# Block sourcing plus

**Citation for published version:**
Sakovics, J, Cardona, D & Bru, L 2023, 'Block sourcing plus', *European Journal of Operational Research*, vol. 305, no. 3, pp. 1130-1140. https://doi.org/10.1016/j.ejor.2022.06.039

**Digital Object Identifier (DOI):**
10.1016/j.ejor.2022.06.039



**Published In:**
European Journal of Operational Research

European Journal of Operational Research 305 (2023) 1130–1140

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing, Transportation and Logistics

# Block sourcing plus☆

Lluís Bru[a], Daniel Cardona[a], József Sákovics[b,*]

[a] Universitat de les Illes Balears, Spain
[b] Universitat de les Illes Balears, Spain and The University of Edinburgh, UK

ARTICLE INFO

*Article history:*
Received 9 November 2021
Accepted 19 June 2022
Available online 27 June 2022

*JEL classification:*
D42
D44
L12

*Keywords:*
Supply chain management
Multi-sourcing
Split-award auction
Two-stage procurement

ABSTRACT

We study how a buyer unable to (directly) price discriminate should satisfy his demand for a divisible good, produced with increasing marginal cost. As expected, we find that dynamic pricing cannot, while auctioning contracts for lots (*block sourcing*) need not, lead to a higher buyer surplus than setting a price (classical monopsony). However, we show that the optimal combination of block sourcing with setting a price for the residual supply is always strictly superior. Thus, we provide a rationale for two-stage contracting even in the absence of uncertainty.



## 1. Introduction

Auctions are the primary vehicle to procure goods and services in large companies. In fact, for their role in mitigating the potential for corruption and promoting efficiency, they are often a legal requirement for procurement in public institutions. In this paper, we investigate the somewhat understudied – but nonetheless empirically relevant – case of suppliers (the bidders in our auction) with increasing marginal costs. Diseconomies of scale are wide-spread in many industries, due to capacity constraints, input scarcity or other organizational and production reasons. For example, Jofre-Bonet & Pesendorfer (2003) study procurement auctions for highway construction contracts of the State of California between 1996 and 1999. Their estimates show that firms with higher capacity utilization experience a first-order stochastic dominance shift in their cost distributions compared with less constrained firms. Similarly, De Silva, Dunne, & Kosmopoulou (2002; 2003) find empirical evidence that firms with greater backlogs bid higher prices in procurement auctions. Convex costs also appear in the provision of services. Bel & Sebő (2020) discuss the existing evidence for waste collection, that suggests that returns to scale are fully exhausted at volumes corresponding to between 25,000 and 50,000 inhabitants. For bus routes in London, Cantillon & Pesendorfer (2007) show that the technology of operating bus routes exhibits decreasing returns to scale.

Diseconomies in scale have an outstanding feature: it is efficient – in the sense of minimising aggregate production costs – to multi-source and, therefore, a buyer is likely looking for multiple winners, potentially leading to a split-award (reverse) auction (SAA). In contrast, in the standard set-up studied in the literature there are no diseconomies of scale. Consequently, the efficient outcome would be single sourcing, and SAA is presented as a superior alternative: *splitting* up the requirements, for reasons like reducing sellers' rents or assuring supply in the presence of idiosyncratic shocks. With increasing marginal costs, our insight is that the buyer wants to *group* his demand into larger blocks than would result from production cost minimisation. To emphasise this distinction, we refer to these auctions as *block sourcing* (BS).

Specifically, we consider the buyer of a divisible homogeneous good. He can choose among combinations of setting either a price or quantities: As any monopsonist, he can set a *price* per unit at which he commits to buy any quantity from any seller. For obvious reasons, we will refer this mechanism as classical monopsony (CM). In addition, he can also purchase (part of) his requirements

☆ We thank three anonymous referees, Roberto Burguet, Gianni De Fraja, Ed Hopkins, Carmen Matutes, Ina Taneva, Mike Waterson and the audiences at EARIE 2018, Jornadas de Economía Industrial 2018, Simposio de Análisis Económico 2018 and of seminars at UIB and UoE for their comments. Financial support from the Spanish government through grants PID2019-107833GB-I00 MCIN/AEI/10.13039/501100011033, PID2020-115018RB-C33 and BG20/00079, and from the ESRC through grant ES/N00776X/1 is gratefully acknowledged.

* Corresponding author.
*E-mail addresses:* lluis.bru@uib.cat (L. Bru), d.cardona@uib.cat (D. Cardona), j.sakovics@uib.eu (J. Sákovics).

https://doi.org/10.1016/j.ejor.2022.06.039
0377-2217/

by block sourcing (auctioning block orders for suitably set lot *quantities*).[1]

The aggregation of purchases into blocks, with a separate tender for each lot, is used both in public and private procurement when products are physically or functionally homogeneous (Grimm, Pacini, Spagnolo, & Zanza, 2006). An important example is health provision, where 'BS' is observed in the public procurement of pharmaceutical drugs (see the discussion in Fugger & Laitenberger 2020), medical devices (Bucciol, Camboni, & Valbonesi, 2020), etc. Public authorities also use 'BS' to award contracts for services. Examples include bus transport provision in the city of London, where the bus routes are grouped into lots (see Cantillon & Pesendorfer, 2006; Iossa & Waterson, 2019) and waste collection in Barcelona, where the city has been divided in four exclusive waste collection zones, and the provision of each zone has been awarded by means of 'BS' to private firms (see Bel & Sebő, 2020).

In addition to the use of BS, sometimes public authorities set a regulated price for quantities procured outside the auction. This is standard practice for generic pharmaceutical drugs in many European countries. Fugger & Laitenberger (2020) and references therein discuss cases in Germany.[2] In Canada, the Patented Medicine Prices Review Board (PMPRB) regulates the prices of patented medicines sold in Canada. Procurement of patented drugs can also be organized through lots plus regulated prices if there are other patented or generic drugs that can be used as substitutes. Consider the example of COVID-19 vaccines developed by Moderna, Janssen, and Pfizer–BioNTech, that provide similar acquired immunity against SARS-CoV-2 and that have been used by health authorities as interchangeable. As it became evident during the pandemic, pharmaceuticals also suffer from difficulties in increasing production on short notice, consistent with our assumption of increasing marginal costs.

Our first new insight relates to the profitability for the buyer to open an "aftermarket" once the auction has taken place. As we know since the contributions of Coase (1972) and Stokey (1979), normally it is not possible to increase the monopsony profit by dynamic pricing: since the price in the residual market would have to be higher than the original price – as (theoretically) all supply at the original price has been exhausted – the suppliers would prefer to wait for that price rather than selling for the original one, and thus the market would unravel. We find that this classical insight is not robust: unlike following price setting, after BS there *is* room for a residual market.

To see this, note that BS separates the suppliers into two groups: winners and losers. Importantly, as they have already committed to produce the lot they have won, in the residual market the winners have higher marginal costs than the losers. As a result, the buyer can set a residual market price that is *lower* (recall that, in the classic set-up above, it had to be higher in order to generate trade) than the per-unit price paid to the winners – so that they are not tempted to give up on the lot auction – and is still able to buy from the losers. We call this buying method *block sourcing plus* (BSP).

From the buyer's point of view, monopsony pricing has the unwanted feature that – as marginal cost is increasing – each supplier makes a profit. He can extract all the supplier profit by excluding some of them from BS: auctioning fewer lots than the number of suppliers. He needs to trade off these gains against the losses from the inefficient allocation of production, as with increasing marginal costs it is inefficient to leave any supplier out of production. Whether BS can improve on CM depends on the number of suppliers. If there are many, the resulting inefficiency will be small, while the profits extracted can still be sizeable. On the other hand, if there are only two suppliers, single sourcing can lead to a large loss of productive efficiency relative to double sourcing, not necessarily compensated for by the extraction of the supplier profit.

Complementing BS with a price in the residual market (that is, BSP), however, turns out to be always superior: the buyer employs all the sellers, but still can squeeze their profit. Of course, the reopening of the market reduces the intensity of competition in the auction, but the buyer is able to manage this to his advantage. To see this, note that how keen a supplier is to obtain a block contract depends on her inside option: the profit she can expect to make in the residual market.

Suppose that the buyer sets some lots that are equal to the per-firm monopsony quantity. Then, if he were to set a price in the residual market after the auction has taken place, he would set the same monopsony price as in CM, leading to the same overall profit. Note that the optimal price in the residual market exactly balances the marginal gain in utility from the extra units purchased (in that market) with the marginal increase of the payment for the inframarginal units bought from the "losers"– as the result of a marginal price increase. Compare this to the case where the buyer can commit to the residual market price prior to the auction. The gain from a marginal price increase stays the same, while the marginal increase in payment now includes not only the losers' increased profit but, additionally, the profit increase of the "winners" who – in the knowledge of a higher inside option, will bid less aggressively (asking for a higher price). This implies that with *ex ante* price setting the buyer optimally commits to a strictly lower price in the residual market than in CM and thereby increases his overall profit above the CM one.

Note that for the above result we simply took the lot sizes as given by the quantities sold in CM. If the buyer chooses the lot sizes optimally, we obtain an even stronger result: BSP is superior even in the – arguably more realistic – case where the buyer is unable to commit to the residual market price before the auction. The lack of commitment power implies that he is bound to set the monopsony price corresponding to the residual supply and demand, which is higher than the price he would prefer to set taking into account its effect on the bidding behavior in the auction. Nevertheless, we show that by reducing his residual demand via increasing the lot sizes, he can always improve his payoff over that of CM.

In the next subsection we position our results in the related literature. In Section 2 we present our model, followed by – in Section 3 – the derivation and characterization of our main results. In Section 4 we check the robustness of our results to heterogeneity of cost functions and asymmetric information. Section 5 contains some concluding remarks. We present the omitted proofs in an appendix.

### 1.1. Related literature

Few of the studies on split-award auctions consider diseconomies of scale in the suppliers' technology. The seminal paper along this line of research is Anton & Yao (1989). In their model, the sellers have complete information on their rival's costs and the way the award is split is endogenous: sellers submit bids for different possible splits of the whole requirement of the buyer. In this

[1] Note that the unconstrained optimal mechanism would be for the buyer to control both price *and* quantity by making a take-it-or-leave-it offer to each supplier for the efficient quantity, leaving them zero profits. Equivalently, he could use two-part tariffs. Motivated by the widespread existence of cultural, legal, and reputational constraints, we maintain that such non-linear pricing ("direct" price discrimination) is not feasible, just as in the benchmark case of CM. By the same token, we do not allow our buyer to collect an entry fee – or set a reserve price – to the auction, as then he could reproduce the above result by setting the efficient lots, circumventing competition, the very thing we wish to analyse.

[2] For the Netherlands, see https://www.government.nl/topics/medicines/keeping-medicines-affordable.

set-up, sellers can collude in an equilibrium that involves the efficient split; this collusive bidding leads to the striking result that the buyer will prefer to auction off a sole-sourcing contract, where total production costs increase but sellers rents are completely dissipated.

Later papers have put these results into perspective. If suppliers have private cost information, Anton & Yao (1992) show that the buyer can benefit from a split-award format when suppliers have relatively poor information regarding each other's costs, because bidding collusion is much reduced. Inderst (2008) qualifies Anton & Yao (1989) by pointing out that, when there is more than one buyer, single sourcing results if and only if the buyer controls a sufficiently large share of the market. The intuition is that single sourcing would increase competition among suppliers only when the alternative to winning is bad enough (that is, the residual demand is low). Otherwise, because of convex costs, the losing supplier will be able to obtain a large share of the residual demand and therefore she will require more for the sole-sourcing contract. In our model the buyer can auction a single lot and can buy from the losing supplier in the residual market.

Another strand of the literature has explored other motivations, beyond reducing current procurement costs, that may lead the buyer to use a split-award auction instead of sole-sourcing when there are diseconomies of scale. Gong et al. (2012) show that split-award auctions improve sellers incentives to invest in cost-reduction, while in Anton, Biglaiser, & Vettas (2014) one advantage of splitting orders is to preserve competition for future orders. Likewise, Saini (2012) shows that scheduling frequent auctions for small lots increases future competition; and Iossa, Rey, & Waterson (2022) analyze the best schedule of split-award auctions to preserve competition in a dynamic framework.

Both Saini (2012) and Iossa et al. (2022) recommend the use of small lots in procurement (the recommendation already appears in Grimm et al. (2006); see also the discussion in Iossa & Waterson (2019)). Indeed, also the results in Burguet & Sákovics (2017) and Bru & Cardona (2016) show that a reduction in the size of lots (where every seller obtains in equilibrium many lots) reduces bidding collusion, and, in the limit as lots become infinitesimal, leads to the competitive outcome. In Bru & Cardona (2016) it is also shown that a proper combination of large and small lots can improve upon the competitive outcome; whether it improves upon sole-sourcing (or, more generally, upon leaving some supplier without any lot) depends on the details of the cost function.

What we show below is that if we replace the small lots in Bru & Cardona (2016) with a price in the combination with large lots, procurement costs are always lower than those under sole-sourcing. Compared with the combination of large and small lots, a price allows to overcome the lack of competitive pressure from suppliers that win large lots in the auction on those without lots, and translates both into a reduction of the bids, and to an improved allocation of production among suppliers.

Finally, in Fugger & Laitenberger (2020) a buyer is forced to use a procurement auction and a price at the same time because suppliers may fail to deliver or because there is an unexpected increase in demand. They show that multi-sourcing may prevail over sole-sourcing as it reduces this risk of supply disruption. The failures in vaccine production has made us fully aware that supply disruption is a real possibility. Nonetheless, in this paper, we show that the price is also, as we state above, a way to control for a lack of competition once some firms already are committed to produce a lot, and this is the case even if, as in their analysis, prices are set in a second stage, after the lots have been procured.

*Alternative modelling approaches that also have a similar structure*

Alcalde & Dahm (2013; 2019) have analyzed the performance of share auctions, split-award auctions in which lot size is endogenous: a lower bid than those of the rivals leads to a larger share of production but not to the right to all the production. In their model, there are economies instead of diseconomies of scale; thus, production costs are minimized with sole sourcing from the most efficient supplier. Nonetheless, strikingly, they show that an endogenously split-award auction forces the efficient supplier to bid lower prices and, as a consequence, properly calibrated shares reduce overall procurement costs. It is not clear to us what their share auction mechanism may imply in the presence of diseconomies of scale.

It is important to note that our two-stage process is qualitatively different from other mechanisms where there is also a first-stage auction followed by additional interaction (see, for example, Tunca & Wu (2009)). In our case, the second stage involves the loser, while in the preselection models it is the winners who earn the right to participate in the final round.

There is also a growing literature, starting with Wu, Kleindorfer, & Zhang (2002),[3] that analyzes a two-stage procurement process where in the first stage suppliers bid capacities, and the buyer decides how much of these options to convert, once the (exogenous) spot price is realized. The main difference is that in our case the buyer sets the lot sizes, which in turn directly affect the (endogenous, and thus non-stochastic) spot price.

Finally, Biancalani, Gnecco, & Riccaboni (2022) analyse the use of price-volume agreements in a one buyer, two sellers model. These agreements are a soft cap on the amount transacted, and are shown to be beneficial to the buyer (when marginal costs are constant). In contrast, in our model the important constraint on the volume traded is from below: suppliers are not allowed to supply less than the lot they obtain.

## 2. The model

We consider $n > 1$ identical suppliers producing an infinitely divisible homogeneous good with a strictly increasing, strictly convex and thrice differentiable cost function $c(x)$, with $c(0) = c'(0) = 0$.[4] There is a single buyer, with a twice continuously differentiable, quasi-linear vNM utility function, $V(x, y) = U(x) + y$ – where $y$ is a numeraire interpreted as "wealth" – with $U'(x) > 0$, $U''(x) < 0$ for $x \in [0, 1)$, with the normalization $U'(1) = 0$. That is, the maximal demand is 1, the buyer has no use for additional units. The cost and utility functions, as well as $n$, are common knowledge. Before describing the interaction between buyer and suppliers, let us justify our main assumptions. We consider that the number of suppliers is known (both to the buyer and to the suppliers). This is indeed the case in many applications where either there is a long-term relationship, or there is a pre-auction interaction, where the buyer clarifies his requirements and/or the sellers explain the strong points of their product. Chiefly, however, it greatly simplifies the analysis, still allowing for the identification of the main forces shaping the buyer's choices. Identical suppliers are assumed for clarity's sake. We investigate the potential effects of cost differences in Section 4. We also assume that marginal costs are strictly increasing. This is a generic way of modelling soft capacity constraints – like paying overtime, hiring extra equipment, buying input in the last minute etc. – present in most industries.

We study a two-stage procurement game, starting with an auction stage, followed by a market stage. At the beginning, the buyer announces $m \in \{0, 1, \dots, n-1\}$ contracts for (indivisible) lot sizes $z_1 \geq \dots \geq z_m$, with $\sum_{i=1}^{m} z_i = Z$ and $\mathbf{z} = (z_1, \dots, z_m)$. Next, these

[3] See also, Hazra & Mahadevan (2009); Kleindorfer & Wu (2003); Wu & Kleindorfer (2005) and Zhao, Choi, Cheng, & Wang (2018), among others.

[4] To ensure that second-order conditions for optimality are globally satisfied in classical monopsony, we make the standard assumption that $nc'''(x)x + (n+1)c''(x) > 0$ for $x \in (0, 1]$.

contracts are assigned to suppliers in a sequence of first(lowest)-price sealed-bid auctions, in decreasing order of size. To simplify the assignment of lots among suppliers (who make the same bids in equilibrium), we assume that – as standard in actual multi-sourcing arrangements – each supplier can win at most one block contract, and therefore she does not participate in the remaining auctions once she has won a lot. Following the lot auctions, the buyer has the option to open a residual market, setting a (unit) price $p^r$ at which each supplier (whether or not they have won a block contract) can make further sales of the quantity they choose. We will analyze the cases where the buyer commits to this price before (strong commitment) or after (weak commitment) the auctions, separately. Note that not setting any lot corresponds to classical monopsony, while not buying in the residual market is the same as setting $p^r = 0$.

## 3. Results

Our first observation is that – since all suppliers are identical – in equilibrium it must be the case that a seller who does not win a lot earns the same profit as any of the lot winners.[5] Basically, the auction and the residual market serve as inside options for the suppliers, enforcing indifference in equilibrium. Denote the profits of each supplier that only sells in the residual market – where they sell $c'^{-1}(p^r)$, the quantity that equates their marginal cost to this price – by $\pi(p^r) = p^r c'^{-1}(p^r) - c\left(c'^{-1}(p^r)\right)$.

**Lemma 1.** *Given any* $\mathbf{z}$ *and* $p^r \geq 0$*, the equilibrium profit of every supplier is equal to* $\pi(p^r)$*.*

**Proof.** See the Appendix. □

This result points to the important linkage between the lot auction and the residual market. The lemma implies that – conditional on the lot sizes – the market for the residual demand determines the bids in the lot auction and, therefore, all the payoffs. This interconnection is what the buyer exploits when choosing his lot policy.

Our next observation is that the buyer's optimal policy sets lots in a way that the lot winners are effectively priced out of the residual market – due to their high (interim) marginal costs.[6]

**Lemma 2.** *Given the optimal* $p^r$ *for* $\mathbf{z}$*, removing any lot* $z_j$ *such that* $c'(z_j) \leq p^r$ *does not alter the equilibrium payoffs.*

**Proof.** See the Appendix. □

The logic of this result is simple: if a lot winner participated (selling $q'$ additional units) in the residual market – joining at least one loser (selling $q$ units) – then, in equilibrium, marginal costs would equalize, $c'(z_i + q') = c'(q) \Rightarrow z_i + q' = q$, leading to the same quantities and buyer surplus as if the lot won had not been offered.

**Remark 1.** The larger the inside option (represented by the residual market), the larger is the minimum size of a lot that can make a difference. This puts into perspective the result of Inderst (2008), that buyer competition makes single-sourcing (setting one lot, with no aftermarket) less likely: If there were additional buyers, then our buyer would have to increase his price in the residual market, and then he would have to increase his lot size to make a difference. As that increase would worsen the productive inefficiency, he would be less inclined to set lots than when he is in a monopsony position. Put another way, when the buyer has competition, he has less control over the supplier profits, so while setting lots has the same inefficiency cost, its effect on decreasing supplier rents is weaker.

Given Lemma 2, we can assume without loss that in the optimal lot policy all $m$ lot winners are "priced out" of the residual market. That is,

$$c'(z_i) \geq p^r,\ i = 1, \dots, m. \tag{1}$$

We are now ready to turn to the derivation of the buyer's optimal Block Sourcing Plus policy. There are two cases to consider, based on whether the buyer can commit to the residual market price at the beginning of the game or he is bound to behave sequentially rationally – and therefore not factoring in the effect of $p^r$ on the lot prices –, given the residual demand/supply following the lot auctions. As the next proposition shows, both cases lead to the same optimal number of lots: a single supplier will be left without.

**Proposition 1.** *It is strictly optimal to set* $n-1$ *identical lots. Consequently, Block Sourcing Plus strictly increases buyer surplus over classical monopsony.*

**Proof.** See the Appendix. □

Note that this result has no additional preconditions: it holds for all cost and demand functions that satisfy our initial assumptions. The fact that the lots need to be equal follows from the fact that the supplier profits only depend on the aggregate size of the lots ($Z$) – via the residual demand – and, therefore, the buyer can afford to set the lot sizes efficiently. The logic for setting $n-1$ lots harks back to Lemma 2: Suppose the buyer has set fewer lots (possibly zero as in CM). Now, consider setting an additional lot of the same size as the quantity sold by the lotless suppliers in the residual market. By Lemma 2, the outcome will remain the same. However, the incentives to set the sizes of the lots and the residual market price do change with this reshuffling: In the case of strong commitment, the buyer will now prefer to further reduce the residual market price (as it now decreases his residual market purchases by less); while with weak commitment the buyer will prefer to increase the size of the new lot slightly (as decreasing his demand in the residual market is less costly than before).[7]

The optimal lot size – and, of course, the residual market price – does depend on the timing of commitment, as stated in the next propositions.[8]

**Proposition 2** (Strong Commitment (SC))**.** *If the buyer can commit to the price for the residual market before the lot auction, the optimal price is* $p^{SC} = c'(q^{SC})$*, where the quantity bought from the loser,* $q^{SC}$*, and the optimal size of the* $n-1$ *lots,* $z^{SC}$*, uniquely solve*

$$U'((n-1)z + q) = c'(q) + nqc''(q), \tag{2}$$

$$U'((n-1)z + q) = c'(z). \tag{3}$$

**Proof.** By Proposition 1, we know that there will be $n-1$ identical lots. Thus, the buyer's objective function is

$$\begin{aligned} &U((n-1)z + q) - (n-1)c(z) - c(q) - n(qc'(q) - c(q)) \\ &= U((n-1)z + q) - (n-1)(c(z) - c(q)) - nqc'(q), \end{aligned} \tag{4}$$

where, to calculate the total cost, we have used the fact that by Lemma 1, each supplier's profit is $qc'(q) - c(q)$. The two first-order

[5] Of course, this observation does not hold for all symmetric games with identical players, but it holds in our game as shown in the proof of Lemma 1.

[6] Note that this also implies that the buyer is not interested in combinatorial auctions as in Kokott, Bichler, & Paulsen (2019). Indeed, the competition-enhancing effect of setting fewer lots than there are potential suppliers dominates.

[7] Note that $n-1$ identical lots are also optimal in block sourcing (without the aftermarket). However, it need not increase buyer surplus over CM.

[8] We replace $p^r$ with $p^{SC}$ and $p^{WC}$ for the optimal prices with strong and weak commitment, respectively.

conditions are the ones enunciated in the proposition. Uniqueness of the solution follows from our assumptions on $U(.)$ and $c(.)$. □

When the buyer has weak commitment power, the aggregate quantity bought through lots determines the price he will charge in the residual market, making the calculations somewhat more involved.

**Proposition 3** (Weak Commitment (WC))**.** *If the buyer can set the price for the residual market only after the lot auction, then the optimal price is $p^{WC} = c'(q^{WC})$, where the quantity bought from the loser, $q^{WC}$, and the optimal size of the $n-1$ lots, $z^{WC}$, solve*

$$U'((n-1)z+q) = c'(q) + qc''(q), \tag{5}$$

$$U'((n-1)z+q) = \frac{c'(z) - \left[c'(q) + nqc''(q)\right]h}{1-h}, \tag{6}$$

*where*

$$h = \frac{U''((n-1)z+q)}{U''((n-1)z+q) - 2c''(q) - qc'''(q)} \in (0,1). \tag{7}$$

**Proof.** By Proposition 1, we know that there will be $n-1$ identical lots. Thus, the buyer's problem is

$$\max_z U((n-1)z+q(z)) - (n-1)(c(z) - c(q(z))) - nq(z)c'(q(z)) \tag{8}$$

where $q(z) = \arg\max_q U((n-1)z+q) - c'(q)q$. Again, total costs are derived from Lemma 1. The first-order condition for the latter maximization problem is (5) and for the former is (6), where we have used $h = -\frac{1}{n-1}\frac{\partial q}{\partial z}$. Fully differentiating (5), we obtain the formula for $h$, which is in (0,1) by our assumptions. □

The above propositions have an important practical implication:

**Corollary 1.** *The buyer will always purchase in the residual market.*

**Proof.** See the Appendix. □

Block sourcing on its own – running an auction, if you will – is thus never optimal. This result is qualitatively important, as it implies that optimally the buyer purchases from every supplier – for example, he never employs sole-sourcing (c.f. Anton & Yao, 1989) – and, therefore, all suppliers make positive profits in equilibrium.

The logic of the result is based on two observations. First, the profits of suppliers have zero derivative at zero: $\pi'(q) = \frac{d[qc'(q)-c(q)]}{dq} = qc''(q)$. That is, purchasing a small amount in the residual market increases the suppliers profits by very little. Second, since the supplier profits are zero if there is no residual market, the marginal value of the last unit to the buyer – having bought $(n-1)z$ units, with $z$ chosen optimally for $p^r = 0$ – is $c'(z)$, which is always larger than $c'(0)$. Thus, it is efficient to increase production (via the loser). While these arguments show the optimality of (at least) a marginal purchase, we can see from the example below that the quantity sourced from the residual market is not simply symbolic.

Let us present an example to illustrate these results.

**Example 1.** Let the buyer's utility be given by $U(Q) = Q - \frac{Q^2}{2}$, leading to the simple linear demand function of $U'(Q) = 1-Q$; let there be two suppliers with identical cost functions $c(q) = \frac{q^2}{2}$. Then, the efficient quantity is the solution to

$$U'(Q) = c'(Q/2). \tag{9}$$

The monopsony quantity, $Q^{CM}$, is the solution to

$$U'(Q) = c'(Q/2) + \frac{Qc''(Q/2)}{2}. \tag{10}$$

With strong commitment the system of equations (2) and (3) becomes

$$1-z-q = 3q \text{ and } 1-z-q = z. \tag{11}$$

With weak commitment the system of equations (5) and (6) becomes

$$1-z-q = 2q \text{ and } 1-z-q = \frac{z-q}{1-\frac{1}{3}}. \tag{12}$$

Table 1 summarizes the results (we define Welfare as the sum of the Buyer Surplus and the Seller Profits)

As most comparisons in Table 1 generalize, it is worth discussing them in detail. Let us start with the main object of interest in our analysis, the Buyer Surplus. By the strict optimality of Block Sourcing Plus (c.f. Proposition 1), the observation that strong commitment strictly dominates weak commitment[9] and the fact that there is always trade in the secondary market (c.f. Corollary 1), the ranking is clear, with the exception of the comparison between Block Sourcing and Classical Monopsony. As we mentioned in the Introduction, here there is a trade-off between two effects: the buyer extracts all the seller surplus, but at the cost of introducing a production inefficiency. In this example they just cancel out, but in general it could go either way. Also noteworthy is that BSP (with strong commitment) increases the buyer surplus by more than 14% over CM or BS alone (at least in this example). For completeness and ease of reference, we state the ranking of buyer surpluses as a corollary.

**Corollary 2.** *Adding an aftermarket (to an auction) or a preauction (to a price), as well as strengthening commitment, strictly increase Buyer Surplus (BuS). That is,* $\max\{BuS^{CM}, BuS^{BS}\} < BuS^{WC} < BuS^{SC}$.

Next, let's turn to the comparison of quantities. The larger aggregate production with weak commitment obtained in the example can be shown to be general.

**Corollary 3.** *The aggregate quantity traded with weak commitment exceeds aggregate quantities with both strong commitment and CM. That is,* $\max\{Q^{CM}, Q^{SC}\} < Q^{WC}$.

**Proof.** See the Appendix. □

The weak buyer buys more than the strong one for a combination of two reasons: First, since he cannot commit to a low price, even for the same lot sizes he would have higher aftermarket trade; second, as he needs to use his alternative tool to reduce supplier profits, he increases the amount bought via the auction (what is not compensated for by the resulting reduction in the residual purchases). The intuition why the weak buyer will buy more than the classical monopsonist is that otherwise the residual market quantity would have to be (at least) as much lower as the decrease in the residual demand, but such a drastic decrease is not optimal at that point.

The quantities bought by the classical and the strong monopsonist cannot be ranked in general, though the ranking $Q^{CM} < Q^{SC}$ displayed in the example is "more standard", in the sense that this ranking is guaranteed for a reasonable family of cost functions: the homogeneous ones.

**Lemma 3.** *If the cost function $c(q)$ is homogeneous of degree $k > 1$,*[10] *then $Q^{CM} < Q^{SC}$.*

**Proof.** See the Appendix. □

[9] Comparing (2) and (5) it is immediate that the two solutions cannot coincide. Given that strong commitment weakly dominates weak commitment (as the buyer could always commit to the *ex post* optimal price) the result follows.

[10] That is, $c(q) = cq^k$. Note that the assumed strict convexity of the cost function implies that the degree of homogeneity must exceed 1.

**Table 1**

| | z | q | Q | p | p(z) | Buyer Surplus | Seller Profit | Welfare |
|---|---|---|---|---|---|---|---|---|
| Efficient | - | - | .667 | - | - | - | - | .333 |
| Classic Monopsony | - | .250 | .500 | .250 | - | .250 | .031 | .313 |
| Block Sourcing | .500 | 0 | .500 | 0 | .250 | .250 | 0 | .250 |
| Strong Commitment | .429 | .143 | .571 | .143 | .238 | .286 | .010 | .306 |
| Weak Commitment | .438 | .188 | .625 | .188 | .259 | .281 | .018 | .316 |

The ranking of the lot sizes and the quantities sold in the aftermarket displayed in the example is nearly fully general.

**Corollary 4.** *The optimal lot size exceeds, while the residual sale is less than the CM quantity per supplier. Moreover, weak commitment leads to more trade than strong commitment in the residual market. That is,* $\min\{z^{WC}, z^{SC}\} > q^{CM} > q^{WC} > q^{SC}$.

**Proof.** See the Appendix. □

These results reinforce the intuition we have pointed out before: with strong commitment the buyer can squeeze the suppliers' profits by committing to a low residual market price, what leads to a low $q^{SC}$. The weak buyer cannot do that, but instead he can squeeze the residual demand – by setting larger lots than in CM – in order to reduce supplier profits, again leading to lower trade in the aftermarket than in CM. At the same time, due to its inefficient allocation of production, the higher lot size under weak commitment need not lead to it exceeding the lot size with strong commitment if the marginal valuation of the good is high.

Residual market prices are – obviously – ranked in the same way as the quantities (though the fact that they actually coincide with the quantities is a peculiarity of the example). As a result, it is always the case that the suppliers lose as a result of BSP and the more so if the buyer has strong commitment power. On the other hand, they are better off than with BS, which leaves them with zero profit.

Of course, for every buying mechanism the imputed unit prices exceed the aftermarket price, as the supplier profits are the same but higher quantities are traded, leading to a higher average production cost.

Finally, the welfare ranking is indeterminate in general. It depends on the trade-off between higher production and (potentially) higher inefficiency.

## 4. Heterogeneity and asymmetric information

For simplicity, in the above analysis we have abstracted away from asymmetry in cost functions and, consequently, also about asymmetric information. In this section we argue that this was without much loss of generality, by extending our model to incorporate asymmetry in a variety of ways. It is useful to note that if the cost asymmetry is large the buyer will simply disregard the inefficient supplier(s), in which case our results apply for the subset of efficient ones.

Let us consider two sellers, with possible cost functions $c_1(q) = (1-\varepsilon)c(q)$ and $c_2(q) = (1+\varepsilon)c(q)$, for some $\varepsilon \in (0,1)$. We focus attention on the simpler case of strong commitment, where the buyer sets the aftermarket price before the auction.[11] For simplicity, we also assume that the auction is second-price, so that the suppliers bid their true valuation.

[11] Note that with asymmetric information the bids in the auction might reveal information, considerably complicating the analysis.

### 4.1. Heterogeneous suppliers

Our first extension assumes that the sellers have different costs (common knowledge among them), while the buyer knows what the cost functions are, but he does not know which seller has which (or is not allowed/able to use that information, in line with our original assumption that he cannot price discriminate). We argue that our results are robust to a moderate level of such heterogeneity but large asymmetries render BSP ineffective.

The buyer can choose three qualitatively different combinations of the size of the lot $z$ and the residual market price $p$:

I. $c_2'(z) \le p$. Both firms participate in the residual market.
II. $c_1'(z) \le p < c_2'(z)$. Firm 1 participates for sure in the residual market, firm 2 only if it does not win the lot.
III. $p < c_1'(z)$. Only the loser of the auction participates in the residual market.

Define $q_1(p)$ and $q_2(p)$ as the supply function of firm $i$, derived from $p = c_i'(q_i)$. The bid of firm $i$ given $z$ and $p$ is denoted by $B_i(z,p)$. For transparency, we drop the arguments when there is no room for confusion.

In (I), both firms bid $B_i = pz$: In case of winning the auction, their profits are $B_i + p(q_i(p) - z) - c_i(q_i(p))$; when they lose, their profits are $pq_i(p) - c_i(q_i(p))$. Taking the difference, we see that both firms value winning at $pz$. Here, lot $z$ is too small to have any real effect on total quantities and payments: At the end of the day, the buyer obtains quantity $X = q_1(p) + q_2(p)$ and pays $pX$, irrespective of which firm wins the auction. Thus, just as in the homogeneous case, for lots that are too small, BSP reproduces the outcome of CM.

In (II), the more efficient seller must receive at least $pz$ for lot $z$ as above, whereas the less efficient supplier compares $B_2 - c_2(z)$ and $pq_2 - c_2(q_2)$; therefore $B_2 = c_2(z) + pq_2 - c_2(q_2)$. Note that $pz < c_2(z) + pq_2 - c_2(q_2)$, as

$$pq_2 - c_2(q_2) = \max_q\{pq - c_2(q)\} > pz - c_2(z), \tag{13}$$

since $p < c_2'(z)$. The efficient firm wins the auction and charges $B_2$. Note that the buyer obtains quantity $X = q_1 + q_2$ but pays more than in CM:

$$B_2 + p(q_1 + q_2 - z) = c_2(z) + pq_2 - c_2(q_2) + p(q_1 + q_2 - z) = \tag{14}$$

$$= p(q_1 + q_2) + \{[pq_2 - c_2(q_2)] - [pz - c_2(z)]\} > p(q_1 + q_2), \tag{15}$$

where the inequality follows by (13). Therefore, setting a lot and a price such that the winner is excluded from the residual market would actually hurt the buyer. The reason is that the lot is too big for the inefficient firm, dampening its valuation of winning the lot and it is the efficient firm who gains the difference (from the buyer).

Finally, in (III), seller $i$ must receive at least $c_i(z) + pq_i - c_i(q_i)$ to be willing to supply the lot. Note that the efficient firm will value more winning the auction as

$$c_1(z) + pq_1 - c_1(q_1) < c_2(z) + pq_1 - c_2(q_1) < c_2(z) + pq_2 - c_2(q_2), \tag{16}$$

where the first inequality follows from $c(z) - c(q_1) > 0$ when $q_1 < z$ (what follows from $p < c_1'(z)$); and the last inequality from the fact that $q_2 = \arg\max_q\{pq - c_2(q)\}$. Therefore, the efficient seller wins the auction (and does not participate in the residual market) charging $B_2 = c_2(z) + pq_2 - c_2(q_2)$. As we have just seen, this lot price is above its cost of production, $c_1(z)$, plus its opportunity cost $pq_1 - c_1(q_1)$. In particular, if the buyer set the lot size at $z = q_1$, the efficient firm would make a profit

$$\begin{aligned} B_2(q_1) - c_1(q_1) &= c_2(q_1) + pq_2 - c_2(q_2) - c_1(q_1) \\ &> c_2(q_1) + pq_1 - c_2(q_1) - c_1(q_1) \\ &= pq_1 - c_1(q_1), \end{aligned} \tag{17}$$

making the buyer worse off than under CM (similarly to (II) above). Of course, $z = q_1$ is not optimal, but the efficient seller's extra rents always present a countervailing effect.

The following example illustrates this trade-off.

**Example 2.** Let $U(Q) = (1 - Q/2)Q$ and $c(q) = q^2/2$.

Suppose that the optimal lot size and residual price satisfy $p^{SC}_{het} < c_1'(z^{SC}_{het})$, so we are in case (III). Since only the inefficient firm participates in the residual market, we write $q_2 = q$ and use $p = c_2'(q) = (1 + \varepsilon)q$. The buyer chooses $p$ and $z$ to maximize

$$U(z+q) - (B_2 + pq) = \left(1 - \frac{z+q}{2}\right)(z+q) - \frac{(1+\varepsilon)}{2}\left(z^2 + 3q^2\right). \tag{18}$$

We obtain that the optimal lot, residual market price and total production are $z^{SC}_{het} = \frac{3}{4+3(1+\varepsilon)}$, $p^{SC}_{het} = \frac{1+\varepsilon}{4+3(1+\varepsilon)}$ $\left(\text{and } q^{SC}_{het} = \frac{1}{4+3(1+\varepsilon)}\right)$ and $Q^{SC}_{het} = z^{SC}_{het} + q^{SC}_{het} = \frac{4}{4+3(1+\varepsilon)}$, respectively. (Note that $p^{SC}_{het} < c_1'(z^{SC}_{het})$ for $\varepsilon < .5$). Buyer surplus is $BuS^{SC}_{het} = \frac{2}{4+3(1+\varepsilon)}$.

Let us compare this with the CM solution: If the buyer sets a price $p$, firm 1 produces $q_1 = \frac{p}{1-\varepsilon}$ whereas firm 2 produces $q_2 = \frac{p}{1+\varepsilon}$; thus the buyer must set price $p = \frac{1-\varepsilon^2}{2}Q$ to obtain total quantity $Q$. The buyer chooses $Q$ to maximize

$$U(Q) - pQ = \left(1 - \frac{Q}{2}\right)Q - \frac{1-\varepsilon^2}{2}Q^2 = \left(1 - \frac{2-\varepsilon^2}{2}Q\right)Q. \tag{19}$$

We obtain $Q^{CM}_{het} = \frac{1}{2-\varepsilon^2}$ and $BuS^{CM}_{het} = \frac{1}{2(2-\varepsilon^2)}$. Comparing the buyer surpluses, $BuS^{SC}_{het} > BuS^{CM}_{het} \iff \varepsilon < .25(< .5)$.

When sellers have not too dissimilar cost structures, it still makes sense to set a lot, followed by setting a price in a residual market. As the asymmetry grows, the inefficient firm is turning into a poorer competitor in the auction for the lot, so the efficient firm needs to be paid more. This is accompanied by a smaller optimal lot size, which dampens the effect of block sourcing on the aftermarket price, which indeed increases. In addition – and in contrast – CM actually benefits from the heterogeneity (since the firms can adjust their production to their costs and the quadratic cost structure means that the cost savings for the efficient firm exceed the losses by the inefficient one). If this effect were not present – monopsony profit were constant at 1/4 – then BSP would be superior up to $\varepsilon = 1/3$, corresponding to one firm having twice the cost as the other.

### 4.2. Asymmetric information I: common costs

In the previous section the buyer knew the empirical distribution of the supplier costs. What if he did not? To obtain a feel for how robust our results are to asymmetric information, we include buyer uncertainty about the costs. To isolate the effect of uncertainty from the effect of asymmetry, we first assume that costs are common.

In particular, let us assume that the buyer's belief about the (common) cost function is given by $c(q; b) = b\frac{q^2}{2}$, where $b$ takes the values $1 - \varepsilon$ and $1 + \varepsilon$, each with equal probability. To avoid complications,[12] we assume that $\varepsilon \le 0.5$, what still allows for a cost ratio of 3:1. The sellers know their actual $b$. Their equilibrium bid function is denoted by $B(b) = c(z; b) + pq - c(q; b)$.[13]

The buyer's objective function is

$$E_{(b)}[U(z+q) - B(b) - pq] = E_{(b)}\left[U(z+q) - b\left(\frac{z^2}{2} - \frac{q^2}{2}\right) - 2pq\right]. \tag{20}$$

Taking into account that price equals marginal cost implies that $q = p/b$, and substituting in for the utility function $U(Q) = (1 - Q/2)Q$, we obtain

$$\begin{aligned} &E_{(b)}\left[z + p/b - \frac{(z+p/b)^2}{2} - b\frac{z^2}{2} - \frac{3p^2}{2b}\right] \\ &= z + \frac{p}{1-\varepsilon^2}\left(1 - \frac{p}{2}\left(3 + \frac{1+\varepsilon^2}{(1-\varepsilon^2)^2}\right) - z\right) - z^2. \end{aligned} \tag{21}$$

Differentiating with respect to $z$, we obtain the first-order condition

$$1 - \frac{p}{1-\varepsilon^2} = 2z. \tag{22}$$

Differentiating with respect to $p$, we obtain the second first-order condition

$$1 - z - 3p = p\frac{1+\varepsilon^2}{1-\varepsilon^2}. \tag{23}$$

Solving the system of equations we obtain

$$z^{SC}_{as} = \frac{3-2\varepsilon^2}{7-4\varepsilon^2} \text{ and } p^{SC}_{as} = \frac{1-\varepsilon^2}{7-4\varepsilon^2}. \tag{24}$$

Substituting the optimal values of $z$ and $p$ into the buyer's (expected) surplus – and simplifying – we obtain

$$EBuS^{SC}_{as} = \frac{2-\varepsilon^2}{7-4\varepsilon^2}. \tag{25}$$

It is easy to see that this is increasing in $\varepsilon$. Of course, this does not mean that the buyer prefers to be asymmetrically informed,[14] it simply reflects that the (indirect) buyer surplus is convex in $b$ – in the relevant range and the optimal lot size and price. Asymmetry increases the productive efficiency.

The classical monopsonist would maximize (in $p$)

$$E_{(b)}\left[2(1 - p/b)p/b - 2p^2/b\right] \tag{26}$$

$$= (1-p)\frac{2p}{1-\varepsilon^2} - \frac{2p^2\left(1+\varepsilon^2\right)}{\left(1-\varepsilon^2\right)^2} = \frac{2p}{1-\varepsilon^2} - p^2\frac{4}{\left(1-\varepsilon^2\right)^2} \tag{27}$$

Leading to the first-order condition

$$1 - \frac{4}{1-\varepsilon^2}p = 0. \tag{28}$$

Solving, we obtain

$$p^{CM}_{as} = \frac{1-\varepsilon^2}{4}. \tag{29}$$

[12] With $\varepsilon$ small enough, we avoid the scenario in which a low cost supplier could still participate in the aftermarket after winning the lot.

[13] See (16) and the discussion before.

[14] This can be easily seen. If the buyer is fully informed about the common costs his surplus is $\frac{16-2b}{(4+3b)^2}$. Evaluating this when $b$ takes the values $1-\varepsilon$ and $1+\varepsilon$ with equal probability, we obtain $\frac{686+210\varepsilon^2}{\left(49-9\varepsilon^2\right)^2}$, which exceeds $EBuS^{SC}_{as}$ by more, the larger the extent of heterogeneity, $\varepsilon$, is. Being informed is (very) valuable.

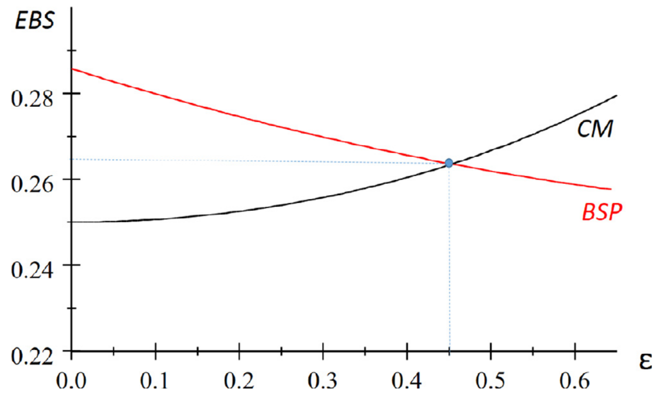


**Fig. 1.** The expected buyer surplus.

Substituting back into the profit function we have

$$EBuS_{as}^{CM} = \frac{1}{4}. \tag{30}$$

The CM profit is independent of the level of uncertainty (the indirect profit function is linear in $b$), and it is always less than the buyer surplus of the BSP monopsonist. As $EBuS_{as}^{SC}$ is increasing in $\varepsilon$, in the absence of heterogeneity, asymmetric information actually increases the superiority of BSP over CM.

### *4.3. Asymmetric information II: i.i.d. costs*

Finally, we analyze the case where $b$ is independently drawn for each seller and, therefore, they are not perfectly informed about their competitor's cost. Figure 1 depicts the expected buyer surplus as a function of $\varepsilon$, for BSP – the decreasing curve – and CM.[15]

As we can see, when uncertainty is i.i.d., BSP with asymmetric information is superior to classical monopsony up to $\varepsilon \approx .45$; that is, for an even higher variance than the limit imposed by heterogeneity ($\varepsilon = .25$) above.

We can therefore conclude that, while heterogeneity reduces the advantage of BSP – basically because it dampens competition – asymmetric information (between the buyer and the sellers) need not do so.

## 5. Conclusions

We have revisited the classic problem of a monopsonist, in the context where the aggregate supply is constructed from a finite number of producers with diseconomies of scale in production. We have proposed a (theoretically) novel procurement procedure: to group together part of the requirements into block contracts and auction them off, followed by a residual market. The buyer optimally will set just one lot less than the number of suppliers. Importantly, he does not want to reduce the quantity bought from the last supplier to zero – that is, he always wants to buy in the residual market – despite this having a negative effect on the competitiveness of the auction. We have shown that this procurement method always leads to higher buyer surplus (unless there is excessive cost heterogeneity among suppliers, what is unlikely in applications). It is important to underline that this result is not a simple consequence of making the suppliers compete in an auction and neither does it rely on a commitment to the price in the residual market.

Although our general result is proved for complete information, we have displayed examples that indicate that asymmetric information – on its own – not only need not invalidate our conclusion, but it might even magnify the advantage of our mechanism over classical monopsony.

Finally, while we have framed our discussion around the decisions of a single buyer, our model can also be interpreted as one where many independent buyers consider grouping together to improve their bargaining position versus the suppliers. Given the absence of quantity discounts, as we have increasing marginal costs, this does not sound an obvious strategy.[16] However, if we interpret setting a block as the establishment of a purchasing group, our results imply that the prices obtained for the block contracts are indeed lower than the competitive price. Interestingly, the buyers not part of the block improve their prices even more, so the formation of the group may be a complicated process.

## Appendix

**Proof of Lemma 1.** Note that in equilibrium all the lots will be "won" as for a high enough price a lot contract is always attractive. Let the equilibrium profit of the winner of lot $m-k+1$ be denoted by $\pi_w^{(k)}$. Induction hypothesis (IH): If there are $k$ lots left then $\pi_w^{(k)} = \pi(p^r)$.

**Step 1: The IH holds when** $k=1$. Since $m<n$ there are $n-m+1 \geq 2$ remaining suppliers. It is immediate that in equilibrium neither $\pi_w^{(1)} > \pi(p^r)$ nor $\pi_w^{(1)} < \pi(p^r)$. In the first case any losing bidder could do better by bidding slightly below the winner's bid (which must have been the (weakly) lowest), whereas in the second case the winner could increase her profits by increasing her offer in order to lose. The latter argument presupposes that there is another valid bid for the lot in equilibrium – so that she indeed loses the auction and so that the number of suppliers in the residual market, and thus $p^r$, remain the same. But, if there were no other bid, the winner could increase her offer and still win, contradicting that we were in an equilibrium to start with.

**Step 2: If the IH holds for** $k$ **then it is also true for** $k+1$. By the IH, all the remaining suppliers who do not win lot $m-k$ will earn $\pi(p^r)$. Thus, the argument used in Step 1 can be directly applied to show that $\pi_w^{(k+1)} = \pi(p^r)$. □

**Proof of Lemma 2.** We start by showing that if, in equilibrium, the winner of the smallest lot is interested in participating in the residual market then the buyer's surplus is the same as if the smallest lot was not offered. Assume there is at least one lot winner, $m$, such that $c'(z_m) \leq p^r$, that is she is not strictly excluded from the residual market. We have two cases to consider. i) If the buyer can only set $p^r$ after the auction, then the quantity traded in the residual market by a loser is $q'$, where $U'\left(Z + (n-m)q' + \sum_{i=1}^{m-1} \max\left\{q' - z_i, 0\right\} + q' - z_m\right) = c'(q')$, as $c'(z_m) \leq p^r$ implies $q' \geq z_m$. Without lot $m$, the quantity traded in the residual market by a loser would be $q$, where $U'\left(Z - z_m + (n-m+1)q + \sum_{i=1}^{m-1} \max\{q - z_i, 0\}\right) = c'(q)$. By the monotonicity of supply and demand, it is immediate that $q = q'$ and, consequently, the two outcomes are the same. By Step 1 of the proof of Lemma 1, the payoffs will also be unchanged. ii) If the buyer can commit to $p^r$ at the beginning, then we show that for any $p^r$ the smallest lot makes no difference. If the smallest lot is offered, the market clearing condition is $p^r = c'\left(q'\right)$, leading to total quantity bought $Q' = Z + (n-m)q' + \sum_{i=1}^{m-1} \max\left\{q' - z_i, 0\right\} + q' -$

[15] The derivations are in the Appendix.

[16] Group purchasing organizations have recently received some special attention, specially in what refers to the health care reform debate in the US. In particular, the analysis is concerned about their effects on the total health care costs and the competitive effects of these groups (see, e.g. Blair & Durrance (2014) and Rooney (2011)). Gong, Li, & McAfee (2012) cite examples in Canada and Australia that see significantly lower prices vis-à-vis the U.S. for the same drugs. Liang, Ma, Xie, & Yan (2014) provide a theoretical analysis in a context of dynamic infomation.

$z_m$, and $\pi' = p^r q' - c(q')$. If lot $m$ were not offered, we would have $p^r = c'(q)$, $Q = Z - z_m + (n-m+1)q + \sum_{i=1}^{m-1} \max\{q - z_i, 0\}$ and $\pi = p^r q - c(q)$. It is obvious that $q = q'$ and, therefore, $Q = Q'$, $\pi = \pi'$ and the buyer's payoff is unchanged. □

**Proof of Proposition 1.** Note that since, by (1), no lot winner participates in the residual market, only the aggregate lot size, $Z$, affects the residual market outcome (which by Lemma 1 determines the profits of all suppliers). Thus, the buyer could appropriate all the efficiency gains from equalizing lots while keeping $Z$ constant. Therefore, setting identical lots is optimal for any number of lots, $m$.

Now, note that we can strengthen (1) to a strict equality: since, by Lemma 2, lots equal to the residual market quantities are equivalent to setting no lots, we can just represent this outcome by $m = 0$ and for $m > 0$ restrict attention to the case where $c'(z) > p_r$.

i) When the buyer can commit to a price *ex ante*.

First, let's show that setting one lot, $m = 1$, is better than CM, $m = 0$:

With no lots, procurement costs of quantity $Q = nq_0$ are $PC_0 = nc'(q_0)q_0$. Set one lot $z > q_0$ and readjust the price from $p_0 = c'(q_0)$ to $p_1 = c'(q_1)$ to buy the same aggregate quantity $nq_0 = z + (n-1)q_1$. Note that $q_1 < q_0$. According to Lemma 1, the procurement cost of lot $z$ is $c(z) + \pi(p_1) = c(z) + p_1 q_1 - c(q_1)$ and therefore total procurement costs are

$$PC_1 = c(z) - c(q_1) + np_1 q_1. \tag{31}$$

An increase in quantity $q_1$ leads to a change in procurement costs

$$\frac{dPC_1}{dq_1} = (n-1)\left[c'(q_1) - c'(Q - (n-1)q_1)\right] + nc''(q_1)q_1 \tag{32}$$

that evaluated at $q_1 = q_0$ is positive: $\left.\frac{dPC_1}{dq_1}\right|_{q_1=q_0} = nc''(q_0)q_0 > 0$. Hence, since $PC_0 = PC_1(q_0)$, it is profitable to set a lot.

Next, we show that optimally $m = n-1$. Suppose, by way of contradiction, that setting $m < n-1$ (identical) lots $z$, is optimal. Suppose that total quantity procured is $Q = mz + (n-m)q_m$ with $q_m < z$ and $p_m = c'(q_m)$. According to Lemma 1, the procurement cost of lot $z$ is $c(z) + \pi(p_m) = c(z) + p_m q_m - c(q_m)$ and therefore total procurement cost are

$$PC_m = m[c(z) - c(q_m)] + np_m q_m. \tag{33}$$

Let's set $m+1$ (identical) lots $\tilde{z}$ that lead to the same total quantity $Q$ as above (keeping the price constant at $c'(q_m)$), $\tilde{z} = \frac{mz + q_m}{m+1}$. Suppliers have the same profits as before, since the price is unchanged. Hence total procurement costs are

$$PC_{m+1} = (m+1)[c(\tilde{z}) - c(q_m)] + np_m q_m. \tag{34}$$

The change in procurement costs is

$$PC_{m+1} - PC_m = (m+1)\left[c(\tilde{z}) - \left(\frac{m}{m+1}c(z) + \frac{1}{m+1}c(q_m)\right)\right] < 0, \tag{35}$$

since we have set the new lots as $\tilde{z} = \frac{m}{m+1}z + \frac{1}{m+1}q_m$ and the cost function $c(.)$ is strictly convex.

So the move from $m$ to $m+1$ lots has an additional effect when compared to the move from zero to one lot: even if suppliers are left with the same profits, there is a more efficient distribution of production that reduces procurement costs. Of course, optimally the buyer will take advantage of the extra lot to lower the price in the aftermarket.

ii) In case the buyer can fix the price only after the tendering process, he will choose the monopsony price at the residual demand, say $\hat{p} = c'(\hat{q})$, where

$$\hat{q}(z, m) = \arg\max_q U(mz + (n-m)q) - (n-m)c'(q)q. \tag{36}$$

If $m > 0$, he can again set an additional lot of size $\hat{q} < z$, without changing the outcome. And then he could strictly improve his payoff by equalizing the lot sizes and capture the efficiency gains as before. If $m = 0$, we will now show that setting a lot slightly larger than $q^{CM} := \hat{q}(0, 0)$ strictly increases buyer surplus. The latter, given a lot $z$, is

$$U(z + (n-1)\hat{q}(z,1)) - c(z) + c(\hat{q}(z,1)) - nc'(\hat{q}(z,1))\hat{q}(z,1). \tag{37}$$

The derivative of the objective function with respect to $z$ is[17]

$$(1 + (n-1)\hat{q}'(z))U'(z + (n-1)\hat{q}(z)) - c'(z) - \hat{q}'(z)\left[(n-1)c'(\hat{q}(z)) + nc''(\hat{q}(z))\hat{q}(z)\right]. \tag{38a}$$

Substituting in the first-order condition for $\hat{q}(z)$ – $U'(z + (n-1)\hat{q}(z)) = c'(\hat{q}(z)) + c''(\hat{q}(z))\hat{q}(z)$ – evaluating it at $z = q^{CM}$ and observing that $\hat{q}(q^{CM}, 1) = q^{CM}$, we obtain

$$q^{CM}c''(q^{CM})\left(1 - \hat{q}'(q^{CM})\right) > 0, \tag{39}$$

since, obviously, $d\hat{q}/dz < 0$. Thus, increasing the lot size from $q^{CM}$ would strictly benefit the buyer. □

**Proof of Corollary 1.** Imagine otherwise. From (2) and (5), $q = 0$ would imply $U'(Z) = c'(0)$. However, by (3) $U'(Z) = c'(z)$ so, since $c(.)$ is strictly convex and $z > 0$, we have a contradiction. In case of weak commitment we can also substitute $U'(Z) = c'(0)$ into (6) and reach a contradiction (observing that $\frac{\partial q}{\partial z} > 1 - n$). □

**Proof of Corollary 3.** Suppose that $Q^{WC} \leq Q^{SC}$; then by Propositions 2 and 3:

(i) $c'(z^{SC}) = U'(Q^{SC}) \leq U'(Q^{WC}) < c'(z^{WC})$, which implies $z^{SC} < z^{WC}$; and

(ii) $c'(q^{SC}) + c''(q^{SC})q^{SC} < c'(q^{SC}) + nc''(q^{SC})q^{SC} = U'(Q^{SC}) \leq U'(Q^{WC}) = c'(q^{WC}) + c''(q^{WC})q^{WC}$, which implies (given that we have assumed that $c'''(q)q + 2c''(q) > 0$) that $q^{SC} < q^{WC}$. But then $Q^{SC} = (n-1)z^{SC} + q^{SC} < Q^{WC} = (n-1)z^{WC} + q^{WC}$, contradicting the initial assumption.

Next, suppose that $Q^{WC} \leq Q^{CM}$; then, by the equivalent of (10) and Proposition 3, $c'\left(\frac{Q^{CM}}{n}\right) + c''\left(\frac{Q^{CM}}{n}\right)\frac{Q^{CM}}{n} = U'(Q^{CM}) \leq U'(Q^{WC}) = c'(q^{WC}) + c''(q^{WC})q^{WC}$, which implies (given that we have assumed that $c'''(q)q + 2c''(q) > 0$) that $\frac{Q^{CM}}{n} \leq q^{WC} < z^{WC}$. But then $Q^{CM} < Q^{WC} = (n-1)z^{WC} + q^{WC}$, contradicting the initial assumption. □

**Proof of Lemma 4.** Step 1: $q^{WC} > q^{SC}$. From (2) and (3) $c'(z^{SC}) = c'(q^{SC}) + nc''(q^{SC})q^{SC}$. For weak commitment, write $\frac{\partial q}{\partial z}$ as $-(n-1)h$, where $0 < h < 1$. Then, (5) and (6) imply $c'(z^{WC}) = c'(q^{WC}) + \alpha nc''(q^{WC})q^{WC}$, where $0 < \alpha = \frac{1+(n-1)h}{n} < 1$. Suppose, for contradiction, that $q^{WC} \leq q^{SC}$. Then – using our assumption that $nqc'''(q) + (n+1)c''(q) > 0$ – we have that

$$\begin{aligned} c'(z^{SC}) &= c'(q^{SC}) + nc''(q^{SC})q^{SC} \geq c'(q^{WC}) + \alpha nc''(q^{WC})q^{WC} \\ &= c'(z^{WC}), \end{aligned} \tag{40}$$

implying $z^{WC} \leq z^{SC}$. But, from Corollary 3, we know that $Q^{SC} < Q^{WC}$; hence $q^{WC} < q^{SC}$ doesn't make sense.

Step 2: $q^{CM} > q^{WC}$. We know from Corollary 3 that $Q^{CM} < Q^{WC}$. Since $c''(q^{WC})q^{WC} + c'(q^{WC}) = U'(Q^{WC}) < U'(Q^{CM}) = c''(q^{CM})q^{CM} + c'(q^{CM})$, $c'''q + 2c'' > c'''q + \frac{n+1}{n}c'' > 0$ implies $q^{WC} < q^{CM}$.

Step 3: $min\{z^{SC}, z^{WC}\} > q^{CM}$. This follows from Proposition 1 and Lemma 2. □

**Proof of Lemma 3.** We start by showing that total procurement cost inherits the homogeneity of the cost function. Assume the cost function $c(q)$ is homogeneous of degree $k > 1$, $c(\alpha q) = \alpha^k c(q)$. This

[17] We drop the second argument of $\hat{q}$, for transparency

leads to a marginal cost homogeneous of degree $k-1$, $c'(\alpha q) = \alpha^{k-1}c'(q)$ and to a second derivative homogeneous of degree $k-2$, $c''(\alpha q) = \alpha^{k-2}c''(q)$. Procurement cost under classical monopsony is

$$T^{CM}(Q^{CM}) = c'\left(\frac{Q^{CM}}{n}\right)Q^{CM}. \tag{41}$$

This function inherits the homogeneity of the cost function: $T^{CM}(\alpha X) = c'\left(\frac{\alpha X}{n}\right)\alpha X = \alpha^k c'\left(\frac{X}{n}\right)X = \alpha^k T^{CM}(X)$. Procurement cost under strong commitment is

$$\begin{aligned} T^{SC}(Q^{SC}) &= (n-1)c\left(\frac{Q^{SC} - q(Q^{SC})}{n-1}\right) + c(q(Q^{SC})) \\ &+ n\left[c'(q(Q^{SC}))q(Q^{SC}) - c(q(Q^{SC}))\right], \end{aligned} \tag{42}$$

where $q(X) = \arg\min_q \left\{(n-1)c\left(\frac{X-q}{n-1}\right) + c(q) + n\left[c'(q)q - c(q)\right]\right\}$.

Note that $q(X)$ is the solution to $nc''(q)q + c'(q) - c'\left(\frac{X-q}{n-1}\right) = 0$, while $q(\alpha X)$ solves $nc''(q)q + c'(q) - c'\left(\frac{\alpha X - q}{n-1}\right) = 0$. Thus, using the homogeneity property of the cost function, we obtain

$$\begin{aligned} &nc''(\alpha q(X))\alpha q(X) + c'(\alpha q(X)) - c'\left(\frac{\alpha X - \alpha q(X)}{n-1}\right) \\ &= \alpha^{k-1}\left\{nc''(q)q + c'(q) - c'\left(\frac{X-q}{n-1}\right)\right\} = 0. \end{aligned} \tag{43}$$

That is, $\alpha q(X) = q(\alpha X)$.

Then,

$$\begin{aligned} T^s(\alpha X) &= (n-1)c\left(\frac{\alpha X - q(\alpha X)}{n-1}\right) + c(q(\alpha X)) \\ &+ n\left[c'(q(\alpha X))q(\alpha X) - c(q(\alpha X))\right] = \end{aligned} \tag{44}$$

$$\begin{aligned} &= (n-1)c\left(\frac{\alpha X - \alpha q(X)}{n-1}\right) + c(\alpha q(X)) \\ &+ n\left[c'(\alpha q(X))\alpha q(X) - c(\alpha q(X))\right] = \end{aligned} \tag{45}$$

$$\begin{aligned} &= \alpha^k\left\{(n-1)c\left(\frac{X - q(X)}{n-1}\right) + c(q(X)) \right. \\ &\left. + n\left[c'(q(X))q(X) - c(q(X))\right]\right\} = \alpha^k T^s(X). \end{aligned} \tag{46}$$

Next, observe that, by revealed preference, $U(Q^{CM}) - T^{CM}(Q^{CM}) > U(Q^{SC}) - T^{CM}(Q^{SC})$ and $U(Q^{SC}) - T^{SC}(Q^{SC}) > U(Q^{CM}) - T^{SC}(Q^{CM})$. The sum of these inequalities implies

$$\left[T^{CM}(Q^{SC}) - T^{CM}(Q^{CM})\right] - \left[T^{SC}(Q^{SC}) - T^{SC}(Q^{CM})\right] > 0. \tag{47}$$

Write $Q^{SC}$ in terms of $Q^{CM}$ as $Q^{SC} = \alpha Q^{CM}$. Using the fact that both procurement cost functions are homogeneous of degree $k$, we obtain

$$\begin{aligned} &\left[T^{CM}(\alpha Q^{CM}) - T^{CM}(Q^{CM})\right] - \left[T^{SC}(\alpha Q^{CM}) - T^{SC}(Q^{CM})\right] \\ &= (\alpha^k - 1)\left[T^{CM}(Q^{CM}) - T^{SC}(Q^{CM})\right] > 0. \end{aligned} \tag{48}$$

Now, recall that, by the argument displayed in the proof of Proposition 1, for any level of procurement $X$, $T^{CM}(X) > T^{SC}(X)$ (the buyer has strictly lower procurement costs when he sets $n-1$ lots). Thus, $\alpha^k - 1 > 0$, which – given $k > 1$ – requires $\alpha > 1$. Consequently, $Q^{SC} = \alpha Q^{CM} > Q^{CM}$. □

**The derivation of** Figure 1: If the buyer wants to implement a BSP (with a random winner selected in case both bids are the same, as sharing the production would undermine BSP) his objective function is

$$\begin{aligned} &E_{(b_1,b_2)}\left[U(z+\tilde{q}) - \max_i B(b_i) - p\tilde{q}\right] \\ &= E_{(b_1,b_2)}\left[U(z+\tilde{q}) - \max_i \{c_i(z) + pq_i - c_i(q_i)\} - p\tilde{q}\right], \end{aligned} \tag{49}$$

where $\tilde{q} = q_{\arg\max_i \{c_i(z)+pq_i - c_i(q_i)\}}$ and $c_i'(q_i) = p$. To see this, note that in the auction both sellers will bid their true opportunity cost plus their cost of producing $z$ units. The seller with the lowest bid wins, but she earns the higher bid. The seller with the higher bid is the loser, who will produce up to the quantity that makes her marginal cost equal to the price.

Substituting in for the cost function, we have that

$$B(b_i) = c_i(z) + pq_i - c_i(q_i) = \frac{b_i z^2}{2} + \frac{p^2}{2b_i}, \tag{50}$$

which for $z \geq q_i = p/b_i$ is increasing in $b_i$.[18] Consequently,

$$\arg\max_i \{c_i(z) + pq_i - c_i(q_i)\} = \arg\max_i \{b_i\}. \tag{51}$$

Then, we can write the objective function as

$$\begin{aligned} &.25\left[\left(1 - \frac{z + p/(1-\varepsilon)}{2}\right)(z + p/(1-\varepsilon)) - \frac{(1-\varepsilon)z^2}{2} - \frac{3p^2}{2(1-\varepsilon)}\right] + \\ &.75\left[\left(1 - \frac{z + p/(1+\varepsilon)}{2}\right)(z + p/(1+\varepsilon)) - \frac{(1+\varepsilon)z^2}{2} - \frac{3p^2}{2(1+\varepsilon)}\right] \end{aligned} \tag{52}$$

where we have used that in 3 out of the 4 possible configurations the loser of the auction will have the high cost.

Differentiating with respect to $z$ and $p$, respectively, we obtain two first-order conditions

$$\begin{aligned} &.25[1 - (z + p/(1-\varepsilon)) - (1-\varepsilon)z] \\ &+ .75[1 - (z + p/(1+\varepsilon)) - (1+\varepsilon)z] \\ &= 1 - (2 + \varepsilon/2)z - \frac{p(1-\varepsilon/2)}{1-\varepsilon^2} = 0 \end{aligned} \tag{53}$$

and

$$\begin{aligned} &.25\left[(1 - (z + p/(1-\varepsilon)))/(1-\varepsilon) - \frac{3p}{1-\varepsilon}\right] \\ &+ .75\left[(1 - (z + p/(1+\varepsilon)))/(1+\varepsilon) - \frac{3p}{1+\varepsilon}\right] = 0. \end{aligned} \tag{54}$$

Solving the system, we arrive at $z_{ai}^{SC} = \frac{3(2\varepsilon^3 - 3\varepsilon^2 - 2\varepsilon + 4)}{3\varepsilon^4 + 8\varepsilon^3 - 22\varepsilon^2 - 8\varepsilon + 28}$ and $p_{ai}^{SC} = \frac{\varepsilon^4 - 5\varepsilon^2 + 4}{3\varepsilon^4 + 8\varepsilon^3 - 22\varepsilon^2 - 8\varepsilon + 28}$.

The condition that the winner does not participate in the aftermarket is $(1-\varepsilon)z_{ai}^{SC} \geq p_{ai}^{SC}$, equivalent to $\varepsilon \leq \hat{\varepsilon}$, where $\hat{\varepsilon} \approx .65$ is the solution to $7\varepsilon^4 - 15\varepsilon^3 - 2\varepsilon^2 + 18\varepsilon - 8 = 0$. Substituting back into the expected profit function, we have $EBuS_{ai}^{SC} = \frac{13\varepsilon^3 - 20\varepsilon^2 - 16\varepsilon + 32}{4(3\varepsilon^4 + 8\varepsilon^3 - 22\varepsilon^2 - 8\varepsilon + 28)}$.

What would the classical monopsonist do? He would maximize

$$E_{(b_1,b_2)}\left[U(p/b_1 + p/b_2) - p^2/b_1 - p^2/b_2\right]. \tag{55}$$

Differentiating the maximand with respect to $p$, we obtain the first-order condition

$$E_{(b_1,b_2)}[(1 - (p/b_1 + p/b_2))(1/b_1 + 1/b_2) - 2p/b_1 - 2p/b_2] = 0. \tag{56}$$

Substituting in for the random variables, we obtain

[18] We know from the main model that setting a lot that is smaller than the competitive quantity is not helpful.

$$.25\Big[2\Big(1-\frac{2p}{1-\varepsilon^2}\Big)\frac{2}{1-\varepsilon^2}-\frac{8p}{1-\varepsilon^2}+$$
$$\Big(1-\frac{2p}{1-\varepsilon}\Big)\frac{2}{1-\varepsilon}-\frac{4p}{1-\varepsilon}+\Big(1-\frac{2p}{1+\varepsilon}\Big)\frac{2}{1+\varepsilon}-\frac{4p}{1+\varepsilon}\Big]$$
$$=\frac{2(1-2p)}{1-\varepsilon^2}-\frac{2p}{\left(1-\varepsilon^2\right)^2}-\frac{p}{(1-\varepsilon)^2}-\frac{p}{(1+\varepsilon)^2}=0,$$

leading to $p_{ai}^{CM}=\frac{1-\varepsilon^2}{4-\varepsilon^2}$. Substituting back into the expected profit function, we have $EBuS_{ai}^{CM}=\frac{1}{4-\varepsilon^2}$.

## References


Alcalde, J., & Dahm, M. (2013). Competition for procurement shares. *Games and Economic Behavior, 80*, 193–208.

Alcalde, J., & Dahm, M. (2019). Dual sourcing with price discovery. *Games and Economic Behavior, 115*, 225–246.

Anton, J. J., Biglaiser, G., & Vettas, N. (2014). Dynamic price competition with capacity constraints and a strategic buyer. *International Economic Review, 55*(3), 943–958.

Anton, J. J., & Yao, D. A. (1989). Split awards, procurement, and innovation. *The RAND Journal of Economics,, 20*(4), 538–552.

Anton, J. J., & Yao, D. A. (1992). Coordination in split award auctions. *The Quarterly Journal of Economics, 107*(2), 681–707.

Bel, G., & Sebő, M. (2020). Introducing and enhancing competition to improve delivery of local services of solid waste collection. *Waste Management, 118*, 637–646.

Biancalani, F., Gnecco, G., & Riccaboni, M. (2022). Price-volume agreements: A one principal/two agents model. *European Journal of Operational Research, 300*(1), 296–309.

Blair, R. D., & Durrance, C. P. (2014). Group purchasing organizations, monopsony, and antitrust policy. *Managerial and Decision Economics, 35*, 433–443.

Bru, L., & Cardona, D. (2016). Strategic sourcing in procurement. Working Paper No. 82, Universitat de les Illes Balears, Departament d'Economía Aplicada.

Bucciol, A., Camboni, R., & Valbonesi, P. (2020). Purchasing medical devices: The role of buyer competence and discretion. *Journal of Health Economics, 74*, 102370.

Burguet, R., & Sákovics, J. (2017). Bertrand and the long run. *International Journal of Industrial Organization, 51*, 39–55.

Cantillon, E., & Pesendorfer, M. (2006). Auctioning bus routes: The london experience. *Combinatorial Auctions, 22*, 573–592.

Cantillon, E., & Pesendorfer, M. (2007). Combination bidding in multi-unit auctions. CEPR Discussion paper #6083.

Coase, R. (1972). Durability and monopoly. *Journal of Law and Economics, 15*(1), 143–149.

De Silva, D. G., Dunne, T., & Kosmopoulou, G. (2002). Sequential bidding in auctions of construction contracts. *Economics Letters, 76*(2), 239–244.

De Silva, D. G., Dunne, T., & Kosmopoulou, G. (2003). An empirical analysis of entrant and incumbent bidding in road construction auctions. *The Journal of Industrial Economics, 51*(3), 295–316.

Fugger, N., & Laitenberger, U. (2020). Split-award auctions and supply disruptions. ZEW Discussion Papers 20-082, Mannheim. http://hdl.handle.net./10419/228443.

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

Grimm, V., Pacini, R., Spagnolo, G., & Zanza, M. (2006). Division into lots and competition in procurement. In N. Dimitri, G. Piga, & G. Spagnolo (Eds.), *Handbook of procurement* (pp. 168–192). Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511492556.008

Hazra, J., & Mahadevan, B. (2009). A procurement model using capacity reservation. *European Journal of Operational Research, 193*(1), 303–316.

Inderst, R. (2008). Single sourcing versus multiple sourcing. *RAND Journal of Economics, 39*(1), 199–213.

Iossa, E., Rey, P., & Waterson, M. (2022). Organizing competition for the market. *Journal of the European Economic Association*. forthcoming. https://doi.org/10.1093/jeea/jvab044

Iossa, E., & Waterson, M. (2019). Maintaining competition in recurrent procurement contracts: A case study on the london bus market. *Transport Policy, 75*, 141–149.

Jofre-Bonet, M., & Pesendorfer, M. (2003). Estimation of a dynamic auction game. *Econometrica, 71*(5), 1443–1489.

Kleindorfer, P. R., & Wu, D. J. (2003). Integrating long-and short-term contracting via business-to-business exchanges for capital-intensive industries. *Management Science, 49*(11), 1597–1615.

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

Liang, X., Ma, L., Xie, L., & Yan, H. (2014). The informational aspect of the group-buying mechanism. *European Journal of Operational Research, 234*(1), 331–340.

Rooney, C. (2011). The value of group purchasing organizations in the united states. *World Hospitals and Health Services, 47*(1), 24–26.

Saini, V. (2012). Endogenous asymmetry in a dynamic procurement auction. *The RAND Journal of Economics, 43*(4), 726–760.

Stokey, N. L. (1979). Intertemporal price discrimination. *Quarterly Journal of Economics*, 355–371.

Tunca, T. I., & Wu, Q. (2009). Multiple sourcing and procurement process selection with bidding events. *Management Science, 55*(5), 763–780.

Wu, D. J., & Kleindorfer, P. R. (2005). Competitive options, supply contracting, and electronic markets. *Management Science, 51*(3), 452–466.

Wu, D. J., Kleindorfer, P. R., & Zhang, J. E. (2002). Optimal bidding and contracting strategies for capital-intensive goods. *European Journal of Operational Research, 137*(3), 657–676.

Zhao, Y., Choi, T. M., Cheng, T. E., & Wang, S. (2018). Supply option contracts with spot market and demand information updating. *European Journal of Operational Research, 266*(3), 1062–1071.