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Split-Award Auctions and Supply Disruptions

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Problem definition: We consider a buyer that needs to source a fixed quantity. She faces several potential suppliers that might fail to deliver. The buyer conducts a procurement auction to determine contract suppliers and can choose between single-sourcing and multi-sourcing. If contract suppliers fail to deliver, the buyer tries to source from non-contract suppliers but has little bargaining power due to time pressure. ***Academic / Practical Relevance:*** The mitigation of supply risks plays an important role in procurement practice but attracted little attention in the academic analysis of procurement auctions. Academic research on multi-sourcing procurement auction typically analyzes these auctions as stand-alone events. In contrast, we investigate the influence of the auction design on the post-auction market structure and identify an effect favoring multi-sourcing. The insights provide procurement managers guidance for their sourcing decisions.

Methodology: We apply game-theoretical methods to analyze a stylized model in which a cost-minimizing buyer needs to source from profit-maximizing suppliers who might fail to deliver. The buyer conducts a procurement auction to determine contract suppliers and can choose between single-sourcing and multi-sourcing. If contract suppliers fail to deliver, the buyer tries to source from a non-contract supplier. We assume that in this situation, the non-contract supplier has almost all the bargaining power. ***Results*** First, we show that in such a setting multi-sourcing does not only reduce the supply risk but might also yield lower prices than single-sourcing. The sourcing decision affects the post-auction market structure such that being a non-contract supplier becomes less attractive in case of multi-sourcing. Second, if suppliers are heterogeneous regarding their disruption probabilities, less reliable suppliers will bid more aggressively than their more reliable competitors causing an adverse selection problem. Furthermore, we show that attracting an additional supplier can be risky as it can increase the auction price and the buyer's total expenses. ***Managerial Implications:*** Our analysis reveals a pro-competitive effect of multi-sourcing. This effect is especially important if the buyer's value for the item is substantially larger than suppliers' production costs and for intermediate disruption probabilities.

Key words: Adverse selection, auctions, multi-sourcing, supply disruptions, procurement

JEL Classification: D44, D47, H57

1. Introduction

Firms and governments frequently employ procurement auctions to award long-term supply contracts. These auctions induce competition among suppliers, enabling the buyer to identify the most efficient suppliers and to yield low prices. However, generating low prices is not sufficient when supply disruptions are possible. Multi-sourcing is one way to mitigate the risk of supply disruptions. We analyze the interaction between competition in the procurement auction and the risk of supply disruptions. While it is typically assumed that the buyer faces a trade-off between lower prices and a smaller disruption risk, we show that multi-sourcing can result in lower prices than single-sourcing. Furthermore, we show that such auctions might lead to adverse selection because less reliable suppliers bid more aggressively than their more reliable competitors.

When contract suppliers fail to deliver, the buyer needs to find alternative sources quickly to end the supply disruption. Then, the urgency often renders it impossible for the buyer to conduct another procurement auction and also implies a weak bargaining position when negotiating with a potential alternative supplier. As a consequence, suppliers may see disruptions of competing suppliers as a profitable business opportunity for themselves. Those suppliers speculate on gaining high profits when contract suppliers fail to deliver. The higher the disruption probability, the more attractive is the outside option of not being awarded a contract. A more attractive outside option implies less aggressive bidding in the procurement auction. Thus, reducing the risk of supply disruptions by employing a multi-sourcing strategy has also a pro-competitive effect.

Due to this effect, multi-sourcing is especially attractive for the buyers in settings where the number of potential suppliers is not too small, and the setup costs for production are not too high. A specific example is the market for off-patent pharmaceutical drugs. Several pharmaceutical firms produce substitute drugs and compete in auctions set up by insurance companies (or healthcare providers). Drug manufacturers have been prone to supply disruptions (See Boonen et al. (2010), Hollis and Grootendorst (2012)). Disruptions in the manufacturing process are due to quality or other production issues, see, for instance, Food and Drug Administration (2011), Gerlach et al. (2014). In Germany, for example, the insurance companies can buy from pharmaceutical firms at regulated prices or they can sign rebate contracts with those firms. With a rebate contract the insurance company grants one or more pharmaceutical firms exclusive access to its customers in exchange for lower drug prices. For the customers of the insurance company that means that they only get reimbursed for drugs of a contracted pharmaceutical firm. Only if no contracted firm can deliver the required drug, customers also get reimbursed after buying from other pharmaceutical firms.

In the last years, insurance companies and associations of insurance companies conducted auctions to award rebate contracts. Multi-sourcing is popular in drug procurement. A typical practice is to announce the number of contract suppliers before the auction. These contract suppliers will supply the good in equal shares, as done by German statutory health insurers. See Bauer et al. (2014). The auctions regularly yield prices that are substantially lower than the regulated prices. Due to supply disruptions, however, it may also be attractive to speculate on selling at the regulated price if contract suppliers fail to deliver. (This is very similar to a situation in which a buyer faces a supply disruption and needs to find an alternative supplier quickly. Due to the time pressure the supplier is likely to pay a high price.)

One example for such a market is the German pharmaceutical market, which is the fourth largest pharmaceutical market in the world (IQVIA 2019). According to (Progenerika 2019, p. 29), the 109 German insurers concluded 31,260 supply contracts for drugs with 216 different firms in 2019, of which 95 percent were for off-patent drugs. The auctions resulted in substantial savings. For contracted off-patent drugs, the average price for a daily dose was 6 Euro cents. In contrast to that, the corresponding regulated price was 17 Euro cents, implying a discount of about 65 percent (Progenerika 2019, p.17)

Overall savings are not as high as the price discount due to ineffective supply contracts. Reasons for the lack of effectiveness include supply disruptions by the manufacturer, supply chain problems in wholesale and retail, and the lack of varieties and doctors prohibiting substitution to different brand (Bauer et al. 2014). In a study about the ten biggest insurers (covering 55 percent of all sales), Institut (2019) finds that for all drugs of active ingredients for which a procurement auction was held before, only 59.3 to 78 percent of all packages were sold by a contracted supplier.(Institut 2019, slide 21 and 25) Insurers aim mitigating the low effectiveness of contracts by multi-sourcing and the popularity of multi-sourcing increased over the last years. A common rule of thumb is that by contracting three instead of one supplier, the average coverage increases by 10 to 15 percentage points Bauer et al. (2014).

We consider a stylized model in which a cost-minimizing buyer needs to source a fixed quantity from profit-maximizing suppliers who might fail to deliver. The buyer conducts a procurement auction to determine contract suppliers and can choose between single-sourcing and multi-sourcing. If contract suppliers fail to deliver, the buyer tries to source from a non-contract supplier. We argue that in this situation, the non-contract supplier has almost all the bargaining power. Multi-sourcing has two opposing effects. On the one hand, it reduces the scarcity of contracts, which implies less aggressive bidding. On the other hand, it makes suppliers' outside option less attractive, which means more aggressive bidding. We show that the second effect dominates the first effect if the buyer's valuation (or the regulated price) is high. Then, multi-sourcing not only reduces the risk of supply disruptions but also yields lower prices.

The attractiveness of this outside option depends on the reliability of the contract suppliers. The more reliable the contract firms the less attractive is the outside option. If suppliers differ with regard to their reliability this induces an adverse selection problem. A less reliable bidder faces a less attractive outside option than his more reliable competitors. Consequently, he bids more aggressively and becomes contract supplier with inefficiently high frequency.

From the buyer's perspective, an increasing disruption probability of a supplier has both a direct and an indirect negative effect. The direct effect is that it becomes more probable that no contract supplier or no supplier at all can deliver the product. The indirect effect stems from reduced competition. The higher the disruption probability of a supplier the more attractive is the outside option for his competitors, which implies that they will bid less aggressively and the prices will go up.

Finally, the adverse selection problem also implies that attracting an additional supplier can actually backfire if his disruption probability is high. In this case his participation can increase the auction price and, more importantly, the buyer's total expenses. When he replaces a more reliable contract supplier, not being a contract supplier becomes more attractive which implies less aggressive bidding of the other suppliers.

The paper is organized as follows. We discuss the related literature in Section 2. In Section 3, we develop our model and conduct in Section 4 our analysis. We provide extensions in Section 5. Section 6 concludes. All omitted calculations and proofs are relegated to the Appendix.

2. Related literature

Our paper contributes to the literature on split-award auctions. Split-award auctions play an important role in procurement practice. Buyers conduct split-award auctions for several reasons, e.g., (i) to reduce supply risks by sourcing from multiple suppliers (Babich et al. 2007, Yu et al. 2009, Chaturvedi and Martínez-de Albéniz 2011, Yang et al. 2012), (ii) to identify the cost-efficient sourcing strategy if they are uncertain about economies of scale (Anton et al. 2010, Kokott et al. 2019a,b), (iii) to fill the demand if it exceeds the capacity of a single supplier (Chaturvedi 2015) or (iv) to maintain a sufficiently large supply base (Chaturvedi et al. 2014). One can further distinguish between ex-ante and ex-post split-award auctions. In an ex-ante split award auction, the size of the shares is pre-determined, and each supplier can win at most one share. In an ex-post split-award auction, the size of the shares need not be pre-determined, and a single supplier can win more than one share. We analyze ex-ante split-award auctions in a setting in which supply disruptions can occur.

In his seminal paper Wilson (1979) points out that split-award auctions reduce competition and typically generate less revenue than unit auctions. Further research identifies situations in which multi-sourcing yields lower prices than single-sourcing. Dasgupta and Spulber (1989) consider suppliers with convex production cost and show that in such a setting, multi-sourcing is more efficient and can generate lower prices than single-sourcing. Seshadri et al. (1991), Klotz and Chatterjee (1995), Perry and Sákovics (2003) compare multi-sourcing to single-sourcing if entry is costly to suppliers. These papers show that increasing the number of contracts or the size of the smaller contract in case of dual-sourcing makes entry more attractive. If multi-sourcing causes more entry, it may also result in lower prices. Gong et al. (2012) show that investment costs may be another reason for split-award auctions. They consider a setting in which suppliers can invest in cost-decreasing technologies. If the investment exhibits diseconomies of scale, dual-sourcing reduces procurement expenses by giving a second supplier an incentive to invest. In contrast to these papers, we consider a setting with constant marginal cost and fixed industry size. Furthermore, we abstract away from investment costs.

The performance of split-award auctions also depends on the design of the shares. Typically the buyer can minimize prices by maximizing the share she sources from the cost-efficient supplier. However, as just mentioned, in the presence of entry costs, the buyer might want to increase that share up to a certain point to attract more bidders. Chaturvedi et al. (2018) present another exception. If sourcing rules limit the maximum contract size, a supplier can win or require a minimum number of contract suppliers, awarding an additional contract, i.e., splitting a contract into two parts, can reduce the buyer's expenses if the cost distribution is not regular. By splitting a contract into two parts, the competition at the lower end of the cost distribution becomes more intense, which may outweigh reduced competition at the upper end of the cost distribution. In our analysis, we focus on symmetric splits. However, if the buyer could award discriminating contracts, the advantages of multi-sourcing would grow further.

Similar to us Yang et al. (2012), investigate split-award auctions in the presence of supply risk. In a setting with two suppliers, they show a trade-off between higher supply reliability and less competition when turning from single-sourcing to dual-sourcing. For more than two potential suppliers, we find that the buyer's sourcing decision also affects suppliers' outside option, which implies that diversification does not only increase reliability but might also increase competition and yield lower prices than single-sourcing.

Finally, the effect we observe has some similarities to Bru et al. (2018) who consider a buyer facing n suppliers with diseconomies of scale. In their setting, the buyer can conduct an ex-ante split-award auction and can also source from a competitive market. They show that the buyer should award contracts to almost all suppliers ($n-2$ or $n-1$) in the auction and procure the remaining demand on the market. Reducing the (residual) demand on the market makes the outside option of not winning the auction less attractive for suppliers, which implies more aggressive bidding.

3. Model

We consider a setting in which a (female) buyer has a unit demand for a standardized homogeneous good. Her marginal valuation for the good is $v > 1$. The buyer faces n potential (male) suppliers. Suppliers' production costs when producing q units are $q \cdot c_i$.

The (normalized) marginal production costs $c_i \in [0,1]$ are independently and identically distributed according to the distribution function F with continuous density function f. A supplier's cost realization c_i is his private information. Suppliers' production processes are subject to random disruptions, and a disruption results in nondelivery by the affected supplier. For each supplier, the disruption probability is $\delta \in (0,1)$, and disruptions of different suppliers are mutually independent.

The timing is as follows. In period one, the buyer conducts a uniform-price procurement auction to award $k < n$ equivalent contracts. The k suppliers who place the k lowest bids become contract suppliers. Ties are broken at random. The unit price p a contract supplier will receive is equal to the $k+1$-th lowest bid and production is split evenly among all contracted suppliers. In period two, the production stage, disruptions may occur. If a contract supplier fails to deliver, those contract suppliers without disruptions will fill the gap. Even though they are important in practice, we abstract from capacity constraints to keep the analysis tractable. We assume that suppliers can either produce any demanded quantity or not produce at all. (Introducing capacity constraints or assuming that suppliers fail to produce partly would add some complications but does not change the main findings of the model qualitatively.) However, if all k contract suppliers fail to deliver, the buyer will quickly identify those non-contract who can deliver and randomly approach one of them. Alternatively one could assume that the buyer only has time to approach one of the non-contract suppliers. Given that suppliers were already qualified for participating in the auction, it seems to be reasonable to assume that the buyer can quickly identify those suppliers who can deliver. Given that this only happens in case of an emergency with considerable time pressure for the buyer, we assume that even if more than one of the $n-k$ non-contract suppliers were able to supply, the buyer cannot exploit this, e.g., by running an auction. Instead, we assume that the approached non-contract supplier, which can deliver, has (almost) all the bargaining power when negotiating with the buyer. If an agreement is reached, the supplier produces. If no agreement is reached, the buyer has no time for further negotiations with other suppliers and will receive no units. Similarly, if none of the $n-k$ non-contract suppliers is able to deliver, the buyer will also receive no units.

4. Analysis

First, we consider the case in which suppliers are symmetric. Later we turn to the case in which suppliers differ with respect to their individual disruption probabilities.

4.1. Homogeneous disruption probabilities

We start the analysis by examining the production stage and then apply backward induction to investigate suppliers' bidding behavior and the buyer's sourcing decision.

Period 2: Production From the buyer's point of view, one can distinguish between three possible outcomes in the second period. First, the trivial case in which all n suppliers fail to produce. In this case, all parties make zero profit, and it occurs with probability δ^n. Second, the case in which at least one contract supplier can deliver. In this case the buyer pays the auction price p and her profit is $\pi_b = v - p$. This situation occurs with probability $1 - \delta^k$. The expected profit of a contract supplier, in this case, is $\pi_c = (p - c_i)/k$, and non-contract suppliers earn nothing.

Note that this is the expected profit of a contract supplier before he knows if he himself can produce. If he can produce, he will typically produce more than $1/k$ because other suppliers may fail to produce. More precisely, the probability that a contract supplier, who is not affected by a disruption, produces a quantity $1/(k-m)$ is given by $\binom{k-1}{m} \cdot \delta^m \cdot (1-\delta)^{k-1-m}$. Here $m < k$ denotes the number of other contract suppliers failing to deliver.

Finally, there is the case in which all contract suppliers are affected by disruptions, but at least one non-contract supplier can deliver. This case occurs with probability $\delta^k \cdot (1 - \delta^{n-k})$. The approached non-contract supplier, which is able to deliver, will exploit his bargaining power, which leads to a price of v. In this case, the buyer and contract suppliers make zero profit, the approached non-contract supplier makes a profit of $v - c_i$. Since all non-contract suppliers have the same chance of being approached and being able to deliver the (ex-ante) expected profit of a non-contract supplier is given by $\pi_n = (v - c_i)/(n-k)$.

Summing up, the buyer's expected profit is given by

$$\Pi_b := (1 - \delta^k) \cdot (v - p),$$

that of a contract supplier by

$$\Pi_c := \frac{1-\delta^k}{k} \cdot (p - c_i), \tag{1}$$

and that of a non-contract supplier by

$$\Pi_n := \frac{\delta^k \cdot (1-\delta^{n-k})}{n-k} \cdot (v - c_i). \tag{2}$$

Furthermore, let

$$r := \frac{\delta^k \cdot (1-\delta^{n-k})}{n-k} \Big/ \frac{1-\delta^k}{k} = \frac{k \cdot (\delta^k - \delta^n)}{(n-k)\cdot(1-\delta^k)} \in (0,1)$$

denote the expected amount supplied by a non-contract supplier relative to the expected amount provided by a contract supplier. The relative supply probability and thus, the relative attractiveness of being a non-contract supplier depends on several factors. The supply probability of a contract supplier is always larger than the supply probability of a non-contract supplier. The reason is that the buyer will only approach non-contract suppliers if all contract suppliers fail to deliver. Being a non-contract supplier becomes relatively less attractive if the number of suppliers n increases or if the disruption probability δ decreases. Importantly, the buyer's sourcing decision directly influences the relative attractiveness of being a non-contract supplier. Increasing the number of contracts k reduces both the expected quantity provided by contract suppliers and the expected quantity provided by non-contract suppliers. However, the second effect is always stronger than the first.

Proposition 1. *Being a non-contract supplier becomes relatively less attractive if the number of contracts k increases, i.e., $r(k) > r(k+1)$ for all $k \in \{1, 2, \ldots, n-2\}$.*

All proofs are relegated to the appendix.

Period 1: Auction The possibility to deliver the good as a non-contract supplier if all contract suppliers fail has the same effect as an outside option in the auction. From (1) and (2) it follows, that a supplier only prefers being a contract supplier over being a non-contract supplier if

$$\Pi_c \geq \Pi_n$$
$$\frac{1-\delta^k}{k} \cdot (p - c_i) \geq \frac{\delta^k \cdot (1-\delta^{n-k})}{n-k} \cdot (v - c_i)$$

$$p \geq (1-r) \cdot c_i + r \cdot v. \tag{3}$$

It is well known that participants in a uniform-price auction in which each participant can at most win one unit or in an ex-ante split award auction with equal shares have a (weakly) dominant strategy to bid truthfully (See for example Krishna 2009). Applying this result to our setting, it directly follows that suppliers have a (weakly) dominant strategy of bidding

$$b^*(c_i) := (1-r) \cdot c_i + r \cdot v. \tag{4}$$

The equilibrium bidding strategy illustrates that suppliers will increase their bids if the outside option gets more attractive, i.e., if r gets larger. If the failure probability δ is zero, only contract suppliers will provide the good. In this case, r is zero, and suppliers optimally bid their cost truthfully. If, however, the disruption probability goes to one, being a non-contract supplier is no longer a disadvantage, i.e. r approaches 1. In this case, the optimal bid converges to the buyer's valuation v. Furthermore, it implies that the selection of suppliers is efficient in the sense that those suppliers with the lowest costs will become contract suppliers.

Given that the auction price p is equal to the $k+1$-th lowest bid and that each bidder has a (weakly) dominant strategy of bidding according to (4), the expected price can be written as

$$E[p] = (1-r) \cdot E[c^{(k+1,n)}] + r \cdot v.$$

Here $c^{(k+1,n)}$ denotes the $k+1$-lowest of n cost draws. Increasing the number of contracts from k to $k+1$ has two opposing effects on the price. On the one hand, the buyer reduces the scarcity of contracts, which increases the price as the supplier with the $k+2$-th lowest costs will now set the price. On the other hand, the relative attractiveness r of being a non-contract supplier decreases, which implies a smaller mark-up on costs and reduces the price. The overall effect of an increase in the number of contracts on the price is ambiguous.

While the overall effect is ambiguous, it is still possible to show that dual-sourcing becomes more attractive if the buyer's valuation v for the good increases. A higher valuation v puts more weight on the decreasing relative attractiveness of being a non-contract supplier r and does not affect the scarcity effect. Hence, for each environment (δ, F, v) there exists a critical $\hat{v}$ such that for all $v > \hat{v}$, dual-sourcing yields lower prices than single-sourcing.

Following the same reasoning, one can also identify parameters such that sourcing from more than two suppliers decreases prices further. However, the change of r driving the effect is typically largest when switching from a single-sourcing to a dual-sourcing strategy.

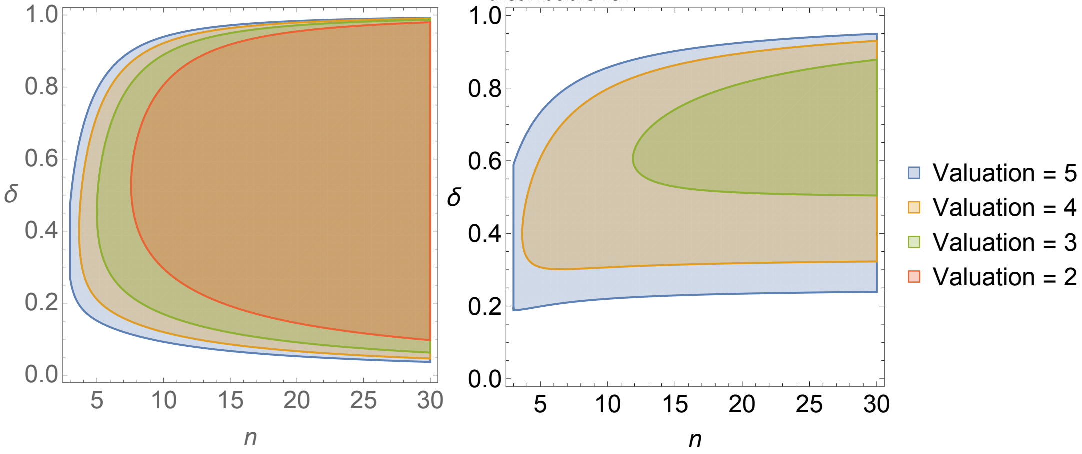
Proposition 2. *For all $v > \hat{v}$ dual-sourcing yields a lower price than single-sourcing.*

The influence of the disruption probability δ on the price-optimal sourcing strategy is non-monotonic. Both for very high and very low disruption probabilities, dual-sourcing is unlikely to yield lower prices than single-sourcing. If the disruption probability goes to zero, the relative attractiveness of being a non-contract supplier is already close to zero for single-sourcing. While increasing the number of contracts decreases the attractiveness further, the absolute change tends to be negligible. Consequently, the scarcity effect dominates at some point, and increasing the number of contracts inflates prices. For high disruption probabilities, the reasoning is quite similar. If the disruption probability goes to one, being a contract supplier has (almost) no advantage over being a non-contract supplier, i.e., r is close to one. Again the absolute change of r when increasing the number of contracts is negligible. Hence, the scarcity effect dominates, and the price increases.

Figure 1 illustrates when dual-sourcing yields higher buyer profit than single-sourcing depending on the number of firms n and the failure probability δ for different buyer valuations v and different cost distributions. For our motivational example, the German market for generic drugs, participation in the auctions typically ranges between 10 and 20 suppliers, and the average failure probability after the auction is 40.7 percent. We can see here that in these cases dual-sourcing is likely to yield lower prices than single-sourcing, especially when taking into account that the regulated price is three times as high as the resulting auction price.

So far, the analysis focused on prices. It demonstrated that multi-sourcing can lower prices by increasing competition. The buyer, however, is typically interested in her total expenses and not only in prices. Independent of the price effect, multi-sourcing implies a

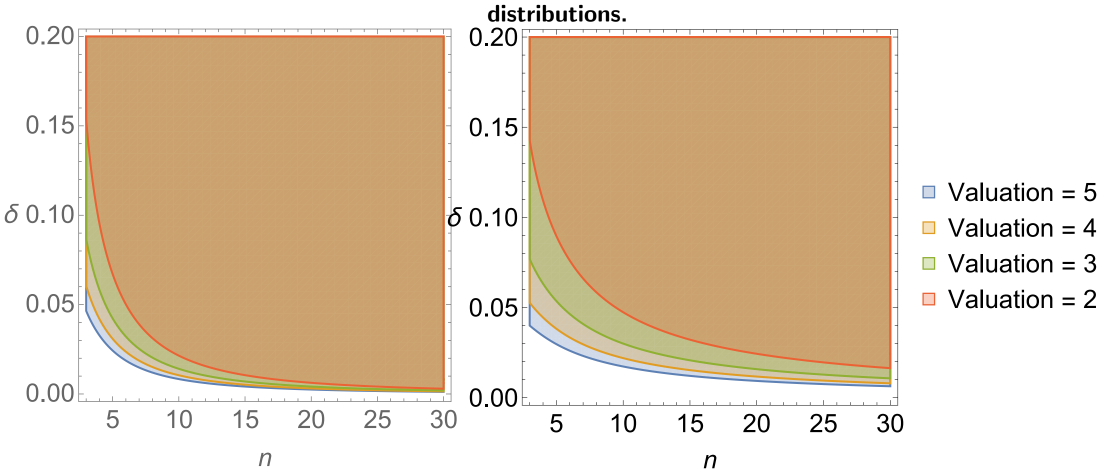
Figure 1 **Iso-price-lines for single- and dual-sourcing for different buyer valuations and cost distributions.**



(a) $F(x) = \sqrt{x}$ (b) $F(x) = x$

Notes: In the colored areas dual-sourcing yields lower price than single-sourcing.

Figure 2 **Iso-cost-lines for single- and dual-sourcing for different buyer valuations and cost distributions.**



(a) $F(x) = \sqrt{x}$ (b) $F(x) = x$

Notes: In the colored areas dual-sourcing results in lower expenses for the buyer than single-sourcing.

higher likelihood of contract suppliers providing the good. As a consequence, the buyer is less likely to pay a high price to non-contract suppliers. Thus, multi-sourcing always results in greater buyer's profit if it does not yield higher prices than single-sourcing. The non-price effect implies that multi-sourcing tends to be profitable if the disruption probability becomes larger.

Figure 2 illustrates when dual-sourcing is more profitable than single-sourcing for the buyer depending on the number of suppliers n and the failure probability δ for different valuations. A higher number of firms n, a higher disruption probability δ, and a higher valuation v all speak in favor of multi-sourcing over single-sourcing.

4.2. Heterogeneous disruption probabilities

In practice, suppliers are likely to differ with regard to their disruption probabilities. In this section, we will investigate the consequences of such a heterogeneity and show that it causes an adverse selection problem in the auction. We assume that suppliers know about the disruption probabilities of their competitors and that the buyer cannot observe it. Suppliers might have better information about their competitors' disruption probabilities than the buyer because they know more about the production process or about risks further up the supply chain. The heterogeneity implies that less reliable suppliers gain relatively more from winning a contract which makes them bid more aggressively than more reliable suppliers. As a consequence, less reliable suppliers might win a contract even if they have higher costs than their more reliable competitors which causes an inefficiency.

Proposition 3. *Heterogeneity with respect to suppliers' disruption probabilities results in an adverse selection problem. Less reliable suppliers bid more aggressively and win inefficiently many contracts compared to more reliable competitors.*

To get an intuition consider a single-sourcing auction with just two bidders of two types: one supplier has a higher disruption probability δ_h and another supplier has a lower disruption probability δ_l, i.e. $\delta_h > \delta_l$. Both suppliers have a (weakly) dominant strategy of bidding $b(c_i) = (1 - \delta_j) \cdot c_i + \delta_j \cdot v$. This, however, implies that for each cost realization, the more reliable type will bid less aggressively than the less reliable type. For the more reliable supplier, losing is less problematic because his chances of selling as a non-contract supplier are higher than for the less reliable supplier.

Another consequence of the heterogeneity with regard to suppliers' disruption probabilities is that suppliers now care about the identities or rather the disruption probabilities of the other contract suppliers when placing their bids. Awarding a contract to a supplier causes an externality for other suppliers that depends on the awardee's disruption probability. In a static uniform-price auction in which each supplier places a single bid, suppliers face uncertainty about the composition of the group of contract suppliers and, hence, do not have a (weakly) dominant bidding strategy anymore. To guarantee the existence of a (weakly) dominant bidding strategy, the buyer would need to allow for a more complex bidding language that enables suppliers to condition their bids on the composition of the group of contract suppliers. Alternatively, the buyer could conduct dynamic descending uniform-price auction. If suppliers can observe which competitors are still active, the uncertainty about the composition of the group of contract suppliers is at least reduced.

If the buyer knows the individual disruption probabilities of the suppliers, she should conduct a scoring auction to account for the heterogeneity and to reduce distortions (See, e.g., Che 1993). Suppliers' scores need to reflect both the direct effect and the indirect effect of a higher disruption probability. The direct effect considers the buyer's additional expenses when a certain supplier fails to deliver. The indirect effect also takes into account that competitors of this supplier will bid less aggressively if his disruption probability becomes larger.

Finally, the adverse selection effect also implies that attracting an additional bidder might actually increase the auction price and the buyer's total expenses. We illustrate this finding with an example.

Example. *A buyer with valuation $v = 2$ faces two suppliers, A and B. Both suppliers have a disruption probability of $\delta_A = \delta_B = 0.1$. Supplier A's costs are $c_A = 1$ and supplier B's cost are $c_B = 0.8$. If the buyer conducts an auction and awards one contract, supplier B will win, the auction price will be $p = 1.1$, and the buyer's total expenses are $e = 1.19$.*

Now suppose that a new supplier C shows up. This supplier has very low costs $c_C = 0$ and, unbeknown to the buyer, a high disruption probability of $\delta_C = 0.9$. If the buyer conducts an auction and awards one contract, supplier C will win, the auction price will be $p = 1.394$, and the buyer's total expenses will be $e = 1.9394$. Both price and total expenses are substantially larger than in the case with just two bidders.

The example shows that attracting an additional bidder can increase the price and the buyer's total expenses. This effect does not only occur if the additional supplier has a high disruption probability and replaces a more reliable competitor as a contract supplier. To tackle this effect the buyer could increase the number of contracts, however, this can only work out if additional supplier has low costs. If the buyer is not sure about this, she might do better by excluding the additional supplier.

5. Extensions and discussions

The model setup is as parsimonious as possible to focus on the main effect of the possibility of supply disruptions on procurement auctions. This section discusses the implications of relevant extensions and the generalizability of the findings.

The assumption that suppliers have the entire bargaining power in the production period may be extreme. An alternative is to assume that both the buyer and non-contract suppliers have some bargaining power when negotiating about the split of the guaranteed gains from trade. These guaranteed gains from trade are equal to the difference between the buyer's valuation and the highest possible cost realization. Given that suppliers' production costs are their private information, it does not seem to be reasonable to assume that the parties negotiate over the entire gains from trade. If the buyer were informed about suppliers' production costs, she would not need to run an auction in the first place and could just make optimal take-it-or-leave-it offers.

A buyer with bargaining power $\theta \in [0, 1]$ yields a profit of $\theta \cdot (v - 1)$ if all contract suppliers fail to deliver. Assuming that the buyer has bargaining power does not change the results qualitatively. Higher buyer bargaining power has the same effect on prices as a lower valuation. Increased bargaining power benefits the buyer twice. First, the buyer makes a (relatively) higher profit if all contract suppliers fail to deliver. Second, it makes suppliers already compete more fiercely in the auction.

The analysis considered a case in which the buyer conducted a uniform-price auction to award the contracts. Given that the buyer does not discriminate between contract suppliers, one can directly apply the results of Engelbrecht-Wiggans (1988) or Wambach (2002) and prove the revenue equivalence to other auction formats, e.g., the discriminatory price auction if suppliers do not differ with regard to their disruption probabilities. In this sense, the buyer cannot do better by choosing another auction format. However, theory predicts that the buyer would benefit from discriminating between contract suppliers. E.g., the buyer could award two types of contracts, say A and B. She would then always try to source from contract-A suppliers and only approach to contract-B suppliers if all contract-A supplier failed to deliver. As a consequence, being a contract-A supplier would be more attractive than being a contract-B supplier and being a contract-B supplier more attractive than being a non-contract supplier. Indeed, the theory implies that its most extreme form maximizes the buyer's profit. In this case, the supplier who placed the lowest bid covers the buyer's entire demand if no disruption occurs. If he fails, the buyer approaches the supplier who placed the second-lowest bid to cover her entire demand, and so on. While such a sourcing strategy maximizes efficiency, it also implies huge (demand) uncertainty for all but the supplier with the lowest bid. This might be problematic, especially if capacity constraints play a role.

6. Conclusion

We investigated the influence of supply disruptions on the design of split-award auctions and showed that increasing the number of contract suppliers does not only reduce the risk of supply disruptions but might also lower prices. The reason is that increasing the number of contract suppliers makes bidders' outside option less attractive and can thereby foster competition. Multi-sourcing is likely to decrease prices in competitive settings in which the buyer's valuation for the good is large. Even if the pro-competitive effect of multi-sourcing does not dominate and decrease prices, multi-sourcing might still minimize the buyer's costs. From this point of view, our study highlights the benefits of multi-sourcing.

Furthermore, we show that heterogeneity among suppliers with regard to their individual disruption probabilities causes an adverse selection problem in the procurement auction. Less reliable suppliers have an incentive to bid more aggressively than their more reliable competitors. As a consequence, unreliable suppliers win inefficiently often. The adverse selection effect also implies that attracting an additional (unreliable) supplier might actually increase the auction price and the buyer's expenses. This highlights the importance of screening and qualification measures taken by the buyer.

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Appendix

Proof of Proposition 1

We have to prove that for all $\delta \in (0,1)$ and all $0 < k < n$ it holds that

$$\frac{\partial r}{\partial k} < 0$$

$$\Leftrightarrow n \cdot (\delta^k - \delta^n) \cdot (1 - \delta^k) + k \cdot (n-k) \cdot \delta^k \cdot (1-\delta^n) \cdot \ln \delta < 0. \tag{5}$$

We denote the LHS of (5) as z, i.e.,

$$z := n \cdot (\delta^k - \delta^n) \cdot (1 - \delta^k) + k \cdot (n-k) \cdot \delta^k \cdot (1-\delta^n) \cdot \ln \delta. \tag{6}$$

Lemma 1. $\lim_{k\to 0+} z = \lim_{k \to n-} z = 0$

Proof.

$$\lim_{k\to 0+} z = n \cdot (1-\delta^n) \cdot 0 + 0 \cdot (n-0) \cdot (1-\delta^n) \cdot \ln \delta = 0$$
$$\lim_{k\to n-} z = n \cdot 0 \cdot (1-\delta^n) + n \cdot 0 \cdot \delta^n \cdot (1-\delta^n) \cdot \ln \delta = 0$$

□

In the following we show that z is decreasing in k for small values of k and then increasing in k for all larger values of $k < n$. Together with Lemma 1 this implies that $\partial r / \partial k$ is negative for all $0 < k < n$. We now take the derivative of z with respect to k and define

$$\begin{aligned} y := & \frac{\partial z}{\partial k} \cdot \frac{1}{\delta^k \cdot \ln \delta} \\ = & n \cdot (\delta^k - \delta^n) \cdot (1 - \delta^k) + k \cdot (n-k) \cdot \delta^k \cdot (1-\delta^n) \cdot \ln \delta. \end{aligned} \tag{7}$$

Note that $\delta^k \cdot \ln \delta < 0$, hence $sign\,[\partial z / \partial k] = sign\,[-y]$. To prove that y is positive for small values of k and then negative for all larger values of $k < n$, we calculate the following derivatives

$$\frac{\partial y}{\partial k} = 2 \cdot \delta^n - 2 + \ln \delta \cdot \left[(n - 2 \cdot k) \cdot (1 - \delta^n) - 2 \cdot n \cdot \delta^k \right], \tag{8}$$
$$\frac{\partial^2 y}{\partial k^2} = -2 \cdot \ln \delta \cdot (1 - \delta^n + n \cdot \delta^k \cdot \ln \delta), \tag{9}$$
$$\frac{\partial^3 y}{\partial k^3} = -2 \cdot n \cdot \delta^k \cdot (\ln \delta)^3 > 0. \tag{10}$$

Using (8) we show that our claim holds at the boundaries.

Lemma 2. $\lim_{k\to 0+} \partial y / \partial k = \lim_{k \to n-} \partial y / \partial k > 0$

Proof.

$$\lim_{k\to 0+} \partial y / \partial k = \lim_{k \to n-} \partial y / \partial k = 2 \cdot \delta^n - 2 + \ln \delta \cdot [n \cdot (1 - \delta^n) - 2 \cdot n] \tag{11}$$

Let w denote the RHS of (11) with

$$\partial w/\partial n = -\ln\delta\cdot(1-\delta^n + n\cdot\delta^n\cdot\ln\delta),$$
$$\partial^2 w/\partial n^2 = -n\cdot\delta^n\cdot(\ln\delta)^3 > 0.$$

Since $\partial w/\partial n$ is increasing in n, it only remains to check that

$$\lim_{n\to 0+}\partial w/\partial n = -\ln\delta\cdot(1-1+0\cdot 1\cdot\ln\delta) = 0.$$

□

Note that (9) is strictly increasing in k and only equal to zero for $k_0 = \log_\delta\left(-\frac{1-\delta^n}{n\cdot\ln\delta}\right)$. Hence, $\partial y/\partial k$ reaches a (local) maximum at k_0. To complete the proof we prove the following lemmas.

Lemma 3. $0 < k_0 < n$

Proof.

$$0 < k_0$$
$$\Leftrightarrow 0 > 1-\delta^n + n\cdot\ln\delta \tag{12}$$

Let t denote the RHS of (12) and observe the following

$$\lim_{n\to 0+} t = 0$$
$$\partial t/\partial n = \ln\delta\cdot(1-\delta^n) < 0$$

Hence, $k_0 > 0$.

$$k_0 < n$$
$$\Leftrightarrow 1-\delta^n + \delta^n\cdot n\cdot\ln\delta > 0 \tag{13}$$

Let s denote the LHS of (13) and observe the following

$$\lim_{n\to 0+} s = 0$$
$$\partial s/\partial n = n\cdot\delta^n\cdot(\ln\delta)^2 > 0$$

Hence, $k_0 < n$.

Lemma 4. $\frac{\partial y(k_0)}{\partial k} < 0$

Proof.

$$
\begin{aligned}
\frac{\partial y(k_0)}{\partial k} &= \ln\delta \cdot (1-\delta^n)\cdot(n-2\cdot k_0) < 0 \\
&\Leftrightarrow 1-\delta^n + n\cdot\delta^{n/2}\cdot\ln\delta > 0
\end{aligned} \tag{14}
$$

Let o denote the RHS of (14) and observe the following

$$
\begin{aligned}
&\lim_{n\to 0+} o = 0 \\
&\partial o/\partial n = -\delta^{n/2}\cdot\ln\delta\cdot(1-\delta^{n/2} - \frac{n\cdot\ln\delta}{2} > 0
\end{aligned}
$$

This proves the lemma and completes the proof of Proposition 1. □

Proof of Proposition 2

A buyer who faces n suppliers and awards k contracts expects a price of

$$E[p(k,n)] = [1-r(k,n)]\cdot E[c^{(k+1,n)}] + r(k,n)\cdot v.$$

Hence, for single-sourcing it holds that

$$E[p(1,n)] = [1-r(1,n)]\cdot E[c^{(2,n)}] + r(1,n)\cdot v$$

and for dual-sourcing it holds that

$$E[p(2,n)] = [1-r(2,n)]\cdot E[c^{(3,n)}] + r(2,n)\cdot v.$$

Furthermore, Proposition 1 implies that $r(2,n) < r(1,n)$. Both the single-sourcing price and the dual-sourcing price a linearly increasing in the buyer's valuation v with $r(1,n)$ and $r(2,n)$ being the slopes, respectively. Since $r(2,n) < r(1,n)$ there must exist a $\bar{v}$ such that $E[p(1,n)] > E[p(2,n)]$ for all $n > \bar{v}$. □

Proof of Proposition 3

Consider a setting with n suppliers and k contracts. There is one supplier with high disruption probability δ_h, one supplier with a low disruption probability δ_l, and the remaining $n-2$ suppliers have a disruption probability of δ.

First, we analyze the case in which supplier l will be a contract supplier independent of supplier h's bid. In this case the expected profit of supplier h when being a contract supplier is given by

$$\Pi_c^h = (1-\delta_h)\cdot(p-c_i)\cdot\Bigg[[\delta_l\cdot\overbrace{\sum_{f=0}^{k-2}\frac{1}{k-f-1}\cdot\binom{k-2}{f}\cdot\delta^f\cdot(1-\delta)^{k-2-f}}^{X_1}$$

$$\underbrace{+ (1-\delta_l) \cdot \sum_{f=0}^{k-2} \frac{1}{k-f} \cdot \binom{k-2}{f} \cdot \delta^f \cdot (1-\delta)^{k-2-f} \Bigg]}_{Y_1}. \qquad (15)$$

The expected profit of supplier h when being a non-contract supplier is given by

$$\Pi_n^h = (1-\delta_h) \cdot (v - c_i) \cdot \delta_l \cdot \delta^{k-1} \cdot \overbrace{\sum_{f=0}^{n-k-1} \frac{1}{n-k-f} \cdot \binom{n-k-1}{f} \cdot \delta^f \cdot (1-\delta)^{n-k-1-f}}^{Z_1} .. \qquad (16)$$

Combining (15) and (16) shows that supplier h will bid more aggressively if δ_l decreases. Due to symmetry this implies that bidder h bids more aggressively than bidder l if $\delta_h > \delta_l$.

Second, we analyze the case in which supplier l will be a non-contract supplier independent of supplier h's bid. In this case the expected profit of supplier h when being a contract supplier is given by

$$\Pi_c^h = (1-\delta_h) \cdot (p - c_i) \cdot \overbrace{\sum_{f=0}^{k-1} \frac{1}{k-f} \cdot \binom{k-1}{f} \cdot \delta^f \cdot (1-\delta)^{k-1-f}}^{X_2} . \qquad (17)$$

The expected profit of supplier h when being a non-contract supplier is given by

$$\Pi_n^h = (1-\delta_h) \cdot (v - c_i) \cdot \delta^k \cdot \Bigg[\delta_l \cdot \overbrace{\sum_{f=0}^{n-k-2} \frac{1}{n-k-1-f} \cdot \binom{n-k-2}{f} \cdot \delta^f \cdot (1-\delta)^{n-k-2-f}}^{Y_2}$$
$$+(1-\delta_l) \cdot \underbrace{\sum_{f=0}^{n-k-2} \frac{1}{n-k-f} \cdot \binom{n-k-2}{f} \cdot \delta^f \cdot (1-\delta)^{n-k-2-f}}_{Z_2} \Bigg]. \qquad (18)$$

Combining (17) and (18) again implies that suppliers bid more aggressively if their competitors become more reliable. Hence, bidder h bids more aggressively than bidder l if $\delta_h > \delta_l$.

Finally, we consider the case in which supplier l will be a contract supplier if supplier h is not a contract supplier and vice versa supplier l is no contract supplier if supplier

h is a contract supplier. In this case the expected profit of supplier h when being a contract supplier is given by

$$\Pi_c^h = (1-\delta_h)\cdot(p-c_i)\cdot \overbrace{\sum_{f=0}^{k-1}\frac{1}{k-f}\cdot\binom{k-1}{f}\cdot\delta^f\cdot(1-\delta)^{k-1-f}}^{X_3}. \tag{19}$$

The expected profit of supplier h when being a non-contract supplier is given by

$$\Pi_n^h = (1-\delta_h)\cdot(v-c_i)\cdot\delta_l\cdot\delta^{k-1}\cdot \overbrace{\sum_{f=0}^{n-k-1}\frac{1}{n-k-f}\cdot\binom{n-k-1}{f}\cdot\delta^f\cdot(1-\delta)^{n-k-1-f}}^{Y_3}. \tag{20}$$

Combining (19) and (20) implies that also in this case more reliable suppliers bid less aggressively than their less reliable competitors which completes the proof. Note that $X_1, X_2, X_3, Y_1, Y_2, Y_3, Z_1$, and Z_2 do not differ between supplier l and supplier h. This implies that the result does not depend on the homogeneity of the $n-2$ other suppliers. □

References

Anton JJ, Brusco S, Lopomo G (2010) Split-award procurement auctions with uncertain scale economies: Theory and data. *Games and Economic Behavior* 69(1):24–41.

Babich V, Burnetas AN, Ritchken PH (2007) Competition and diversification effects in supply chains with supplier default risk. *Manufacturing & Service Operations Management* 9(2):123–146.

Bauer C, Jahn R, Hunold M, Hüschelrath K, Kotschedoff M, Laitenberger U, Lux G, May U, Walendzik A, Wasem J, Weegen L (2014) Auswirkungen von rabattvertragsausschreibungen auf die generikaindustrie in deutschland. *Project report to the German Ministry of Economics and Technology (BMWi)* .

Boonen LHHM, van der Geest SA, Schut FT, Varkevisser M (2010) Pharmaceutical policy in the netherlands: from price regulation towards managed competition. *Pharmaceutical Markets and Insurance Worldwide* 53–76, ISSN 0731-2199.

Bru L, Cardona D, Sákovics J (2018) Block sourcing.

Chaturvedi A (2015) Procurement auctions with capacity constrained suppliers. *European Journal of Operational Research* 247(3):987–995.

Chaturvedi A, Beil DR, Martinez-de Albeniz V (2014) Split-award auctions for supplier retention. *Management Science* 60(7):1719–1737, ISSN 0025-1909.

Chaturvedi A, Katok E, Beil DR (2018) Split-award auctions: Insights from theory and experiments. *Management Science* ISSN 0025-1909.

Chaturvedi A, Martínez-de Albéniz V (2011) Optimal procurement design in the presence of supply risk. *Manufacturing & Service operations management* 13(2):227–243.

Che YK (1993) Design competition through multidimensional auctions. *RAND Journal of Economics* 24(4):668–680.

Dasgupta S, Spulber DF (1989) Managing procurement auctions. *Information Economics and Policy* 4(1):5–29, ISSN 0167-6245.

Engelbrecht-Wiggans R (1988) Revenue equivalence in multi-object auctions. *Economics Letters* 26(1):15–19, ISSN 0165-1765.

Food and Drug Administration (2011) A review of fda's approach to medical product shortages. *FDA Report* 31.

Gerlach F, Greiner W, Haubitz M, Schaeffer D, Thürmann P, Thüsing G, Wille E (2014) Bedarfsgerechte versorgung-perspektiven für ländliche regionen und ausgewählte leistungsbereiche. *Sachverständigenrat zur Begutachtung der Entwicklung im Gesundheitswesen, Gutachten* .

Gong J, Li J, McAfee RP (2012) Split-award contracts with investment. *Journal of Public Economics* 96(1-2):188–197.

Hollis A, Grootendorst P (2012) Tendering generic drugs: What are the risks? *Paper commissioned by the Canadian Generic Pharmaceutical Association* .

Institut I (2019) Nichtverfügbarkeit von rabattierten arzneimitteln - ergebnispräsentation - berlin, 19. november 2019. Technical report, URL https://www.iges.com/kunden/gesundheit/forschungsergebnisse/2019/rabattvertraege/index_ger.html.

IQVIA (2019) The global use of medicine in 2019 and outlook to 2023. Technical report, URL https://www.iqvia.com/insights/the-iqvia-institute/reports/the-global-use-of-medicine-in-2019-and-outlook-to-2023.

Klotz DE, Chatterjee K (1995) Variable split awards in a single-stage procurement model. *Group Decision and Negotiation* 4(4):295–310, ISSN 0926-2644.

Kokott GM, Bichler M, Paulsen P (2019a) The beauty of dutch: Ex-post split-award auctions in procurement markets with diseconomies of scale. *European Journal of Operational Research* 278(1):202–210.

Kokott GM, Bichler M, Paulsen P (2019b) First-price split-award auctions in procurement markets with economies of scale: An experimental study. *Production and Operations Management* 28(3):721–739.

Krishna V (2009) *Auction theory* (Academic press).

Perry MK, Sákovics J (2003) Auctions for split-award contracts. *Journal of Industrial Economics* 51(2):215–242, ISSN 1467-6451.

Progenerika (2019) Generika in zahlen 2019 - daten fakten analysen - so sichern generika die arzneimittelversorgung. Technical report, URL https://www.progenerika.de/download/Generika-in-Zahlen-2019_ES_2.pdf.

Seshadri S, Chatterjee K, Lilien GL (1991) Multiple source procurement competitions. *Marketing Science* 10(3):246–263, ISSN 0732-2399.

Wambach A (2002) A simple result for the revenue in share auctions. *Economics letters* 75(3):405–408, ISSN 0165-1765.

Wilson R (1979) Auctions of shares. *The Quarterly Journal of Economics* 675–689, ISSN 0033-5533.

Yang Z, Aydın G, Babich V, Beil DR (2012) Using a dual-sourcing option in the presence of asymmetric information about supplier reliability: Competition vs. diversification. *Manufacturing & Service Operations Management* 14(2):202–217.

Yu H, Zeng AZ, Zhao L (2009) Single or dual sourcing: decision-making in the presence of supply chain disruption risks. *Omega* 37(4):788–800.

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