p^1_{-i}), R^{-1}_i(p^1_{-i})\right\}, V\right], p^1_{-i} \in \left[\underline{p}_{-i}, \eta\right)\right\} \cup$$
$$\left\{\left(p^1_1, p^1_2\right) \mid p^1_i \in \left(p^1_{-i}, V\right], p^1_{-i} \in [\eta, V)\right\}.$$

Proof of lemma A.5.1. By assumption we have $p^1_{-i} < p^1_i \leq V$. From lemma 2, the lowest price p^1_{-i} in $\mathcal{S}^i_{\mathrm{U}}$ for which competition is sustained is $\underline{p}_{-i}$ and thus $p^1_{-i} \in \left[\,\underline{p}_{-i}\,,\, V\,\right)$. The conditions on prices in $\mathcal{S}^i_{\mathrm{U}}$ are solved for p^1_i. Assuming that P_i binds, we obtain $p^1_i \geq P^{-1}_i(p^1_{-i})$ by using $p^1_{-i} \geq \underline{p}_{-i} > \mu_{-i}$ (cf. lemma 2) and $p^1_i > \eta > \mu_i$ by proposition 1. Now, if R_i binds, we obtain with $\delta\, D\,(V - c_2) > \underline{\pi}$ by assumption 1 that $p^1_i \geq R^{-1}_i(p^1_{-i})$.

P_i^{-1} is continuous and with $\partial_{p^1_{-i}} P_i^{-1}(p^1_{-i}) < 0$ falling for $p^1_{-i} \geq \underline{p}_{-i} > \mu_{-i}$. Furthermore, we acquire $P_i^{-1}(\eta) = \eta$. With assumption 1, R_i is continuous and $\partial_{p^1_{-i}} R_i^{-1}(p^1_{-i}) < 0$ as well as $R_i^{-1}(c_i) = c_i$. Also, $p^1_i > p^1_{-i}$ and the intervals in $\mathcal{S}^i_{\mathrm{U}}$ explicitly state that $p^1_i > \eta$ and $p^1_i \leq V$.

First, for $p^1_{-i} \in \left[\underline{p}_{-i}, \eta\right)$, it follows that $P_i^{-1}(p^1_{-i}) > \eta > p^1_{-i}$. If this holds for P_i^{-1}, it holds for $\max\left\{P_i^{-1}, R_i^{-1}\right\}$ as well. Thus, the interval of prices p^1_i is bounded below by $p^1_i \geq \max\left\{P_i^{-1}, R_i^{-1}\right\}$. Now, we let $p^1_{-i} \in [\eta, V)$. With P_i^{-1} falling and $P_i^{-1}(\eta) = \eta$ it follows that $P_i^{-1}(p^1_{-i}) \leq p^1_{-i}$. Accordingly, with R_i falling, $R_i^{-1}(c_i) = c_i$ and using $\eta > \mu_i > c_i$, we have $R_i^{-1}(p^1_{-i}) < p^1_{-i}$. Hence, $p^1_i > p^1_{-i} \geq \eta$ is the lower bound. For both ranges, the upper bound is $p^1_i \leq V$. $\square$

C) The best response $p^1_{2,\mathrm{r}}$ of supplier $i = 2$ is calculated for each interval of prices p^1_1.

C).*a* For $p^1_1 \in \left[c_1, \underline{p}_1\right)$ in the case of $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$ and $p^1_1 \in [c_1, c_2)$ in the case of $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$ it is only feasible to overbid and exit, $p^1_{2,\mathrm{r}} \in [c_2, V]$. For $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$, when $p^1_1 = c_2$ then matching yields the same profit, $\pi_{2,\mathrm{MA},i} = \pi_{2,\mathrm{OE},i} = 0$. With $\underline{p}_1 \leq \eta$ by lemma 2, for $p^1_1 \in \left(c_2, \underline{p}_1\right)$ in cases $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$, the profit from underbidding to gain exclusivity is maximized for $p^1_{2,\mathrm{UE},a} = p^1_1 - \epsilon$. Then, $\pi_{2,\mathrm{UE},a} > \pi_{2,\mathrm{MA},a} = \pi_{2,\mathrm{OE},a} = 0$ as the first period profit is always higher than zero[1].

C).*b* For $p^1_1 \in \left[\underline{p}_1, \eta\right]$ maximizing the profit from underbidding and excluding supplier 1 yields a price $p^1_{2,\mathrm{UE},b} = p^1_1 - \epsilon$, while overbidding for a duopoly corresponds to setting $p^1_{2,\mathrm{OD},b} \in \left[\max\{P_2^{-1}(p^1_1), R_2^{-1}(p^1_1)\}\,,\, V\right]$ for $p^1_1 < \eta$.

If $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}}$, then for $p_1 \in \left[\underline{p}_1, c_2\right]$, it is optimal to overbid and be sustained in a duopoly as then $\pi_{2,\mathrm{OD},b} = \underline{\pi} > 0$, while $\pi_{2,\mathrm{OE},b} = 0$ and $\pi_{2,\mathrm{MA},b} = 0$ for $p^1_1 = c_2$. The same holds for $p^1_1 \in (c_2, \mu_2]$ for costs in $\mathcal{C}_{\mathrm{L}}$ and $p^1_1 \in \left[\underline{p}_1, \mu_2\right]$ for costs in $\mathcal{C}_{\mathrm{H1}}$, as then $\pi_{2,\mathrm{UE},b} = D\left(p^1_1 - \epsilon - c_2\right) < \underline{\pi} = \pi_{2,\mathrm{OD},b}$, where $p^1_1 = \mu_2$ is included due to marginal underbidding and again $\pi_{2,\mathrm{OE},b} = \pi_{2,\mathrm{MA},b} = 0$. For $(c_1, c_2) \in \mathcal{C}_{\mathrm{H2}}$ this interval is empty as $\underline{p}_1 > \mu_2$.

For $(c_1, c_2) \in \mathcal{C}_{\mathrm{L}} \cup \mathcal{C}_{\mathrm{H1}}$ in the interval $p^1_1 \in (\mu_2, \eta)$ and for $(c_1, c_2) \in \mathcal{C}_{\mathrm{H2}}$ in the interval $p^1_1 \in \left(\underline{p}_1, \eta\right)$, the second period profit from underbidding $\pi^2_{2,\mathrm{UE},b} = \delta D\,(V - c_2)$ is by assumption 1 alone greater than the overall profit from OD, $\pi_{2,\mathrm{OD},b} = \underline{\pi}$ and therefore also than the zero profits from matching or from overbidding and exiting. The same holds for $p^1_1 = \eta$ except that now also $\pi_{2,\mathrm{MA},b}(\eta) = \underline{\pi}$.

C).*c* The profit from underbidding to exclude the other supplier for $p^1_1 \in (\,\eta\,,\, V\,]$ is maximized by $p^1_{2,\mathrm{UE},c} = \max\{P_1(p^1_1), R_1(p^1_1)\} - \epsilon$, while $p^1_{2,\mathrm{UD},c} = p^1_1 - \epsilon$ follows in the case of underbidding for a duopoly.

Again, underbidding and excluding supplier 1 dominates all prices $p^1_2 \geq p^1_1$, as $\pi^2_{2,\mathrm{UE},c} = \delta\, D(V - c_2) > \underline{\pi} = \pi_{2,\mathrm{MA},c} = \pi_{2,\mathrm{OD},c}$ and is also larger than $\pi_{2,\mathrm{OE},c} = 0$.

[1]Treating ϵ strictly as the smallest unit of a discrete price space, the best response to $p^1_1 = c_2 + \epsilon$ is indifference between all prices. Due to our interpretation of ϵ, underbidding is always superior.

The relative size of profits from UE and UD depends on the exact parameters and is not explicitly calculated.

We thus have $p_{2,\mathrm{r}}(p_1^1) \geq p_1^1$ in two cases. The best response is $p_{2,\mathrm{r}}^1 \in [c_2, V]$ for $p_1^1 \in \left[c_1, \underline{p}_1\right]$ when $(c_1, c_2) \in \mathcal{C}_\mathrm{L}$ and for $p_1^1 \in [c_1, c_2]$ when $(c_1, c_2) \in \mathcal{C}_\mathrm{H}$. Furthermore, we find that $p_{2,\mathrm{r}}^1 \in \left[\max\{P_2^{-1}(p_1^1), R_2^{-1}(p_1^1)\}, V\right]$ holds for $p_1^1 \in \left[\underline{p}_1, \mu_2\right]$ when $(c_1, c_2) \in \mathcal{C}_\mathrm{L}$ and for $p_1^1 \in \left[\underline{p}_1, \mu_2\right]$ when $(c_1, c_2) \in \mathcal{C}_\mathrm{H1}$. Otherwise $p_{2,\mathrm{r}}^1(p_1^1) < p_1^1$. □

A.6 Proof of Lemma 6

From lemma 4 the best response of supplier 1 to $p_2^1 = V$ is either matching the price $p_{1,\mathrm{MA}}^1 = V$ or underbidding drastically $p_{1,\mathrm{UE}}^1 = \max\{P_2(V), R_2(V)\} - \epsilon$. Straightforward algebra yields that $P_2(V)$ and $R_2(V)$ are equal for $c_1 = \tilde{c}_1$. With $\partial_{c_1} P_2(V) = 1$ and $\partial_{c_1} R_2(V) = 0$ we obtain that $P_2(V) \geq R_2(V)$ for $c_1 \geq \tilde{c}_1$, while accordingly $P_2(V) \leq R_2(V)$ for $c_1 \leq \tilde{c}_1$. We first assume that $P_2(V)$ binds in $p_{1,\mathrm{UE}}^1$, i.e., that $c_1 \geq \tilde{c}_1$. Then, by equating the profits and using the functional dependence on c_1, we find that $\pi_{1,\mathrm{UE},c}(V) \geq \pi_{1,\mathrm{MA},c}(V)$ if $c_1 > c_1^P$ holds. The strict condition on c_1 stems from marginal underbidding when excluding supplier 1. For cases $c_1 \leq c_1^P$, matching the price is superior. Now, we assume that $R_2(V)$ binds ($c_1 \leq \tilde{c}_1$). By again equating profits and using the derivatives with respect to c_1, we find that $\pi_{1,\mathrm{UE},c}(V) \geq \pi_{1,\mathrm{MA},c}(V)$ holds for $c_1 < c_1^R$, with strictness following from $\epsilon > 0$. For higher c_1, matching is superior.

With $(c_1, c_2) \in \mathcal{C}_\mathrm{L}$ by assumption, setting $p_{1,\mathrm{r}}^1(V) = \underline{p}_1 - \epsilon$ is thus a best response if and only if $c_1 \leq \tilde{c}_1$ and $c_1 < c_1^R$ or $c_1 \geq \tilde{c}_1$ and $c_1 > c_1^P$, i.e., if and only if $(c_1, c_2) \in \mathcal{C}_\mathrm{L2}$. For all other $(c_1, c_2) \in \mathcal{C}_\mathrm{L1} = \mathcal{C}_\mathrm{L} \setminus \mathcal{C}_\mathrm{L2}$ matching is strictly preferred. □

A.7 Proof of Proposition 2

A) First $(c_1, c_2) \in \mathcal{C}_\mathrm{L2}$. By lemma 6, $p_{1,\mathrm{r}}^1(V) = \underline{p}_1 - \epsilon$ is then a best response to $p_2^{1*} = V$. Meanwhile, for $p_1^{1*} = \underline{p}_1 - \epsilon$, the best response of supplier 2 is $p_{2,\mathrm{r}}^1(\underline{p}_1 - \epsilon) \in [c_2, V]$ according to lemma 5. This interval includes V and hence $\left(p_1^{1*}, p_2^{1*}\right) = \left(\underline{p}_1, V\right)$ is an equilibrium.

To prove uniqueness, we show that no other price $\tilde{p}_2^1 \neq V$ can be part of an equilibrium, i.e., fulfills $\tilde{p}_2^1 \in p_{2,\mathrm{r}}^1\left(p_{1,\mathrm{r}}^1(\tilde{p}_2^1)\right)$. For prices $\tilde{p}_2^1 \in [c_2, V)$ the best response of supplier 1 is to underbid or match the price according to lemma 4, $p_{1,\mathrm{r}}^1(\tilde{p}_2^1) \leq \tilde{p}_2^1$. Clearly then, $p_{1,\mathrm{r}}^1 < V$ holds. Also, $p_{1,\mathrm{r}}^1 \geq \underline{p}_1$ as $\underline{p}_1 \leq c_2$ for $(c_1, c_2) \in \mathcal{C}_\mathrm{L}$ and $\underline{p}_1 < \max\left\{P_2(\tilde{p}_2^1), R_2(\tilde{p}_2^1)\right\} - \epsilon$ for $\tilde{p}_2^1 < V$ by lemma 2. Therefore, $p_{1,\mathrm{r}}^1 \in \left[\underline{p}_1, V\right)$.

Now if $p_{1,\mathrm{r}}^1 \in \left[\underline{p}_1, \mu_2\right]$, then supplier 2 sets a price $p_{2,\mathrm{r}}^1 \geq \max\left\{P_2^{-1}(p_{1,\mathrm{r}}^1), R_2^{-1}(p_{1,\mathrm{r}}^1)\right\}$ by lemma 5. From the proof of lemma A.5.1 we know $P_2^{-1}(p_{1,\mathrm{r}}^1) > \eta$ if $p_{1,\mathrm{r}}^1 < \eta$ which is fulfilled here. Thus, $p_{2,\mathrm{r}}^1 > \eta$. This can only yield an equilibrium if also the original price $\tilde{p}_2^1 > \eta$. When supplier 1 responded by matching $p_{1,\mathrm{r}}^1 = \tilde{p}_2^1$, this cannot be the case as then $p^1_{1,\mathrm{r}} > \eta$ which is not in the interval of interest. Hence, if $\tilde{p}^1_2$ is part of an equilibrium, then $p^1_{1,\mathrm{r}} = \max\left\{P_2(\tilde{p}^1_2), R_2(\tilde{p}^1_2)\right\} - \epsilon$. However, this price was chosen in the proof of lemma 4 such that no strategic sourcing equilibrium exists for $\left(p^1_{1,\mathrm{r}}, \tilde{p}^1_2\right)$. Hence, with $p^1_{1,\mathrm{r}} \in \left[\underline{p}_1, \mu_2\right]$ and lemma A.5.1 then $\tilde{p}^1_2 < \max\left\{P_2^{-1}(p^1_{1,\mathrm{r}}), R_2^{-1}(p^1_{1,\mathrm{r}})\right\}$. Above we found $p^1_{2,\mathrm{r}} \geq \max\left\{P_2^{-1}(p^1_{1,\mathrm{r}}), R_2^{-1}(p^1_{1,\mathrm{r}})\right\}$ and therefore $\tilde{p}^1_2 < p^1_{2,\mathrm{r}}$.

If however $p^1_{1,\mathrm{r}} \in (\mu_2, V)$ then by lemma 5, supplier 2 underbids, $p^1_{2,\mathrm{r}} < p^1_{1,\mathrm{r}}$. With $p^1_{1,\mathrm{r}} \leq \tilde{p}^1_2$, it follows that $p^1_{2,\mathrm{r}} < \tilde{p}^1_2$. Hence, no $\tilde{p}^1_2 \neq V$ can be part of an equilibrium. From lemmas 4 and 6 we know that for $\tilde{p}^1_2 = V$ either $p^1_{1,\mathrm{r}} = \underline{p}_1 - \epsilon$ or $p^1_{1,\mathrm{r}} = V$. In the latter case $p^1_{2,\mathrm{r}}(p^1_{1,\mathrm{r}}) < V = \tilde{p}^1_2$. Thus, $\left(p^{1*}_1, p^{1*}_2\right)$ is the only equilibrium.

B) We let $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$. The best response of supplier 1 to $p^{1*}_2 = c_2$ is by the proof of lemma 4, $p^1_{1,\mathrm{r}}(c_2) = c_2 = p^{1*}_1$. Accordingly, with lemma 5, for $p^{1*}_1 = c_2$, supplier 2 is indifferent between prices $p^1_{2,\mathrm{r}} \in [c_2, V]$, which includes $p^{1*}_2 = c_2$ and thus $\left(p^{1*}_1, p^{1*}_2\right) = (c_2, c_2)$ is an equilibrium.

To show that no other equilibria exist we proceed as in A) by showing that no other price $\tilde{p}^1_2 > c_2$ exists with $\tilde{p}^1_2 \in p^1_{2,\mathrm{r}}\left(p^1_{1,\mathrm{r}}(\tilde{p}^1_2)\right)$. By lemma 4, for prices $\tilde{p}^1_2 \in (c_2, V]$ supplier 1 always underbids or matches the price, $p^1_{1,\mathrm{r}}(\tilde{p}^1_2) \leq \tilde{p}^1_2$. Therefore, $p^1_{1,\mathrm{r}} \leq V$ holds. Also, $p^1_{1,\mathrm{r}} > c_2$ follows from matching and $p^1_{1,\mathrm{r}} \geq \underline{p}_1 - \epsilon > c_2$ from underbidding for exclusivity by lemma 3.

For $p^1_{1,\mathrm{r}} \in (c_2, V]$ in the case of $(c_1, c_2) \in \mathcal{C}_{\mathrm{H2}}$ and $p^1_{1,\mathrm{r}} \in \left(c_2, \underline{p}_1\right) \cup (\mu_2, V]$ in the case of $(c_1, c_2) \in \mathcal{C}_{\mathrm{H1}}$, supplier 2 responds by underbidding further, $p^1_{2,\mathrm{r}} < p^1_{1,\mathrm{r}}$ according to lemma 5 and thus $p^1_{2,\mathrm{r}} < \tilde{p}^1_2$.

If for costs $\mathcal{C}_{\mathrm{H1}}$, $p^1_{1,\mathrm{r}} \in \left[\underline{p}_1, \mu_2\right]$, then supplier 2 sets $p^1_{2,\mathrm{r}} \geq \max\left\{P_2^{-1}(p^1_{1,\mathrm{r}}), R_2^{-1}(p^1_{1,\mathrm{r}})\right\}$. By the same arguments as for the corresponding interval in A) we find $p^1_{2,\mathrm{r}} > \tilde{p}^1_2$. Thus, no $\tilde{p}^1_2 > c_2$ can be part of an equilibrium and with $p^{1*}_1 = p^1_{1,\mathrm{r}}(c_2)$ uniquely determined, $\left(p^{1*}_1, p^{1*}_2\right)$ is the only equilibrium[2].

C) Now we let $(c_1, c_2) \in \mathcal{C}_{\mathrm{L1}}$. Then, no $\tilde{p}^1_2 \neq V$ can be part of an equilibrium due to the identical logic as in A). Also, $\tilde{p}^1_2 = V$ is not part of an equilibrium as with lemmas 4 and 6, $p^1_{1,\mathrm{r}}(V) = V$ always, while $p^1_{2,\mathrm{r}}(p^1_{1,\mathrm{r}}) < \tilde{p}^1_2$ from lemma 5. Hence, no equilibrium in pure strategies exists.

For all equilibrium prices of $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}} \cup \mathcal{C}_{\mathrm{H}}$, the buyer does not sustain competition by proposition 1 and purchases myopically from supplier 1 only, $\left(Q^{1*}_1, Q^{1*}_2\right) = (D, 0)$. For $(c_1, c_2) \in \mathcal{C}_{\mathrm{L2}}$, we observe that with $p^{1*}_1 = \underline{p}_1 - \epsilon$ and $\underline{p}_1 > \mu_1$ by lemma 2, the profit of supplier 1 always exceeds $\underline{\pi}$ and he enjoys a monopoly in period 2. When $(c_1, c_2) \in \mathcal{C}_{\mathrm{H}}$, for supplier 1 to attain the profit threshold, $p^{1*}_1 = c_2 > \mu_1$ has to hold. Then a monopoly follows, while otherwise both suppliers exit. $\square$

[2] Treating ϵ as the smallest unit of a discrete price grid, another equilibrium $\left(p^{1*}_1, p^{1*}_2\right) = (c_2 + \epsilon, c_2 + \epsilon)$ exists, which however for $\epsilon \to 0$ becomes identical to $\left(p^{1*}_1, p^{1*}_2\right) = (c_2, c_2)$. Also, if $\underline{p}_1 = c_2 + 2\epsilon$ and $p^1_{1,\mathrm{r}}(V) = \underline{p}_1 - \epsilon$, then $\left(p^{1*}_1, p^{1*}_2\right) = (c_2 + \epsilon, V)$ is an additional equilibrium. Similarly, when $\underline{p}_1 = c_2 + \epsilon$ and $p^1_{1,\mathrm{r}}(V) = \underline{p}_1 - \epsilon$, then also $\left(p^{1*}_1, p^{1*}_2\right) = (c_2, V)$ is an equilibrium, while $(c_2 + \epsilon, c_2 + \epsilon)$ is no longer one.

A.8 Proof of Proposition 3

A) We let $p_1^1 \neq p_2^1$ and $p_i^1 > p_{-i}^1$. If a strategic sourcing equilibrium exists for $n = 1$, then by proposition 1, the demand allocation is uniquely determined as $Q_i^1 = \underline{Q}_i$ and $Q_{-i}^1 = D - \underline{Q}_i$. For $n \geq 2$, $q_{i,j}^1 = \underline{Q}_i/n$ and $q_{-i,j}^1 = d - \underline{Q}_i/n$ is then always an equilibrium, as no profitable deviation to $\tilde{q}_{i,j}^1 \neq q_{i,j}^1$ with $\tilde{q}_{-i,j}^1 = d - \tilde{q}_{i,j}^1$ exists for any buyer j. Deviating to $\tilde{q}_{i,j}^1 > q_{i,j}^1$ decreases period 1 surplus without increasing surplus in period 2, $\mathrm{BS}_j^2 = \delta\, d\,(V - c_2)$. Deviating to $\tilde{q}_{i,j}^1 < q_{i,j}^1$ decreases period 2 surplus to zero as $\pi_i^1 < \underline{\pi}$, while increasing surplus in period 1 by $\left(q_{i,j}^1 - \tilde{q}_{i,j}^1\right)\left(p_i^1 - p_{-i}^1\right)$. Solving for p_{-i}^1, no such deviation is profitable if and only if $p_{-i}^1 \geq R_i(p_i^1)$, which is fulfilled as by assumption prices are in $\mathcal{S}_{\mathrm{U}}^i$. Thus, when a strategic sourcing equilibrium exists for $n = 1$, a strategic sourcing equilibrium also exists for $n \geq 2$.

Now, we let $q_{i,j}^1$ for all j with $q_{-i,j}^1 = d - q_{i,j}^1$ define a strategic sourcing equilibrium for $n \geq 2$. Then competition is sustained by definition, i.e., $\sum_j q_{i,j}^1\left(p_i^1 - c_i\right) \geq \underline{\pi}$ and $\sum_j q_{-i,j}^1\left(p_{-i}^1 - c_{-i}\right) \geq \underline{\pi}$. Solving these relations for p_{-i}^1, we obtain that if a strategic sourcing equilibrium exists, then $p_{-i}^1 \geq P_i(p_i^1)$ holds. Furthermore, as $q_{i,j}^1$ defines a strategic sourcing equilibrium, no profitable deviations exist and thus also $\tilde{q}_{i,j}^1 = 0$ is not profitable. Hence, the additional surplus in period 2 is at least as high as the foregone surplus in period 1, $q_{i,j}^1\left(p_i^1 - p_{-i}^1\right) \leq \delta\, d\,(V - c_2)$. Summing these conditions over all j and solving again for p_{-i}^1 we obtain $p_{-i}^1 \geq p_i^1 - \delta D\,(V - c_2)\,/Q_i^1$. With $Q_i^1\left(p_i^1 - c_i\right) \geq \underline{\pi}$, we then have $p_{-i}^1 \geq R_i(p_i^1)$. Comparing these conditions to $\mathcal{S}_{\mathrm{U}}^i$ we find that when a strategic sourcing equilibrium exists for $n \geq 2$, prices always lie in $\mathcal{S}_{\mathrm{U}}^i$. Then, by proposition 1 a strategic sourcing equilibrium exists also for a single buyer. Combined we have that for $p_1^1 \neq p_2^1$ a strategic sourcing equilibrium exists for $n \geq 2$ if and only if one exists for $n = 1$.

We now show that for $p_1^1 \neq p_2^1$ and $n \geq 2$, the aggregate demand allocation is uniquely determined as $\left(Q_1^{1\mathrm{S}}, Q_2^{1\mathrm{S}}\right)$. $Q_i^1 > \underline{Q}_i$ cannot follow from a strategic sourcing equilibrium as there exists a buyer s which can deviate profitably to $\tilde{q}_{i,s}^1 < q_{i,s}^1$, thereby increasing her surplus in period 1 by $\left(q_{i,s}^1 - \tilde{q}_{i,s}^1\right)\left(p_i^1 - p_{-i}^1\right)$ without decreasing surplus from period 2, as $\tilde{q}_{i,s}^1$ can be chosen such that $\pi_i^1 \geq \underline{\pi}$ still holds. Meanwhile, for $Q_i^1 < \underline{Q}_i$, supplier i exits and the demand allocation cannot be a strategic sourcing equilibrium by definition.

If for equal prices $p_1^1 = p_2^1$ a strategic sourcing equilibrium exists for $n = 1$, then by proposition 1, $\left(D - \underline{Q}_2, \underline{Q}_2\right)$ is an equilibrium. This allows to always construct a strategic sourcing equilibrium for $n \geq 2$ buyers by setting $q_{2,j}^1 = \underline{Q}_2/n$ with $q_{1,j}^1 = d - q_{2,j}^1$. No profitable deviation is possible as period 1 surplus is constant and period 2 surplus cannot increase further. Thus also for $n \geq 2$ there exists an equilibrium which yields the aggregate demand allocation $\left(D - \underline{Q}_2, \underline{Q}_2\right)$.

If conversely, for equal prices $q_{i,j}^1$ is a strategic sourcing equilibrium for $n \geq 2$, then $Q_i^1 = \sum_j q_{i,j}^1$ defines a strategic sourcing equilibrium for a single buyer. Competition is sustained and therefore surplus cannot increase further due to the equal prices in period 1. Thus, also for $p_1^1 = p_2^1$, a strategic sourcing equilibrium for $n \geq 2$ buyers exists if and only if one exists for a single buyer.

B) We let $p_1^1 \neq p_2^1$ and $p_i^1 > p_{-i}^1$. By definition in a myopic sourcing equilibrium competition is not sustained and therefore $\mathrm{BS}_j^2 = 0$. Thus if a myopic sourcing equilibrium exists, then $q_{i,j}^1 = 0$ and $q_{-i,j}^1 = d$ is the unique equilibrium demand allocation. In aggregate then $(Q_1, Q_2) = \left(Q_1^{1\mathrm{M}}, Q_2^{1\mathrm{M}}\right)$. Any other demand allocation entails $\tilde{q}_{i,s}^1 > 0$ for at least one buyer s. This cannot be a myopic sourcing equilibrium as by definition $\mathrm{BS}_j^2 = 0$ and buyer s could deviate profitably by reducing $\tilde{q}_{i,s}^1$.

Now, this demand allocation is an equilibrium if and only if no profitable deviation exists. As just discussed, any profitable deviation of supplier s has to sustain competition and therefore $\tilde{q}_{i,s}^1 \geq \underline{\pi} / \left(p_i^1 - c_i\right)$. This quantity must not exceed the demand of a single buyer d, which is the case if and only if $p_i^1 \geq \mu_i^{\mathrm{d}}$. Simultaneously, the remaining quantity has to sustain the other supplier, i.e., $\left(nd - \tilde{q}_{i,s}^1\right)\left(p_{-i}^1 - c_{-i}\right) \geq \underline{\pi}$. Solving this for p_{-i}^1 requires $p_{-i}^1 \geq P_i(p_i^1)$. In addition, buyer s deviates only if this is profitable, i.e., if $\tilde{q}_{i,s}^1 \left(p_i^1 - p_{-i}^1\right) \leq \delta d \left(V - c_2\right)$ with the inequality following from assumption 3. Rewritten, this requires $p_{-i}^1 \geq r_i(p_i^1)$.

From $p_{-i}^1 \geq P_i(p_i^1)$, $p_{-i}^1 \geq r_i(p_i^1)$ and $p_i^1 \geq \mu_i^{\mathrm{d}}$, the lower bound on prices p_i^1 for which a deviation is possible is the lowest p_i^1 for which $\max\left\{P_i(p_i^1), r_i(p_i^1\right\} < p_i^1$ and $\mu_i^{\mathrm{d}} \leq p_i^1$. We find that $r_i(p_i^1) < p_i^1$ always for $p_i^1 \geq \mu_i^{\mathrm{d}}$. From the proof of proposition 1 we have $\partial_{p_i^1} P_i < 0$ and $P_i(\eta) = \eta$. Thus, $p_i^1 > \eta$ and $p_i^1 \geq \mu_i^{\mathrm{d}}$ have to hold.

Therefore, a profitable deviation from the unique myopic sourcing equilibrium exists for unequal prices if and only if prices lie in $\mathcal{M}_{\mathrm{U}}^{\mathcal{C},i}$. Conversely, a unique myopic sourcing equilibrium with $\left(Q_1^1, Q_2^1\right) = \left(Q_1^{1\mathrm{M}}, Q_2^{1\mathrm{M}}\right)$ exists for unequal prices $p_1^1 \neq p_2^1$ if and only $\left(p_1^1, p_2^1\right) \in \mathcal{M}_{\mathrm{U}} = \mathcal{P}_{\mathrm{U}} \setminus \mathcal{M}_{\mathrm{U}}^{\mathcal{C}}$ with $\mathcal{M}_{\mathrm{U}}^{\mathcal{C}} = \mathcal{M}_{\mathrm{U}}^{\mathcal{C},1} \cup \mathcal{M}_{\mathrm{U}}^{\mathcal{C},2}$.

For equal prices $p_1^1 = p_2^1$, period 1 surplus is always identical. Therefore all demand allocations which do not sustain competition and which do not allow a single buyer s to sustain competition by deviating are myopic sourcing equilibria. To deduct the maximum price p_2^1 for which a myopic sourcing equilibrium exists, we focus on the demand allocation which requires a maximum deviation $\tilde{q}_{i,s}^1$ to sustain competition. This implies $q_{i,j}^1 = 0$, as then sustaining competition requires $\tilde{q}_{i,s}^1 \geq \underline{Q}_i$. As $\mu_2^{\mathrm{d}} > \mu_1^{\mathrm{d}}$ this is the case for $i = 2$. Therefore p_2^1 is maximized for $\left(q_{1,j}^1, q_{2,j}^1\right) = (d, 0)$, which is then a myopic sourcing equilibrium yielding $\left(Q_1^1, Q_2^1\right) = (D, 0)$.

A profitable deviation is possible if and only if $\tilde{q}_{2,s}^1 \geq \underline{\pi} / \left(p_2^1 - c_2\right)$ is not higher than d. The other buyers then sustain supplier 1 as $c_2 > c_1$. Accordingly, no deviation exists for $p_2^1 < \mu_2^{\mathrm{d}}$. Since $\mu_2^{\mathrm{d}} > \eta$, for equal prices a myopic sourcing equilibrium exists if and only if $\left(p_1^1, p_2^1\right) \in \mathcal{M}_{\mathrm{E}}$. Combining results, a myopic sourcing equilibrium exists if and only if $\left(p_1^1, p_2^1\right) \in \mathcal{M} = \mathcal{M}_{\mathrm{U}} \cup \mathcal{M}_{\mathrm{E}}$. □

A.9 Proof of Corollary 1

In the proof of proposition 3 we showed that for all $\left(p_1^1, p_2^1\right) \in \mathcal{S}$, a symmetric equilibrium for $n \geq 2$ buyers can be constructed from the strategic sourcing equilibrium of a single buyer by setting $\left(q_{1,j}^1, q_{2,j}^1\right) = \left(Q_1^1/n, Q_2^1/n\right)$ for all j.

For prices $\left(p_1^1, p_2^1\right) \in \mathcal{S}$ and $p_i^1 > p_{-i}^1$, proposition 3 assures that strategic sourcing equilibria exist and the aggregate demand allocation is uniquely $Q_i^1 = \underline{Q}_i$ and $Q_{-i}^1 = D - \underline{Q}_i$. Then, the non-symmetric demand allocations defined by $q_{i,s}^1 \in \left[\underline{Q}_i/n, \underline{Q}_i/n + \xi\right]$ and $q_{i,j\neq s}^1 = \left(\underline{Q}_i - q_{i,s}^1\right)/\left(n-1\right)$ are strategic sourcing equilibria if and only if buyer s cannot profitably deviate. With $\sum_j q_{i,j}^1 = \underline{Q}_i$, both suppliers are always sustained. Also, if buyer s cannot profitably deviate, then with $q_{i,s}^1 \geq q_{i,j\neq s}^1$ this holds for all buyers. A deviation to $\tilde{q}_{i,s}^1$ can only be profitable if it increases period 1 surplus by more than it decreases surplus in period 2 due to the loss of sustained competition, $\left(q_{i,s}^1 - \tilde{q}_{i,s}^1\right)\left(p_i^1 - p_{-i}^1\right) > \delta\, d\left(V - c_2\right)$ with assumption 3. Then, using the upper bound of the interval of $q_{i,s}^1$ values we find that no deviation exists for $\xi \leq \delta\, d\left(V - c_2\right)/\left(p_i^1 - p_{-i}^1\right) - \underline{\pi}/\left[n\left(p_i^1 - c_i\right)\right]$.

For $p_{-i}^1 = R_i(p_i^1)$ we obtain $\xi = 0$. Then, only the symmetric equilibrium with $q_{i,j}^1 = \underline{Q}_i/n$ for all j exists. This holds in general as follows from using $p_{-i}^1 = R_i(p_i^1)$ in the condition for the existence of a profitable deviation. Thus, no non-symmetric strategic sourcing equilibria exist for $\left(p_1^1, p_2^1\right) \in \mathcal{R}_{\mathrm{U}}$. For $p_{-i}^1 > R_i(p_i^1)$ however, we find $\xi > 0$ as the first term increases while the second term is unchanged. Therefore, $q_{i,s}^1 \in \left(\underline{Q}_i/n, \underline{Q}_i/n + \xi\right]$ is non-empty and thus for $\left(p_1^1, p_2^1\right) \in \mathcal{S}_{\mathrm{U}} \setminus \mathcal{R}_{\mathrm{U}}$ there exist infinitely many non-symmetric strategic sourcing equilibria.

For $p_1^1 = p_2^1$ in $\mathcal{S}$ the demand allocations defined by $q_{2,s}^1 \in \left[\underline{Q}_2/n, \underline{Q}_2/n + \xi'\right]$ and $q_{2,j\neq s}^1 = \left(\underline{Q}_2 - q_{2,s}^1\right)/\left(n-1\right)$ are strategic sourcing equilibria. As they yield the aggregate demand allocation of proposition 3, $\left(Q_1^1, Q_2^1\right) = \left(\left[D - \underline{Q}_2\right]/n, \underline{Q}_2/n\right)$, survival of both suppliers is assured. Hence, no buyer can profitably deviate as period 1 surplus is identical for all demand allocations. As $\underline{Q}_2/n < d$ since $Q_1^1 = nd - \underline{Q}_2 > 0$ for competition to be sustained, $\xi' > 0$ can always be chosen such that the interval $q_{2,s}^1 \in \left(\underline{Q}_2/n, \underline{Q}_2/n + \xi'\right]$ is non-empty. Then, infinitely many non-symmetric strategic sourcing equilibria exist also for $\left(p_1^1, p_2^1\right) \in \mathcal{S}_{\mathrm{E}}$. □

A.10 Proof of Corollary 2

For $p_1^1 = p_2^1$ we know from proposition 3 that for $n \geq 2$ buyers there exist strategic sourcing equilibria if and only if $\left(p_2^1, p_2^1\right) \in \mathcal{S}_{\mathrm{E}}$ and myopic sourcing equilibria if and only if $\left(p_2^1, p_2^1\right) \in \mathcal{M}_{\mathrm{E}}$. This requires $p_2^1 \geq \eta$ and $p_2^1 < \mu_2^{\mathrm{d}}$ respectively. Thus, both equilibrium types exist at least for $p_2^1 \in \left[\eta, \mu_2^{\mathrm{d}}\right)$ since $\mu_2^d > \eta$ from the the proof of proposition 3.

Let first $p_1^1 = p_2^1$ such that both equilibrium types exist. Then buyer surplus in period 1 is identical in both cases for all buyers, $\mathrm{BS}_j^1 = d\left(V - p_2^1\right)$. However, surplus in period 2 is higher when competition is sustained with $\mathrm{BS}_j^{\mathrm{2D}} > 0$. Thus strategic sourcing equilibria yield a higher surplus for all buyers j and are thus pareto-superior for buyers.

For $p_1^1 \neq p_2^1$ meanwhile with $p_i^1 > p_{-i}^1$ such that both equilibrium types exist, from proposition 3 the myopic sourcing surplus is for all buyers j equal to $\mathrm{BS}_j = d\left(V - p_{-i}^1\right)$. The lowest surplus in a strategic sourcing equilibrium is realized by buyer s with $q_{i,s}^1 = \max_j q_{i,j}^1$. Then $\mathrm{BS}_s = q_{i,s}^1\left(V - p_i^1\right) + \left(d - q_{i,s}^1\right)\left(V - p_{-i}^1\right) + \delta\, d\,(V - c_2)$. Comparing surplus values, the surplus in the strategic sourcing equilibrium is at least as high as in the myopic one if and only if $p_{-i}^1 \geq p_i^1 - \delta\, d\,(V - c_2)\,/q_{i,s}^1$. By the proof of proposition 3, if a strategic sourcing equilibrium exists for a price combination, this condition is fulfilled. Now, if this holds for buyer s, it clearly holds for all other buyers, since $\mathrm{BS}_{j \neq s} > \mathrm{BS}_s$ in a strategic sourcing equilibrium. Accordingly, strategic sourcing equilibria are weakly pareto-superior for buyers.

Also from proposition 3, a profitable deviation from myopic sourcing exists in the case of unequal prices if and only if $p_i^1 \geq \mu_i^{\mathrm{d}}$ and $p_i^1 > \eta$. Meanwhile, the maximum p_i^1 which yields a strategic sourcing equilibrium is $p_i^1 = V$. Hence, a strategic but no myopic sourcing equilibrium exists for some prices if and only if both $\eta < V$ and $\mu_i^{\mathrm{d}} \leq V$. For equal prices $p_1^1 = p_2^1$ a similar condition follows with $\mu_2^{\mathrm{d}} \leq V$. Thus, with $\mu_1^{\mathrm{d}} < \mu_2^{\mathrm{d}}$ and $\eta < \mu_2^{\mathrm{d}}$, the least restrictive condition follows as $\eta < V$ and $\mu_1^{\mathrm{d}} \leq V$. □

A.11 Proof of Corollary 3

With assumptions 3 and 5, whenever a strategic sourcing equilibrium exists one is implemented. With propositions 1 and 3 this yields that for all $\left(p_1^1, p_2^1\right) \in \mathcal{S}$ buyers purchase such that the aggregate demand allocation is identical to that for a single buyer. The same then holds for $\left(p_1^1, p_2^1\right) \notin \mathcal{S}$. Thereby, as assumed, for equal prices the same tie-breaking behavior is implemented in aggregate as for a single buyer.

Since buyer behavior enters the profit function of suppliers only through the aggregate quantities in period 1, supplier behavior is thus independent of the number of buyers. Then, this holds also for the pure strategy subgame-perfect equilibria with regard to prices, aggregate quantities and the market structure in period 2. □

A.12 Proof of Lemma 7

When both suppliers are active in period 2 and the buyer sets $\left(Q_{\mathrm{low}}^{2\mathrm{D}}, Q_{\mathrm{high}}^{2\mathrm{D}}\right) = (D, 0)$, then supplier 1 sells $Q_1^{2\mathrm{D}} = D$ for $p_1^{2\mathrm{D}} \leq p_2^{2\mathrm{D}}$ and $Q_1^{2\mathrm{D}} = 0$ otherwise. For supplier 2, $Q_2^{2\mathrm{D}} = D - Q_1^{2\mathrm{D}}$ always. This is identical to the one period model and therefore yields unique equilibrium prices $p_1^{2\mathrm{D}} = p_2^{2\mathrm{D}} = c_2$.

We assume now the buyer sets $\tilde{Q}_{\mathrm{low}}^{2\mathrm{D}} < D$ and $\tilde{Q}_{\mathrm{high}}^{2\mathrm{D}} = D - \tilde{Q}_{\mathrm{low}}^{2\mathrm{D}}$ instead. Supplier 2 then posts $p_2^{2\mathrm{D}} > c_2$, since prices $p_2^{2\mathrm{D}} \leq c_2$ are strictly dominated due to $\tilde{Q}_2^1 > 0$ always. For $p_1^{2\mathrm{D}} \leq p_2^{2\mathrm{D}}$, supplier 1 then sells $\tilde{Q}_{\mathrm{low}}^{2\mathrm{D}}$. The profit $\pi_1^{2\mathrm{D}} = \tilde{Q}_{\mathrm{low}}^{2\mathrm{D}}\left(p_2^{2\mathrm{D}} - c_1\right)$ from matching $p_1^{2\mathrm{D}} = p_2^{2\mathrm{D}}$ then strictly dominates all prices $p_1^{2\mathrm{D}} \leq c_2$ except when $\tilde{Q}_{\mathrm{low}}^{2\mathrm{D}} = 0$. Then however, any sales of supplier 1 are priced at $p_1^{2\mathrm{D}} \geq p_2^{2\mathrm{D}} > c_2$. The expected transaction price is thus always $\overline{p}_{\mathrm{T}}^{2\mathrm{D}} > c_2$ and therefore buyer surplus is lower than for $Q_{\mathrm{low}}^{2\mathrm{D}} = D$. Accordingly, the same equilibrium arises as in the initial process.

If a single supplier i is active in period 2 then the buyer purchases all demand from this supplier $Q_i^{2\mathrm{M}} = D$. Accordingly, supplier i prices at $p_i^{2\mathrm{M}} = V$ as in the initial process. $\square$

A.13 Proof of Lemma 8

When the buyer sets Q_{low}^1 and $Q_{\mathrm{high}}^1 = D - Q_{\mathrm{low}}^1$, for supplier 2 this implies $Q_2^1 = Q_{\mathrm{low}}^1$ for $p_2^1 < p_1^1$ and $Q_2^1 = D - Q_{\mathrm{low}}^1$ otherwise. Setting $p_2^1 < c_2$ is then weakly dominated by posting $p_2^1 = c_2$, as this always yields $\pi_2 = Q_2^1 \left(p_2^1 - c_2\right) = 0$, while $\pi_2 \leq 0$ for lower prices. Then, also for supplier 1 prices $p_1^1 < c_2$ are weakly dominated by $p_1^1 = c_2$. Since $p_2^1 \geq c_2$, supplier 1 is guaranteed $\pi_1^1 = Q_{\mathrm{low}}^1 \left(c_2 - c_1\right)$ at $p_1^1 = c_2$. For $p_1^1 < c_2$, supplier 1 also sells Q_{low}^1 but at a lower price and therefore π_1^1 cannot increase. Period 2 surplus cannot increase since if $\underline{\pi}$ is attained with $p_1^1 < c_2$, this also holds for $p_1^1 = c_2$. As both suppliers thus set $p_i^1 \geq c_2$, also the expected transaction price $\overline{p}_{\mathrm{T}}^1 \geq c_2$. $\square$

Appendix B

Experimental Instructions

Instructions[1]

Welcome to this experiment! Please read these instructions carefully. Do not talk with other participants from now on and do not look at the screens of other participants. Please switch off your mobile phone and let it remain switched off until the end of the experiment. If you have any questions, please raise your hand. One of the experimenters will then come to you.

This experiment will last about 1.5 to 2 hours. There are 4 firms, 2 "sellers" and 2 "buyers". You take the decisions for one of these firms. The computer will inform you at the start of the experiment whether your firm is a seller or a buyer. You keep your role during the whole experiment.

Overview

The experiment runs for 20 rounds. Each of these rounds consists of 2 periods.

In both periods, the active sellers set a price for an identical good. In period 1 always both sellers are active. In period 2 only those sellers are active who realized a profit in period 1 at least as high as the profit threshold.

The two buyers purchase the same predetermined number of units of the good from the sellers in both periods. Thereby buyers decide how many units to purchase from each of the active sellers.

Details Sellers

Two sellers sell identical goods. The sale generates costs for the sellers. One seller has a cost per unit of 200. For the other seller, the cost per unit is 400. These costs are identical in both periods.

[1]Translated instructions for the baseline treatment REF. Instructions for other treatments are identical except for treatment-specific modifications. To facilitate understanding by subjects, suppliers are designated as sellers in the experiment.

Period 1. Independently from each other both sellers set their price per unit in period 1 at which they offer the good to the buyers. The price can be between 0 and 1000 in both periods.

Period 2. Only the sellers who are active in period 2 set a price in period 2. This price can be different from the price in period 1, but does not have to be so. If one of the sellers is not active in period 2, he cannot set a price and therefore he cannot sell anything.

Per unit sold, a seller earns as a profit the difference between the price set by him and his cost. In a given period a seller therefore earns as his profit the number of units sold to both sellers together times the difference between his price in this period and his cost:

$$\text{Profit of seller} = \text{Number of units} \times (\text{ Price - Cost })$$

In period 1 always both sellers are active. If the profit of a seller in period 1 is at least as high as the profit threshold of 700, then he is also active in period 2. Therefore, if both sellers have made a profit at least as high as the profit threshold in period 1, then in period 2 both sellers are active. If only a single seller has made a profit at least as high as the profit threshold, then only this seller is active in period 2. If however none of the sellers has made a profit in period 1 at least as high as the profit threshold, then no seller is active in period 2.

Details Buyers

Two buyers purchase the good offered by the sellers in both periods. The good has a value per unit of 1000 for each buyer. This value is identical in both periods. Each of the buyers needs exactly 4 units of the good in each period.

Period 1. The buyers receive the prices of the sellers in period 1. Both buyers decide independently of each other how many units to purchase from each seller. From both sellers together each buyer purchases 4 units of the good.

Period 2. If both sellers are active in period 2, then both buyers decide again independently of each other how many units to purchase from each seller. From both sellers together, each of the buyers purchases 4 units of the good. If only a single seller is active in period 2, then both buyers purchase 4 units from this seller. If no seller is active in period 2, then the buyers cannot buy anything.

Per unit purchased, a buyer earns as a profit the difference between the value and the price paid. In a given period a buyer thus earns as a profit the number of units purchased from seller 1 times the difference between the value and the price of seller 1. In addition, she earns the number of units purchased from seller 2 times the difference between the value and the price of seller 2:

$$\text{Profit of buyer} = \text{Number of units from seller } 1 \times (\text{ Value - Price}_1 \text{ }) + \\ \text{Number of units from seller } 2 \times (\text{ Value - Price}_2 \text{ })$$

Overview Parameters

The numerical values are again summarized here. During the experiment they are also displayed on the screen.

Cost per unit seller 1	200
Cost per unit seller 2	400
Profit threshold	700
Value per unit for buyer	1000
Number of units needed per buyer per period	4

Experimental Procedure

The sequence of period 1 and period 2 is repeated for 20 rounds. Before the first round, you will be informed on the screen whether your firm is a buyer or a seller. Your role remains unchanged in all rounds. You are part of a group of 2 sellers and 2 buyers during the experiment. The decisions of the 3 other firms are taken by other participants in this room.

At the beginning of each round it is determined randomly for the sellers whom of the sellers has a cost of 200 and whom of the sellers has a cost of 400. In the respective round these costs are then identical in both periods. In the experiment, the seller with a cost of 200 is always designated as "seller 1". "Seller 1" is therefore not the same participant in each round.

Each of the 20 rounds consists of the following steps:

- The computer informs each of the sellers about his cost in the current period.
- Both sellers set their prices in period 1. The decision can be simulated in the lower half of the screen. [Screenshot with explanations]
- The prices of the sellers in period 1 are displayed to the buyers. Both buyers decide how many units to purchase from each seller. The buyers can also simulate their decision. [Screenshot with explanations]
- Your profit and the profits of the other firms in period 1 are displayed.
- The sellers who are active in period 2 set their prices for period 2.
- The prices of the active sellers in period 2 are displayed to the buyers. The buyers can decide how many units to purchase from each seller. If no seller is active, the buyers cannot purchase anything.
- Your profit and the profit of the other firms in period 2 are displayed.

Your total profit from all previous rounds is displayed in the upper right part of the screen. You find the remaining time which is available for the respective decision centered at the top.

At the end of the experiment your total profit from all rounds is payed out to you in cash with a conversion rate of 3000 = 1 EUR. For the payment you are called up one after another with your seat number. Please leave these instructions at your place then.

Thanks a lot for your participation and we wish you successful decisions!

Control Questions

Before the experiment starts, please answer the following control questions. When you have answered them, please raise your hand. One of the experimenters will then come to you, check your answers and discuss open issues with you.

1. If your firm is a seller, is your cost then identical in all of the 20 rounds (yes/no)?
2. The seller with a cost per unit of 400 has set a price per unit of 750 in period 1.
   a) The seller sells in total 1 unit of the good. What is the profit of the seller?
   b) How many units does the seller at least have to sell to earn a profit in period 1 which is at least as high as the profit threshold?
3. How many units does a buyer purchase from both sellers together in period 1?
4. In period 2 none of the two sellers is active. What profit does a buyer then earn in period 2?

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