Optimal procurement and outsourcing of production in small industries

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Abstract

I study the interaction between optimal procurement and outsourcing of production in small industries. First, two sellers decide about outsourcing. By outsourcing, a seller loses information about the costs of producing to his supplier. Then the buyer designs the procurement mechanism and sellers who outsourced production subcontract with their respective suppliers. The focal equilibrium might exhibit bilateral outsourcing although outsourcing is modeled to have no direct positive effects. When a seller is able to extract his supplier's rent ex ante, the focal equilibrium exhibits bilateral outsourcing for any distribution of production costs satisfying a regularity condition.

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1. Introduction

In an industry in which a buyer can purchase from different sellers, I study the sellers' optimal vertical structure when the buyer responds with his purchasing strategy on the sellers' outsourcing decisions. Outsourcing of production may often reduce the costs of producing, but it comes typically along with a loss of information. I offer a novel explanation for why sellers in small industries might use outsourcing as a strategic tool. The argument is based on strategic effects and does not rely on cost reductions or any other direct positive effects associated with outsourcing.[3]

During the last few decades outsourcing was a very popular business strategy. Firms like Nike and Proctor & Gamble outsourced production almost entirely (see The Economist (2006)). However, outsourcing might also cause severe problems. An example is the large civil aircraft industry. The industry is the duopoly of Airbus and Boeing. Both firms engaged in massive outsourcing in the production of the A350 and the Dreamliner, respectively,[4] whereas they outsourced very little in the production of previous models.[5] After both firms had to struggle with quality problems and repeated delays, an intense discussion about the outsourcing decisions arose. Outsourcing decisions are usually driven by many factors and have ample consequences such as a loss of visibility and information as well as incentive problems.[6] This article aims at the better understanding of the pros and cons of outsourcing. I am interested in the strategic interaction of a seller's outsourcing decision with the other sellers' strategic behavior and with the buyer's purchasing strategy. I abstract from quality issues and moral hazard problems which are also important for the evaluation of many applied outsourcing problems in order to highlight effects which are related to the loss of information.

I consider an independent private values procurement auction set–up with a single buyer who must procure from one of two potential sellers. What is non–standard is that the sellers have ex ante the opportunity to outsource production. When a seller outsources production, the production cost c_i is learned and borne by his supplier instead of by himself. The seller basically becomes an intermediary who has to subcontract

[3] If cost reductions are present, the argument can be seen as one in favor of outsourcing of production instead of buying and integrating a supplier.

[4] According to Betts (2007), "Boeing [...] outsourced more than 90 per cent of the parts for its 787 Dreamliner, [...]. Airbus is now proposing the same approach for its A350, outsourcing about 50 per cent of the aero structure work to low–cost regions."

[5] According to Betts (2007), "Boeing and Airbus are both developing new airliners in a radically new way. In the old days, the companies designed, engineered and manufactured as much as possible in-house, subcontracting components on a strict build-to-print basis. These days, they are increasingly devolving not only components but also design and engineering tasks to international risk-sharing partners."

[6] In the Boeing–Airbus example, guaranteed sales from countries to which production is outsourced, risk–sharing with suppliers, lower production cost and the speeding up of R&D and production are often mentioned as reasons for the outsourcing decisions. See, e.g., Allon (2012).

with his supplier. The timing is as follows: First, the sellers simultaneously decide about outsourcing. Second, the outsourcing decisions become observable and the buyer designs a procurement mechanism. Third, production costs are learned and each seller who outsourced production designs a subcontracting mechanism. The subcontracting mechanism governs the transfer payment to the supplier and the behavior in the procurement mechanism. It is not observable outside the seller–supplier relationship. Fourth, the mechanisms are played and payoffs realize.

In the subcontracting stage, each seller who outsourced production internalizes the informational rent he has to leave to his supplier. He chooses a subcontracting mechanism that induces a behavior in the procurement mechanism which is as if he produced in–house, knew c_i and produces at some cost $k(c_i) \geq c_i$ (Proposition 1).

The buyer's design problem in the second stage reduces to a standard procurement auction design problem with two possibly asymmetric sellers. In the reduced problem, a seller who outsourced production has for the same c_i higher costs and higher virtual costs than a seller who produces in–house. Both properties are a consequence of the double marginalization of information rents. Under a regularity assumption which ensures that virtual costs are increasing, it is optimal for the buyer to procure from the seller with the lowest virtual costs (Proposition 2). In symmetric situations, i.e., under bilateral outsourcing and under bilateral in–house production, the buyer procures from the seller with the lower c_i. Under unilateral outsourcing, the stronger seller who produces in–house gets favored. The buyer procures only from the weaker seller who outsourced production when he has a sufficiently lower c_i. Hence, from the viewpoint of the weaker seller, outsourcing leads to higher costs and also to a disfavoring through the procurement mechanism.

The question arises why a seller might decide to outsource production in the first stage. Besides the two negative effects, there is a positive strategic effect associated with outsourcing. Intuitively, if one seller outsources production, the other seller competes less fiercely.[7] As a consequence, if a seller won in the same cases (i.e., for the same c_i) for each of his outsourcing decisions, his expected profit would be strictly higher under outsourcing than under in–house production. What drives this effect from a mechanism design perspective is that outsourcing stretches the distribution of production costs which a seller faces. Stretching unambiguously increases a seller's informational rent for a given allocation (and a given expected profit for his worst possible cost realization). It follows that both sellers strictly prefer bilateral outsourcing to bilateral in–house production. Thus, if bilateral outsourcing constitutes an equilibrium, it is very focal.

[7]Whether an interpretation of more or less fierce competition is appropriate depends on how the procurement mechanism is implemented. It is most appropriate when a reverse first–price auction is used to implement the buyer's preferred direct procurement mechanism. See Subsection 4.4 for a discussion of such an implementation.

Whether bilateral outsourcing is stable depends on how profitable it is for a seller to deviate unilaterally to in–house production. By deviating, a seller wins more often as he gets favored through the procurement mechanism, but he yields lower profits conditional on winning as the other seller starts competing more fiercely. The resolution of this trade–off depends on the distribution of c_i. Heuristically, the higher the realization of c_i, the more a seller benefits from getting favored and the less he benefits from a higher rent conditional on winning. When the distribution is a power function $F(c_i) = c_i^a$ with $a > 0$, deviating is more profitable if the parameter a is higher as then high cost realizations are more likely. I find that bilateral outsourcing constitutes an equilibrium if $a \leq 1$ but not if $a > 1$ (Proposition 3). When I consider the modified outsourcing game in which a seller who outsources production can extract his supplier's rent ex ante, outsourcing becomes more attractive for a seller. Bilateral outsourcing constitutes then an equilibrium for any distribution satisfying regularity conditions (Proposition 4). However, the result has to be seen as one for small industries. When the number of sellers grows, the higher rent conditional on winning associated with outsourcing stays unaffected, but a seller who deviates unilaterally to in–house production gets favored over more and more sellers. In–house production becomes relatively more attractive. For the class of distributions I considered already in Proposition 3, I can show that multilateral outsourcing does not constitute an equilibrium when the number of sellers is sufficiently large (Proposition 5).

The article is organized as follows: In the next section I discuss the related literature. Then I introduce the game that is played after outsourcing decisions are taken in Section 3 and I analyze it in Section 4. In Section 5, I augment the base model by an outsourcing stage. The analysis in Section 4 allows me to reduce the last stages of the game. I analyze the reduced outsourcing game without rent extraction in Subsection 5.1 and that with rent extraction in Subsection 5.2. Finally, I discuss extensions and robustness in Section 6, and I conclude in Section 7.

2. Literature

A seller's decision to outsource production can be interpreted as a precommitment to behave less competitively in the buyer's procurement mechanism. Such a precommitment might affect the other players' behavior in the procurement mechanism as well. Schelling (1960) argues that precommitment in conflict situations can be beneficial and that precommitment can happen through delegation. Katz (1991) demonstrates that delegation can under certain conditions (e.g., asymmetric information between principal and agent) serve as a precommitment even when the agency contract is unobservable. I investigate whether such a precommitment can be beneficial for a seller in the specific problem I am interested in. More specifically, the central question will be under which conditions it can be optimal for each seller to simultaneously opt for such a precommitment. As outsourcing makes a seller clearly weaker, it is a priori quite unclear whether conditions exist under which it is optimal for a seller to outsource production. First, outsourcing comes with the danger of being exploited by the other seller (which he can do by deciding not to become weak himself). Second, the buyer tries to counteract attempts to induce cooperation. She rewards deviations from cooperation by bilateral outsourcing through her procurement mechanism choice.

My paper is related to the literature on the optimal organization of production by a principal.[8] Baron and Besanko (1992) and Gilbert and Riordan (1995) study the procurement of two perfectly complementary inputs. The marginal production cost of each input is privately learned by its producer. The principal decides about whether each input is produced by a different agent or whether a single agent produces both inputs, and about who contracts with whom.[9] Severinov (2008) and Mookherjee and Tsumagari (2004) allow also for the possibility that the inputs are substitutes. This case is related to the procurement problem I study. The analysis in these articles implies for this case that the principal prefers contracting with each agent separately to contracting with a merged agent who produces both inputs. A two–tier production network is never strictly optimal for the principal. In my article, the structure of the production network is not designed by a principal, but arises through choices of the agents. The focal equilibrium may exhibit a production network with a two–tier structure.

McAfee and McMillan (1995) study the loss of control associated with delegated contracting. They show that aggregating information along longer hierarchies is more costly.[10] A principal who wants to purchase a good from an agent who is privately informed about the production costs prefers contracting directly with the agent to contracting with an uninformed middle principal who is protected by limited liability and who contracts in turn with the agent. The structure of the hierarchy is exogenous. I investigate the endogenous emergence of multi–tier hierarchies in a setting in which the principal can purchase from competing hierarchies of endogenous length.

In the literature on delegation in contests, the participants in the contest decide themselves about delegation as in my article, but the contest game is exogenously given. Delegation of effort provision in two player Tullock contests is analyzed by Baik and Kim (1997) and by Wärneryd (2000). Baik and Kim consider the case in which delegation is voluntary but the contract between a player and his delegate

[8]See Mookherjee (2006) for a broader review of this literature.

[9]Baron and Besanko (1999) and Dequiedt and Martimort (2004) study problems in which two agents who provide perfectly complementary inputs can affect the structure of the supply network by consolidating themselves into a single entity.

[10]Faure-Grimaud and Martimort (2001) introduce a further agency cost associated with subcontracting which relies on risk–aversion on the intermediaries side.

is exogenously given. Bilateral delegation may arise endogenously. Wärneryd considers the case with endogenous contracting but mandatory delegation. He argues that voluntary delegation would induce a prisoner's–dilemma–like structure. Konrad et al. (2004) study voluntary delegation in conjunction with optimal contracting for a first–price all–pay auction with two bidders. In the case where delegates are protected by limited liability and in which there is an upper limit on transfers, there exist only asymmetric equilibria with unilateral delegation. In all three articles, delegation reduces competitiveness by raising the costs of competition through incentive problems and limited liability. Whether bilateral delegation might be stable depends strongly on the considered exogenously given contest game. In my article, delegation has a similar effect although it induces an adverse selection instead of a moral hazard problem: It reduces competitiveness by raising the costs of competition through informational rents that have to be left to the delegates. However, the focus of my article is the interplay of the delegation decisions with the design of the game and the question under which conditions bilateral delegation is stable.

3. The base model

A buyer has to purchase a product from one of two sellers ($i = 1, 2$). Each seller is characterized by whether he produces in–house ($\alpha_i = I$) or has outsourced production to a supplier ($\alpha_i = O$). α_i is observable and it is exogenous until I endogenize it in Section 5. Outsourcing comes along with a loss of information. The producer of product i privately learns the production costs c_i. I.e., c_i is learned by seller i if $\alpha_i = I$ and by the supplier to seller i if $\alpha_i = O$. The production costs c_1 and c_2 are the realizations of independent and identically distributed random variables C_1 and C_2, respectively. The cumulative distribution function $F(c_i)$ is log–concave with density $f(c_i)$ and with support $\mathcal{C} := [0, 1]$.[11] Moreover, I assume that the inverse reversed hazard rate F/f is differentiable and that $f(1) > 0$. I denote the probability with which the buyer purchases from seller i by q_i, her payment to seller i by t_i and, if $\alpha_i = O$, the payment of seller i to his supplier by s_i. If $\alpha_i = I$, seller i's profit is $t_i - q_i c_i$. If $\alpha_i = O$, seller i's profit is $t_i - s_i$ and his supplier's profit is $s_i - q_i c_i$. The buyer minimizes the procurement costs $t_1 + t_2$.[12]

I am interested in the problem where the buyer designs a procurement mechanism and where each seller who outsourced production reacts by subcontracting with his supplier. Subcontracting is not contractible. The procurement mechanism can only specify who has to produce and which payments have to be made as a function of the sellers' reports. Participation of suppliers in subcontracting mechanisms and of sellers

[11] Log–concavity is standard in auction theory and satisfied for the most commonly used distributions. It is equivalent to the the inverse reversed hazard rate $F(c_i)/f(c_i)$ being increasing. See Bagnoli and Bergstrom (2005).

[12] The buyer's payoff may be considered as $(q_1 + q_2)v - t_1 - t_2$ where v is large enough such that she always wants to buy. I discuss in Section 6 what happens when this assumption is relaxed.

in the procurement mechanism is voluntary. By not participating, any seller/supplier can ensure himself a profit of zero. I can restrict attention to procurement mechanisms/subcontracting mechanisms where each seller/supplier always participates, but where the mechanism is designed such that participation is individually rational.[13] Moreover, I am interested in the case where a seller who outsourced production decides about participation after contracting with his supplier. A subcontract specifies a transfer payment to the supplier and a behavior in the procurement mechanism which both become only effective when the seller participates in the procurement mechanism.[14]

The timing of the game is as follows: First, the buyer designs a procurement mechanism $(\mathcal{B}_1, \mathcal{B}_2, q, t)$ with $q : \mathcal{B}_1 \times \mathcal{B}_2 \to [0,1]^2$, $q_1(b_1, b_2) + q_2(b_1, b_2) = 1$ and $t : \mathcal{B}_1 \times \mathcal{B}_2 \to \mathbf{R}^2$. The non–empty set $\mathcal{B}_i$ describes the messages feasible to seller i. As I will be ultimately interested in the implementation of the optimal mechanism in form of an auction, a message $b_i \in \mathcal{B}_i$ can be thought of as a bid. $q = (q_1, q_2)$ describes the allocation rule and $t = (t_1, t_2)$ the payment rule. Second, the procurement mechanism is observed and production costs are learned. Third, each seller who outsourced production chooses a direct subcontracting mechanism (b_i, s_i) with $b_i : \mathcal{C} \to \mathcal{B}_i$ and $s_i : \mathcal{C} \times \mathcal{B}_1 \times \mathcal{B}_2 \to \mathbf{R}$.[15] b_i describes the bidding rule and s_i the rule for transfer payments. Seller i's subcontracting mechanism is only observed by his supplier.[16] Fourth, bids are simultaneously submitted: If $\alpha_i = I$, seller i chooses a bid $b_i \in \mathcal{B}_i$ directly. If $\alpha_i = O$, seller i's supplier announces a cost parameter $\widehat{c}_i \in \mathcal{C}$ which determines the bid $b_i(\widehat{c}_i)$ indirectly. Finally, payoffs realize. As equilibrium concept I adopt the notion of Perfect Bayesian equilibrium.

4. Analysis of the base model

4.1. The optimal subcontracting mechanism

I first study optimal subcontracting by a seller i who outsourced production. Seller i's subcontracting problem is specified by the chosen procurement mechanism $(\mathcal{B}_1, \mathcal{B}_2, q, t)$ and by the supposed bidding behavior $b_{-i}(c_{-i})$ of the other seller whom I denote by $-i$. Thereby it is not important whether the other seller chooses a bid directly or whether it arises indirectly from subcontracting. For a given subcontracting problem, only the ad interim expected probability of producing $\overline{q}_i(c_i) := \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]$

[13] E.g., this can be trivially achieved by including a message in the procurement mechanism/in each subcontract that yields a zero probability of producing and a zero payment.

[14] If the seller had to decide on participation before he can elicit information, the buyer could extract his entire expected profit through a a participation fee. Melumad et al. (1995) impose a similar participation assumption as I do. Similar effects are also induced by alternative assumptions, for example when the seller has to decide on participation before subcontracting and he is either protected by limited liability (see McAfee and McMillan (1995)) or he is risk–averse (see Faure-Grimaud and Martimort (2001)).

[15] As a seller who outsourced production is not subject to a commitment problem in the relation with his supplier, restricting attention to direct subcontracts is by the revelation principle without loss of generality.

[16] See Katz (1991) for a motivation of such a non–observability assumption.

and the ad interim expected transfer $\overline{s}_i(c_i) := \mathbf{E}[s_i(C_i, b_1(C_1), b_2(C_2))|C_i = c_i]$ matter for the supplier's problem. Incentive compatibility requires that the announcement $\widehat{c}_i = c_i$ maximizes $\overline{s}_i(\widehat{c}_i) - \overline{q}_i(\widehat{c}_i)c_i$ for any c_i. Individual rationality requires that $\overline{s}_i(c_i) - \overline{q}_i(c_i)c_i \geq 0$ for any c_i. The derivation of the optimal subcontract is standard in incentive theory, except for the fact that the seller can only induce subcontracts for which his own ad interim participation constraint is satisfied (see, e.g., Baron and Myerson (1982)). The following lemma characterizes the set of incentive compatible subcontracts for which participation is individually rational:

Lemma 1 *For a given subcontracting problem, a subcontracting mechanism (b_i, s_i) is incentive compatible and participation is individually rational if and only if $\overline{q}_i(c_i)$ is non–increasing and $\overline{s}_i(c_i) = \overline{q}_i(c_i)c_i + \int_{c_i}^1 \overline{q}_i(c)dc + \kappa$ with $\kappa \geq 0$.*

Seller i's choice of a subcontracting mechanism reduces to the choice of a bidding behavior $b_i : \mathcal{C} \to \mathcal{B}_i$ and a constant $\kappa \geq 0$. His expected profit can be written as

$$\begin{aligned}
& \mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - s_i(C_i, b_1(C_1), b_2(C_2))] \\
= \; & \int_0^1 \left(\int_0^1 t_i(b_1(C_1), b_2(C_2)) f(c_{-i}) \mathrm{d}c_{-i} - \overline{q}_i(c_i)c_i - \int_{c_i}^1 \overline{q}_i(c)\mathrm{d}c \right) f(c_i)\mathrm{d}c_i - \kappa \\
= \; & \int_0^1 \left(\int_0^1 t_i(b_1(C_1), b_2(C_2)) f(c_{-i}) \mathrm{d}c_{-i} - \overline{q}_i(c_i) \left(c_i + \frac{F(c_i)}{f(c_i)} \right) \right) f(c_i)\mathrm{d}c_i - \kappa \\
= \; & \mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - q_i(b_1(C_1), b_2(C_2))k(C_i)] - \kappa \text{ with } k(c_i) := c_i + F(c_i)/f(c_i). \qquad (1)
\end{aligned}$$

The second inequality follows from Lemma 1 and the third from partial integration. As seller i has no private information when he designs the subcontracting mechanism, he chooses b_i and κ to maximize his expected profit (1) subject to the monotonicity constraint and to his own ad interim participation constraint

$$\mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - s_i(C_i, b_1(C_1), b_2(C_2))|C_i = c_i] \geq 0 \qquad (2)$$

for any c_i.

Observe first that $\kappa = 0$ is clearly optimal. When I ignore the monotonicity constraint and seller i's own individual rationality constraint, maximization of seller i's expected profit corresponds to pointwise maximization of his ad interim expected profit

$$\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i = c_i] - \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]k(c_i). \qquad (3)$$

As $k(c_i)$ is increasing by concavity of $\ln(F(c_i))$, standard incentive compatibility arguments imply that $\mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]$ is non–increasing in c_i for the optimal b_i. I.e., maximization of (3) implies a bidding behavior $b_i(c_i)$ for which the ignored monotonicity constraint is satisfied.

Notice that by maximizing (3) the seller behaves as if he faces costs $k(c_i)$, while his participation incentives depend on his actual (ad interim) costs $\mathbf{E}[s_i(C_i, b_1(C_1), b_2(C_2))|C_i = c_i]$. It is thus not trivial that the ignored individual rationality constraint is also satisfied. By standard reasoning, (2) is satisfied for any c_i if it is satisfied for the worst realization of the cost parameter $c_i = 1$. I.e., sufficient for (2) is $\mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - s_i(C_i, b_1(C_1), b_2(C_2))|C_i = 1] \geq 0$. By using Lemma 1 with $\kappa = 0$, I can write this as $\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i = 1] \geq \overline{q}_i(1)$. As the seller has the possibility of choosing a bid which induces a zero probability of winning and a zero payoff,[17] maximization of (3) for $c_i = 1$ implies $\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i = 1] \geq \overline{q}_i(1)(1 + 1/f(1))$. Hence, also the ignored participation constraint is satisfied.

The above discussion yields the following result:

Proposition 1 *For any given subcontracting problem, $b_i(c_i)$, seller i's incentive to participate in the procurement mechanism and seller i's expected profit are under the optimal subcontracting mechanism such as if $b_i(c_i)$ was chosen by a seller who knows c_i, produces in–house and has production costs $k(c_i) := c_i + F(c_i)/f(c_i)$.*

As seller i is not subject to a commitment problem in the relation with his supplier, he can extract any information and he can use this information at will. However, he has to leave an informational rent to his supplier which depends on how the extracted information is used. From an ex ante perspective, inducing his supplier to produce for a given c_i causes costs $k(c_i)$ for seller i. It follows that the induced bidding behavior is such as if seller i knew c_i, had production costs $k(c_i)$ and produced in–house. This entails that any information that the buyer wants to extract from seller i, seller i is able to extract from his supplier.

Using the mechanism design terminology introduced in Myerson (1981), $k(c_i)$ describes seller i's virtual costs of producing. Notice that his actual production costs differ from $k(c_i)$. E.g., the transfer $s_i(c_i)$ which the supplier receives under the optimal subcontracting mechanism can be designed such that he obtains the price $p_i(c_i) := c_i + \int_{c_i}^{1} \overline{q}_i(c)/\overline{q}_i(c_i)\mathrm{d}c$ when he has to produce and nothing otherwise. $p_i(c_i)$ does not correspond to $k(c_i)$.

The virtual costs $k(c_i)$ play the same role for a seller under outsourcing as the actual costs c_i do under in–house production. This is similar to what is observed in McAfee and McMillan (1995) for a setting with an ex ante participation constraint and limited liability. As $k(0) = 0$ and $k'(c_i) \geq 1$ (which follows from log–concavity of F), the (virtual) costs of producing that a seller faces when he outsources production are stretched upwards relative to his (actual) costs of producing when he produced in–house instead. Thus, disregarding strategic effects, outsourcing is purely wasteful for a seller.

[17] He has at least virtually this possibility. See Footnote 13.

4.2. The optimal procurement mechanism

From the viewpoint of the buyer, a seller who outsources production is by Proposition 1 just like a seller who produces in–house, but who has production costs $k(c_i)$ instead of c_i. I will henceforth slightly abuse notation by referring to $k(c_i)$ simply as seller i's production costs (instead of his virtual production costs). I.e., when I refer henceforth to seller i's production costs, I will mean c_i if $\alpha_i = I$ and $k(c_i)$ if $\alpha_i = O$.[18] The buyer's design problem can be handled as a standard procurement auction design problem with two possibly asymmetric sellers. The analysis of such problems is standard (see Myerson (1981)). By the revelation principle, it is without loss of generality to restrict attention to direct revelation mechanisms, i.e., mechanisms with $\mathcal{B}_1 = \mathcal{B}_2 = \mathcal{C}$. Using notation $\overline{q}_i^d(c_i) := \mathbf{E}[q_i(C_1, C_2)|C_i = c_i]$ and $\overline{t}_i^d(c_i) := \mathbf{E}[t_i(C_1, C_2)|C_i = c_i]$, seller i chooses an announcement $\widehat{c}_i \in \mathcal{C}$ to maximize $\overline{t}_i^d(\widehat{c}_i) - \overline{q}^d(\widehat{c}_i)c_i$ if $\alpha_i = I$ and to maximize $\overline{t}_i^d(\widehat{c}_i) - \overline{q}^d(\widehat{c}_i)k(c_i)$ if $\alpha_i = O$. The subsequent lemma characterizes the set of incentive compatible mechanisms for which the sellers' individual rationality constraints are binding:

Lemma 2 *A direct procurement mechanism $(\mathcal{C}, \mathcal{C}, q, t)$ is incentive compatible with binding individual rationality constraints if and only if $\overline{q}_i^d(c_i)$ is non–increasing and $\overline{t}_i^d(c_i) = \overline{q}_i^d(c_i)c_i + \int_{c_i}^1 \overline{q}_i^d(c)dc$ when $\alpha_i = I$ and $\overline{t}_i^d(c_i) = \overline{q}_i^d(c_i)k(c_i) + \int_{c_i}^1 \overline{q}_i^d(c)k'(c)dc$ when $\alpha_i = O$.*

If $\alpha_i = O$, the expected transfer of the buyer to seller i is

$$\begin{aligned}
\mathbf{E}[t_i(C_1, C_2)] &= \int_0^1 \left(\overline{q}_i^d(c_i)k(c_i) + \int_{c_i}^1 \overline{q}_i^d(c)k'(c)\mathrm{d}c \right) f(c_i)\mathrm{d}c_i \\
&= \int_0^1 \overline{q}_i^d(c_i) \left(k(c_i) + \frac{F(c_i)}{f(c_i)}k'(c_i) \right) f(c_i)\mathrm{d}c_i \\
&= \mathbf{E}[q_i(C_1, C_2)J_O(C_i)] \text{ with } J_O(c_i) := k(c_i) + \frac{F(c_i)}{f(c_i)}k'(c_i). \qquad (4)
\end{aligned}$$

The first equality follows from Lemma 2, the second from partial integration. If $\alpha_i = I$, the expected transfer to seller i follows from the same reasoning with $k(c_i)$ replaced by c_i. It is given by

$$\mathbf{E}[t_i(C_1, C_2)] = \mathbf{E}[q_i(C_1, C_2)J_I(C_i)] \text{ with } J_I(c_i) := k(c_i). \qquad (5)$$

The buyer's expected procurement costs are thus $\mathbf{E}[\sum_i q_i(C_1, C_2)J_{\alpha_i}(C_i)]$. $J_{\alpha_i}(c_i)$ describes the virtual costs of purchasing from a seller with information c_i and vertical structure α_i. When I ignore the monotonicity constraints, minimization of the buyer's expected procurement costs corresponds to pointwise minimization of $\sum_i q_i(C_1, C_2)J_{\alpha_i}(C_i)$. I.e., the procurement contract is awarded to a seller with the lowest virtual costs.

[18]Besides being appropriate for the reduced problem I study from now on, this notational convention has the advantage that the linguistic distinction between a seller's virtual costs (of producing) and the buyer's virtual costs (of purchasing) will become clearer.

When $J_I(c_i)$ and $J_O(c_i)$ are both increasing, a standard reasoning can be applied. Then pointwise optimization implies an allocation rule for which the ignored monotonicity constraints are satisfied. The virtual costs of a seller who produces in–house $J_I(c_i)$ are the standard virtual costs known from auction theory. $J_I(c_i)$ is increasing for any log–concave distribution function. The production costs of a seller who outsources production $k(c_i)$ are basically already virtual costs as they incorporate the information rent the seller has to leave to his supplier. The virtual costs of purchasing from such a seller $J_O(c_i)$ are virtual costs of virtual costs. The solution to the buyer's problem is monotonic under the following regularity assumption:

Assumption 1 *$J_O(c_i)$ is increasing.*[19]

When the required derivatives exist, Assumption 1 is implied by $h''(c_i) > -(1 + h'(c_i))^2/h(c_i)$ with $h(c_i) = F(c_i)/f(c_i)$.[20] I.e., the assumption is satisfied if the inverse reversed hazard rate $F(c_i)/f(c_i)$ is not too concave. This is for example the case for any distribution function $F(c_i) = c_i^a$ with $a > 0$.

The discussion above implies the following result:

Proposition 2 *Suppose Assumption 1 holds. Any procurement mechanism where the allocation rule minimizes $\sum_i q_i(c_1, c_2)J_{\alpha_i}(c_i)$ and where the payment rule satisfies the conditions in Lemma 2 is optimal.*

In symmetric situations, i.e., when both sellers produce in–house or when both sellers outsource production, the optimal allocation does not depend on the sellers' vertical structure. The seller with the lowest c_i wins. In an asymmetric situation, the seller who produces in–house gets favored under the optimal procurement mechanism as

$$J_O(c) = J_I(c) + F(c)/f(c) \cdot J_I'(c) > J_I(c) \text{ for any } c > 0. \tag{6}$$

Because of a double marginalization of rents, outsourcing increases not only a seller's costs, but also his virtual costs.

Example 1 *Suppose $F(c) = c^a$ with $a > 0$. A seller who outsources production behaves as if his costs are linearly higher: $k(c_i) = (1 + a)/a \cdot c_i$. The buyer's virtual costs of purchasing from seller i are linear for either vertical structure α_i: $J_I(c_i) = (1 + a)/a \cdot c_i$ and $J_O(c_i) = (1 + a)^2/a^2 \cdot c_i$. If $\alpha_1 = \alpha_2$, seller i wins when $c_{-i} > c_i$. It follows $\overline{q}_i^d(c_i) = 1 - (c_i)^a$. If $\alpha_i = I$ and $\alpha_{-i} = O$, seller i wins when $k(c_{-i}) > c_i$. I obtain for seller i $\overline{q}_i^d(c_i) = 1 - (a/(1 + a) \cdot c_i)^a$ and for seller $-i$ $\overline{q}_{-i}^d(c_{-i}) = 1 - ((1 + a)/a \cdot c_{-i})^a$ if $c_{-i} < a/(1 + a)$ and $\overline{q}_{-i}^d(c_{-i}) = 0$ otherwise.*

[19] The assumption is analogous to the standard regularity assumption imposed on many auction problems, but more complicated in terms of the primitives of the model. See also the discussion in McAfee and McMillan (1995).

[20] I can write $J_O(c_i) = c_i + h(c_i) + h(c_i)(1 + h'(c_i))$ such that $J_O'(c_i) = 1 + 2h'(c_i) + (h'(c_i))^2 + h(c_i)h''(c_i)$. This implies the inequality in the text.

4.3. Information rents and comparative statics

I can now describe the structure of the sellers' and the suppliers' expected profits which correspond to their expected information rents. Using (5), the expected profit of a seller who produces in–house is

$$\mathbf{E}[t_i(C_1, C_2) - q_i(C_1, C_2)C_i] = \mathbf{E}[q_i(C_1, C_2)F(C_i)/f(C_i)] = \int_0^1 \overline{q}_i^d(c_i)F(c_i)\mathrm{d}c_i. \tag{7}$$

By Lemma 1, the same formula describes the expected profit of seller i's supplier when seller i has outsourced production:

$$\mathbf{E}[s_i(C_i, C_1, C_2) - q_i(C_1, C_2)C_i] = \int_0^1 \overline{q}_i^d(c_i)F(c_i)\mathrm{d}c_i. \tag{8}$$

By (4) and Proposition 1, the expected profit of a seller who outsources production is

$$\mathbf{E}[t_i(C_1, C_2) - q_i(C_1, C_2)k(C_i)] = \mathbf{E}[q_i(C_1, C_2)F(C_i)/f(C_i) \cdot k'(C_i)] = \int_0^1 \overline{q}_i^d(c_i)F(c_i)k'(c_i)\mathrm{d}c_i. \tag{9}$$

The structure of the expected profit of a seller who outsources production differs from that of a seller who produces in–house. As $k'(c_i) > 1$ for any $c_i > 0$ by log–concavity of the distribution, a seller's expected profit is for a given allocation rule $q_i(c_1, c_2)$ higher under outsourcing than under in–house production. The reason is that the stretching of the distribution of production costs increases the information rent a seller earns. Thereby it is inessential that the stretching increases the production costs only. As the optimal allocation rule is by Proposition 2 the same for bilateral in–house production and for bilateral outsourcing, I have $\overline{q}_i^d(c_i) = (1 - F(c_i))$ in both cases. It follows from (7) and (8) that each seller's expected profit under bilateral outsourcing $\Pi_O^{(O,O)} := \int_0^1 (1 - F(c_i))F(c_i)k'(c_i)\mathrm{d}c_i$ is strictly higher than his expected profit under bilateral in–house production $\Pi_I^{(I,I)} := \int_0^1 (1 - F(c_i))F(c_i)\mathrm{d}c_i$. This proves the following result:

Lemma 3 *Under Assumption 1, the sellers' expected profits are higher under* $(\alpha_1, \alpha_2) = (O, O)$ *than under* $(\alpha_1, \alpha_2) = (I, I)$.

Note that not only sellers are better off under bilateral outsourcing, also each seller's supplier earns a positive profit $\Pi_S^{(O,O)}$ in this case.

Whereas I get a clear ranking of the cases where both sellers have the same vertical structure, a comparison of the symmetric cases with the asymmetric case in which one seller produces in–house and the other seller outsources production is less obvious. To see this, fix α_{-i} and consider how seller i's expected profit differs for $\alpha_i = I$ and for $\alpha_i = O$. As virtual costs are generally lower under in–house production (see (6)), Proposition 2 implies that seller i wins with a higher probability under $\alpha_i = I$. On the other hand, (7) and (9) imply that winning under $\alpha_i = O$ yields a higher information rent for seller i. It is a priori unclear whether seller i is better off under the symmetric situation in which he has the same vertical structure as seller $-i$ or under the asymmetric situation in which he has a different vertical structure. It is thus not obvious what happens when the sellers' vertical structure α_i is endogenous. Before I endogenize α_i in Section 5, I present an indirect implementation of the optimal procurement mechanism to give a better impression of the relevant effects.

4.4. Indirect implementation of the optimal procurement mechanism in the uniform case

Suppose C_i is uniformly distributed on $[0, 1]$. For any (α_1, α_2) the optimal procurement mechanism can be implemented by an absolute reverse first–price auction with possibly a bonus for one of the sellers. A bonus is a payment that a seller obtains in addition to his bid when he wins. As I am in this subsection only interested in the induced bidding behavior and in the sellers' expected profits, I can restrict attention to the reduced problem in which a seller with $\alpha_i = O$ knows c_i and has production costs $k(c_i) = 2c_i$ instead of c_i.

If $\alpha_1 = \alpha_2$, an absolute reverse first–price auction implements the optimal mechanism. The aggressiveness of the induced bidding behavior depends on α_i. For $(\alpha_1, \alpha_2) = (I, I)$ the induced bidding behavior is $b_I^{(I,I)}(c_i) = \frac{1}{2} + \frac{1}{2}c_i$,[21] whereas for $(\alpha_1, \alpha_2) = (O, O)$ bidding behavior $b_O^{(O,O)}(c_i) = 1 + c_i$ is induced.[22] Under bilateral outsourcing bidding is much less aggressive but production costs are higher. Losing is less harmful for a seller who outsourced production as it saves on informational rents he has to leave to his supplier. This makes him less eager to win and makes competition less fierce. As $b_O^{(O,O)}(c_i) - k(c_i) = 1 - c_i > b_I^{(I,I)}(c_i) - c_i = (1 - c_i)/2$, the less aggressive bidding behavior overcompensates for the higher production costs: The sellers are better off under bilateral outsourcing than under bilateral in–house production.

If $\alpha_1 \neq \alpha_2$, the optimal mechanism can be implemented by an absolute reverse first–price auction with a bonus for the stronger bidder. The seller who produces in–house (say, seller I) obtains a bonus $B(b_I) = (1 - b_I)/(3 - 2b_I)$ when he wins with bid $b_I \in [0, 1]$. At first glance, seller I seems to be strictly better off relative to the case in which both sellers outsource production: His production costs are lower (c_I instead of $k(c_I) = 2c_I$) and he gets favored by the procurement mechanism through the bonus payment. However, both effects entail a more aggressive bidding behavior by the other seller.[23] In particular, as the bonus is decreasing and concave in seller I's bid, it sets stronger incentives for seller I to reduce

[21] Seller i chooses b_i to maximize $\text{Prob}\{\frac{1}{2} + \frac{1}{2}C_{-i} > b_i\}(b_i - c_i) = (2 - 2b_i)(b_i - c_i)$. This yields the first–order condition $-2(b_i - c_i) + (2 - 2b_i) = 0$ and the optimal response $b_i = \frac{1}{2} + \frac{1}{2}c_i$.

[22] Seller i chooses b_i to maximize $\text{Prob}\{1 + C_{-i} > b_i\}(b_i - 2c_i) = (2 - b_i)(b_i - 2c_i)$. This yields the first–order condition $-(b_i - 2c_i) + (2 - b_i) = 0$ and the optimal response $b_i = 1 + c_i$.

[23] Kaplan and Zamir (2012) derive the bidding behavior in first–price auctions with two bidders when values are distributed according to asymmetric uniform distributions. Their results can be applied to obtain the bidding behavior in our (reverse) auction problem when there is no bonus for the strong bidder. This can be used to show that either factor, the asymmetry and the bonus, makes competition fiercer relative to the bilateral outsourcing case.

his bid for higher bids. I.e., it induces a flatter bidding behavior by seller I which induces in turn a more aggressive bidding by the seller who outsources production (say, seller O). The induced bidding behavior is $b_I^{(I,O)}(c_I) = \frac{1}{2} + \frac{1}{2}c_I$ by seller I and $b_O^{(I,O)}(c_O) = \frac{1}{2} + c_O$ by seller O.[24] Seller O bids exactly $\frac{1}{2}$ less relative to the bilateral outsourcing case ($b_O^{(I,O)}(c_O) - b_O^{(O,O)}(c_O) = -\frac{1}{2}$), seller I bids at least $\frac{1}{2}$ less ($b_I^{(I,O)}(c_I) - b_I^{(I,I)}(c_I) = -\frac{1}{2}(1 + c_I)$). As the bonus is at most $\frac{1}{3}$, seller I has a lower payoff conditional on winning with a given c_I, but he wins more often as he reduces his bidding behavior stronger than seller O. How the better cost distribution and the bonus affect seller I's expected profit is thus not obvious. In the uniform case it turns out that the direct negative effects and the positive strategic effects completely offset each other. Seller I is indifferent between the asymmetric situation and bilateral outsourcing. By contrast, how seller O compares the asymmetric case with bilateral in–house production is clear. As seller I behaves in both cases in the same way ($b_I^{(I,O)}(c_I) = b_I^{(I,I)}(c_I)$), seller O is strictly worse off in the asymmetric case due to the higher costs of production. I have summarized the sellers' expected profits for the different combinations of vertical structures (α_1, α_2) in Table 1.

[insert Table 1 here]

5. Analysis of the outsourcing game

In this section I endogenize the sellers' outsourcing decisions. Each seller's expected profit for a given (α_1, α_2) follows from the analysis in Section 4. It is specified by (7), (9) and the allocation rule characterized in Proposition 2. For a given (α_1, α_2), I denote the expected profit of a seller with vertical structure α_i by $\Pi_{\alpha_i}^{(\alpha_1,\alpha_2)}$. If $\alpha_i = O$, I denote the expected profit of seller i's supplier by $\Pi_S^{(\alpha_1,\alpha_2)}$.

Example 2 *Suppose $F(c) = c^a$ with $a > 0$. For such distributions, the optimal allocation can be computed explicitly and the formulas for expected profits are quite tractable. The ad interim winning probabilities are as described in Example 1. The formulas for expected profits follow from plugging the ad interim probabilities in (7), (8) and (9):*

$$\Pi_I^{(I,I)}(a) = \int_0^1 (1 - c_i^a) c_i^a \, dc_i = \frac{a}{a+1} \frac{1}{2a+1} \tag{10}$$

$$\Pi_O^{(O,O)}(a) = \int_0^1 (1 - c_i^a) c_i^a \frac{a+1}{a} \, dc_i = \frac{1}{2a+1} \tag{11}$$

$$\Pi_S^{(O,O)}(a) = \frac{a}{a+1} \Pi_O^{(O,O)}(a) \tag{12}$$

[24] Seller O chooses b_O to maximize $\text{Prob}\{\frac{1}{2} + \frac{1}{2}C_I > b_O\}(b_O - 2c_O) = (2 - 2b_O)(b_O - 2c_O)$. This yields the first–order condition $-2(b_O - 2c_O) + (2 - 2b_O) = 0$ and the optimal response $b_O = \frac{1}{2} + c_O$. Seller I chooses b_I to maximize $\text{Prob}\{\frac{1}{2} + C_O > b_I\}(b_I + B(b_I) - c_I) = (\frac{3}{2} - b_I)(b_I + (1 - b_I)/(3 - 2b_I) - c_I)$. This yields the first–order condition $-(b_I + (1 - b_I)/(3 - 2b_I) - c_I) + (\frac{3}{2} - b_I)(1 - 1/(3 - 2b_I)^2) = 0$ and the optimal response $b_I = \frac{1}{2} + \frac{1}{2}c_I$.

$$\Pi_I^{(I,O)}(a) = \int_0^1 (1 - \left(\frac{a}{a+1}c_i\right)^a) c_i^a dc_i = \frac{1}{a+1} - \left(\frac{a}{a+1}\right)^a \frac{1}{2a+1} \tag{13}$$

$$\Pi_O^{(I,O)}(a) = \int_0^{a/(a+1)} (1 - \left(\frac{a+1}{a}c_i\right)^a) c_i^a \frac{a+1}{a} dc_i = \left(\frac{a}{a+1}\right)^a \frac{a}{a+1}\frac{1}{2a+1} \tag{14}$$

$$\Pi_S^{(I,O)}(a) = \frac{a}{a+1}\Pi_O^{(I,O)}(a)$$

5.1. The outsourcing game without rent extraction

I first consider the case in which a seller who outsources production is not able to extract his supplier's rent ex ante. I augment the base model by a stage in which the sellers simultaneously choose $\alpha_i \in \{I, O\}$. Afterwards (α_1, α_2) becomes observable and the game described in Section 3 is played. This game can be reduced to a game which ends after the outsourcing decisions are taken and in which the sellers' payoffs are $(\Pi_{\alpha_1}^{(\alpha_1,\alpha_2)}, \Pi_{\alpha_2}^{(\alpha_1,\alpha_2)})$. I refer to this reduced game as the outsourcing game without rent extraction and I am interested in pure strategy equilibria of this game.[25]

For uniformly distributed costs, the outsourcing game is the matrix game displayed in Table 1. It possesses two Nash equilibria, (I, I) and (O, O). (O, O) Pareto–dominates (I, I) (from the viewpoint of the sellers), but it relies on weakly dominated strategies. This suggests that the structure of equilibria is sensitive to the distribution. For $F(c) = c^a$ with $a \in (0, 1)$, I obtain that (I, I) and (O, O) are both Nash equilibria which do not rely on weakly dominated strategies, whereas for $F(c) = c^a$ with $a \in (1, \infty)$, (I, I) is the unique Nash equilibrium.

Proposition 3 *Suppose $F(c) = c^a$ with $a > 0$. The outsourcing game without rent extraction has a Pareto–dominant Nash equilibrium. It is (O, O) for $a \in [0, 1]$ and (I, I) for $a \in (1, \infty)$.*

Proof. $\Pi_I^{(I,I)}(a) > \Pi_O^{(I,O)}(a)$ for any a follows directly from (10), (14) and $(a/(a+1))^a < 1$. I.e., given that one seller produces in–house, the other seller has a strict incentive to produce in–house as well. It follows that (I, I) is a Nash equilibrium and that there cannot exist an asymmetric Nash equilibrium. It remains to check under which conditions (O, O) also constitutes a Nash equilibrium, i.e., when $\Pi_O^{(O,O)}(a) \geq \Pi_I^{(I,O)}(a)$ is true. Using (11) and (13), the inequality can be simplified to $a^{a-1} \geq (a + 1)^{a-1}$. This is true if and only if $a \in (0, 1]$. The Pareto–dominance result is trivial for $a \in (1, \infty)$ as in this case there exists a unique Nash equilibrium. It follows from Lemma 3 for $a \in (0, 1]$. q.e.d.

As argued in Subsection 4.3, there are two countervailing effects associated with the outsourcing decision: For a given behavior of the other seller, in–house production leads to a higher winning probability but a smaller rent conditional on winning as compared to outsourcing. Whether it pays off to deviate from bilateral

[25] Mixed strategy equilibria may exist, but are less interesting. It turns out that there always exists a pure strategy equilibrium which is very focal. When I consider the modified game in which the outsourcing decisions are taken sequentially (which I discuss in Section 6 below), the focal equilibrium of the simultaneous move game becomes the unique equilibrium of the modified game, even if I would allow for mixed strategies.

outsourcing depends on the distribution. When $a > 1$, relatively much probability mass is on high cost parameters. Getting favored then has a large effect on a seller's winning probability: He wins with a much higher probability when his own cost parameter turns out to be high (which is relatively likely). Deviating from bilateral outsourcing is beneficial such that bilateral outsourcing constitutes no Nash equilibrium. By contrast, when $a < 1$, relatively much probability mass is on low cost parameters. The increase in winning probability from getting favored is relatively small. The sellers prefer the higher information rent conditional on winning such that bilateral outsourcing constitutes a Nash equilibrium. As both sellers strictly prefer bilateral outsourcing to bilateral in–house production by Lemma 3, bilateral outsourcing constitutes the focal Nash equilibrium.

5.2. The outsourcing game with rent extraction

I now allow for the possibility that a seller who outsources production extracts his supplier's rent ex ante. I analyze the reduced game which is like the reduced game in Subsection 5.1, but in which the payoff of a seller who outsources production is $\Pi_O^{(\alpha_1,\alpha_2)} + \Pi_S^{(\alpha_1,\alpha_2)}$ instead of $\Pi_O^{(\alpha_1,\alpha_2)}$.[26] I refer to this reduced game as the outsourcing game with rent extraction.

Recall that a seller's trade–off in the outsourcing game without rent extraction is between a higher rent conditional on winning ($\alpha_i = O$) and a higher winning probability ($\alpha_i = I$). The possibility to extract the supplier's rent makes the higher rent conditional on winning even higher. It turns out that this makes outsourcing sufficiently more attractive such that bilateral outsourcing constitutes a Nash equilibrium for any distribution satisfying Assumption 1. The proof makes only use of a very rough upper bound of the expected profit from deviating from bilateral outsourcing: When $\alpha_{-i} = O$, seller i would still prefer $\alpha_i = O$, even if he won for sure when he chose $\alpha_i = I$.

Proposition 4 *For any $F(c_i)$ satisfying Assumption 1, (O,O) is the Pareto–dominant Nash equilibrium of the outsourcing game with rent extraction.*

Proof. A seller's expected profit under bilateral outsourcing is by (9) and (8) with $\overline{q}^d(c_i) = (1 - F(c_i))$

$$\begin{aligned}
\Pi_O^{(O,O)} + \Pi_S^{(O,O)} &= \int_0^1 (1 - F(c_i))F(c_i)(k'(c_i) + 1)\mathrm{d}c_i \\
&= \int_0^1 2(1 - F(c_i))F(c_i)\mathrm{d}c_i + \int_0^1 (1 - F(c_i))F(c_i)(F(c_i)/f(c_i))'\mathrm{d}c_i \\
&= \int_0^1 2(1 - F(c_i))F(c_i)\mathrm{d}c_i + 0 - \int_0^1 [-f(c_i)F(c_i) + (1 - F(c_i))f(c_i)]\frac{F(c_i)}{f(c_i)}\mathrm{d}c_i
\end{aligned}$$

[26] These payoffs can easily be supported through a game in which the interaction between a seller and his potential supplier is modeled explicitly: A seller who wants to outsource production makes a take–it–or–leave–it offer to his designated supplier. If the supplier accepts, he becomes seller i's supplier and pays the offer to seller i. If the supplier rejects, seller i produces in–house.

$$= \int_0^1 F(c_i)\mathrm{d}c_i.$$

The third equality follows from partial integration. If one of the sellers deviates to in–house production, he obtains by (7) $\Pi_I^{(I,O)} = \int_0^1 \overline{q}^d(c_i)F(c_i)\mathrm{d}c_i \le \int_0^1 F(c_i)\mathrm{d}c_i$. Hence, there is never a strict incentive to deviate from bilateral outsourcing. By Lemma 3, bilateral outsourcing is the Pareto–dominant equilibrium. q.e.d.

The technique of proof requires the complete extraction of a supplier's rent. However, normally the extraction of a much smaller part of his rent suffices to render bilateral outsourcing a Nash equilibrium. For $F(c) = c^a$ with $a > 0$, I can compute the part of the rent that needs to be extractable explicitly. Suppose the payoff of a seller who outsources production is now $\Pi_O^{(\alpha_1,\alpha_2)}(a) + \beta\Pi_S^{(\alpha_1,\alpha_2)}(a)$ with $\beta \in [0,1]$. By Proposition 3, (O,O) is an equilibrium even for $\beta = 0$ when $a \in (0,1]$. Consider $a > 1$. I need to compute the smallest β such that $\Pi_O^{(O,O)}(a) + \beta\Pi_S^{(O,O)}(a) \ge \Pi_I^{(I,O)}(a)$. By using (11), (12) and (13), I obtain after simplifying $\beta = 1 - (a/(a+1))^{a-1}$. Figure 1 illustrates how β depends on the parameter a. As $1 - (a/(a+1))^{a-1}$ is increasing with limit $1 - 1/\mathrm{e} < 2/3$, extraction of two third of the supplier's rent suffices to obtain the result in Proposition 4.

[insert Figure 1 here]

Proposition 4 holds for general distributions but it requires that there are only two sellers. For any distribution $F(c) = c^a$ with $a > 0$ I can show that the result breaks down when there are sufficiently many sellers. The existence of an outsourcing equilibrium in the outsourcing game with rent extraction has to be seen as a result for small industries. Suppose now that there are n sellers and denote a seller's expected profit when each seller outsources production by $\Pi_O^{(O,O,\ldots,O)} + \Pi_S^{(O,O,\ldots,O)}$ and his expected profit from deviating unilaterally to in–house production by $\Pi_I^{(I,O,\ldots,O)}$. The expected profits are still given by (7), (8) and (9), but the ad interim winning probabilities $\overline{q}_i^d(c_i)$ change. Under Assumption 1, seller i's ad interim winning probability is $(1 - F(c_i))^{n-1}$ when each seller outsources production and $(1 - F(J_O^{-1}(J_I(c_i))))^{n-1}$ when he deviates unilaterally to in–house production. Intuitively, in–house production becomes relatively more attractive for seller i as he gets favored against more sellers, whereas the factor by which the rent conditional on winning is higher under outsourcing stays unchanged. When n is sufficiently large, the first effect dominates for any parameter a:

Proposition 5 *Suppose $F(c) = c^a$ with $a > 0$. There exists a n' such that for any $n \ge n'$ $(O,\ldots,O)$ is no Nash equilibrium of the outsourcing game with rent extraction.*

Proof. If each seller outsources production, any seller's expected profit is

$$\Pi_O^{(O,O,\ldots,O)} + \Pi_S^{(O,O,\ldots,O)} = (2 + 1/a)\int_0^1 (1 - F(c_i))^{n-1}F(c_i)\mathrm{d}c_i. \tag{15}$$

This follows from (8) and (9) with $\overline{q}_i^d(c_i) = (1 - F(c_i))^{n-1}$ and from using that $k'(c_i) = 1 + 1/a$ for the considered class of distributions. If a seller deviates unilaterally to in–house production, his expected profit is

$$\begin{aligned} \Pi_I^{(I,O,\ldots,O)} &= \int_0^1 (1 - F(a/(1+a) \cdot c_i))^{n-1} F(c_i) \mathrm{d}c_i \\ &= (1 + 1/a)^{1+a} \int_0^{a/(1+a)} (1 - F(x))^{n-1} F(x) \mathrm{d}x. \end{aligned} \tag{16}$$

The first equality follows from (7) with $\overline{q}_i^d(c_i) = (1 - F(J_O^{-1}(J_I(c_i))))^{n-1}$ and from using that $J_O^{-1}(J_I(c_i)) = a/(1+a) \cdot c_i$ for the considered class of distributions. The second equality follows from applying the substitution $x = a/(1+a) \cdot c_i$. The result follows from two properties: First, $(1 + 1/a)^{1+a} > (2 + 1/a)$ for any $a > 0$. Second, $\lim_{n\to\infty} \int_0^{a/(1+a)} (1 - F(c_i))^{n-1} F(c_i) \mathrm{d}c_i / \int_0^1 (1 - F(c_i))^{n-1} F(c_i) \mathrm{d}c_i = 1$.

The first property can be proven as follows: By multiplying both sides of the inequality with a^{1+a}, the inequality becomes $(1 + a)^{1+a} > 2a^{1+a} + a^a$. By subtracting a^{1+a} from both sides and using notation $g(x) := x^{1+a}$, the inequality can be written as $(g(1+a) - g(a))/((1+a) - a) > (1+a)a^a$. The left–hand side is a secant of the strictly convex function g. It is thus strictly larger than $g'(a) = (1 + a)a^a$. This yields the first property. The second property holds because $\psi_n(c_i) := (1 - F(c_i))^{n-1} F(c_i) / \int_0^1 (1 - F(c_i))^{n-1} F(c_i) \mathrm{d}c_i$ specifies a density function on $[0, 1]$ which becomes more and more concentrated close to zero as n grows. Let Ψ_n be the corresponding cumulative distribution function. The quotient under consideration is then $\Psi_n(a/(1 + a))$. $\lim_{n\to\infty} \Psi_n(a/(1 + a)) = 1$ yields the second property. q.e.d.

It remains the question how fast the equilibrium in which each seller outsources production ceases to exist. For uniformly distributed c_i, it still exists for $n = 3$, but it does not exist for more than three sellers (follows from (15) and (16) with $a = 1$). This shows that although the result always holds for $n = 2$, it might break down quite fast as the number of sellers grows.

6. Discussion of extensions and robustness

Sequential outsourcing. In Subsections 5.1 and 5.2 I assumed that the sellers decide simultaneously on their vertical structure. Whereas this might be unrealistic for many applications, it works against bilateral outsourcing. When bilateral in–house production and bilateral outsourcing both constitute Nash equilibria of the simultaneous move game, there is a coordination problem between the two sellers although one of the equilibria is strictly preferred by both of them. When the vertical structure is determined sequentially, bilateral outsourcing constitutes the unique subgame perfect Nash equilibrium of the sequential outsourcing game.

Repeated procurement. In many procurement applications, a buyer needs to purchase repeatedly. Repetition makes it easier to support bilateral outsourcing. Consider the infinitely repeated outsourcing game (with or without rent extraction) with serially independent production costs and a discount factor $\delta \in (0, 1)$. Suppose only bilateral in–house production is a Nash equilibrium of the stage game. It follows directly from Lemma 3, that if δ is sufficiently high, there exists an equilibrium of the infinitely repeated outsourcing game in which (O, O) is played on the equilibrium path in each stage.[27] Note that the argument holds for general distributions satisfying Assumption 1 and can be extended to any number of sellers.

The buyer does not have to purchase. I assumed that the buyer has to procure. Suppose now that her value from purchasing is $v > 0$ and that she may decide not to purchase. I.e., her payoff is now $(q_1 + q_2)v - t_1 - t_2$. By a reasoning that is analogous to the derivation of Proposition 2, the buyer chooses an allocation rule to maximize $\sum_i q_i(c_1, c_2)(v - J_{\alpha_i}(c_i))$. As $J_I(c_i) < J_O(c_i)$ for any $c_i > 0$ (see (6)), there is now an additional negative effected associated with outsourcing. If seller i chooses $\alpha_i = O$ instead of $\alpha_i = I$ for a fixed α_{-i}, it becomes not only less likely that he wins against seller $-i$, it becomes also less likely that the buyer is willing to purchase from him. Outsourcing becomes relatively less attractive. However, bilateral outsourcing might still constitute the Pareto–dominant Nash equilibrium of the outsourcing game (with or without rent extraction). Suppose $F(c) = c^a$ with $a > 0$. If $v \geq (1+a)^2/a^2$, the buyer always procures under the optimal procurement mechanism. All results from Section 5 prevail. If $v \in [(1+a)/a, (1+a)^2/a^2)$, the buyer does not always procure under the optimal procurement mechanism, but not buying might only be optimal under bilateral outsourcing. Bilateral outsourcing becomes clearly less attractive and does less often constitute an equilibrium of the outsourcing game.[28] Although bilateral outsourcing can still constitute an equilibrium when the buyer does not have to purchase, my results are most striking for applications in which it is very costly for the buyer not to purchase. E.g., when the buyer assembles cars, deciding not to procure motors might be very costly for her.

The buyer does not condition the procurement mechanism on the sellers' vertical structure. Suppose the buyer chooses an absolute reverse second price auction irrespective of (α_1, α_2). Using that a seller who outsources production behaves like a seller who produces in–house but has costs $k(c_i)$ (Proposition 1), seller i's bid is c_i if $\alpha_i = I$ and $k(c_i)$ if $\alpha_i = O$. For $F(c_i) = c_i^a$ with $a > 0$, it turns out that this mechanism implements the optimal allocation (see Example 1). However, whereas under the optimal mechanism a seller with $c_i = 1$ obtains for any (α_1, α_2) an expected profit of zero, this is not always true for an absolute reverse second–price auction.[29] Consider $a = 1$. A seller who produces in–house and has cost $c_I = 1$ wins with probability $\text{Prob}\{k(C_O) > 1\} = \frac{1}{2}$ and receives an expected transfer $\mathbf{E}[k(C_O)|k(C_O) > 1] = \frac{3}{2}$ conditional

[27] Wärneryd (2000) makes a similar point in a repeated contest context where agents can delegate effort provision.

[28] If $a = 1$ and rent extraction is not possible, bilateral outsourcing only constitutes an equilibrium when $v \geq 4$, i.e., when it is always optimal for the buyer to purchase. If $a = 1$ and rent extraction is possible, bilateral outsourcing might also constitute an equilibrium when $v \in [2, 4)$. E.g., it constitutes an equilibrium for $v = 3$ but not for $v = 2$.

[29] The way the statement is phrased, it is appropriate for the modified version of the model where a seller with $\alpha_i = O$ faces costs $k(c_i)$. Suppose the buyer wants to buy with probability one from seller 1. This can be implemented by a take–it–or–leave–it offer of $k(1)$ from the buyer to seller 1 and a take–it–or–leave–it offer of 1 from the seller 1 to his supplier. In the original version of the model seller 1 makes a profit of $k(1) - 1$ irrespective of c_i. In the modified version, the seller makes a profit of zero when $c_i = 1$.

on winning when the other seller outsources production. His expected profit is $\frac{1}{2}(\frac{3}{2}-1)=\frac{1}{4}$. The expected profit of the seller who outsources production in this case and the expected profits of both sellers in all other cases are as under the optimal procurement mechanism. How the sellers' expected profits depend on the vertical structure (α_1, α_2) is displayed in Table 2. Table 2(a) displays the sellers' expected profits in the case in which the buyer chooses the optimal procurement mechanism. Outsourcing is more attractive relative to the case without rent extraction (see Table 1). The expected profit of any seller who outsources production is higher. Bilateral outsourcing constitutes a strict equilibrium. Table 2(b) displays the expected profits in the case in which the buyer always conducts an absolute reverse second–price auction. Relative to the case in which the buyer chooses the procurement mechanism optimally, the only difference is that in–house production becomes more attractive for a seller when the other seller outsources production. Bilateral in–house production constitutes the unique equilibrium. This demonstrates that optimality of the buyer's procurement mechanism choice is important for Proposition 4.

[insert Table 2 here]

7. Conclusion

I study the interaction between a buyer's optimal procurement mechanism and the sellers' vertical structure. My modeling paradigm is that outsourcing does not yield any direct positive effects like cost reductions, but comes along with a loss of information. In–house production leads to a favoring through the procurement mechanism and it is cheaper for a seller as it saves on informational costs. Nevertheless, I find that in small industries in which it is very costly for the buyer not to procure, outsourcing might arise endogenously. This is driven by a positive strategic effect associated with outsourcing: Intuitively, under bilateral outsourcing competition is very tranquil, whereas it becomes fierce when at least one seller produces in–house. If a supplier's rent is extractable ex ante, bilateral outsourcing arises endogenously for any distribution satisfying regularity conditions.

Applications might be found in the automotive industry. Many specialized parts that are needed to assemble a car are only producible by a few firms. Not procuring such parts is very costly for the car manufacturer. Further applications might be found in military procurement. The analysis in my article has also implications in the light of normal auctions. For example, if a small number of firms prepares for bidding for a license or a patent, discovering a firm's value might be a very complex task. My analysis is indicative for the question whether to assign internal or external consultants/experts to this task.

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Tables and figures

Table 1: Expected profits of sellers 1 and 2 $[F(c) = c]$

	$\alpha_2 = I$	$\alpha_2 = O$
$\alpha_1 = I$	$\frac{2}{12}, \frac{2}{12}$	$\frac{4}{12}, \frac{1}{12}$
$\alpha_1 = O$	$\frac{1}{12}, \frac{4}{12}$	$\frac{4}{12}, \frac{4}{12}$

Figure 1: Fraction of a supplier's rent that must be extractable to support bilateral outsourcing as an equilibrium $[F(c) = c^a]$

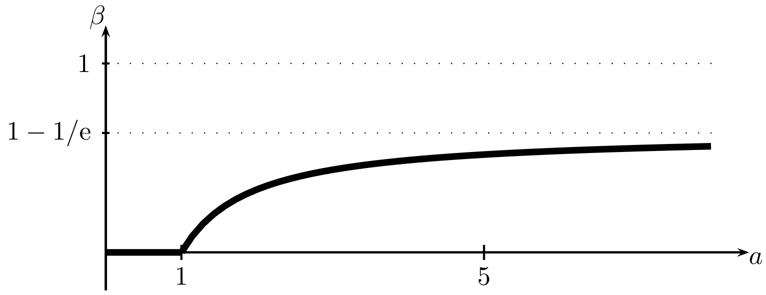

Table 2: Expected profits of sellers 1 and 2 when rent extraction is possible $[F(c) = c]$

(a) optimal procurement mechanism

	$\alpha_2 = I$	$\alpha_2 = O$
$\alpha_1 = I$	$\frac{4}{24}, \frac{4}{24}$	$\frac{8}{24}, \frac{3}{24}$
$\alpha_1 = O$	$\frac{3}{24}, \frac{8}{24}$	$\frac{12}{24}, \frac{12}{24}$

(b) absolute reverse second–price auction

	$\alpha_2 = I$	$\alpha_2 = O$
$\alpha_1 = I$	$\frac{4}{24}, \frac{4}{24}$	$\frac{14}{24}, \frac{3}{24}$
$\alpha_1 = O$	$\frac{3}{24}, \frac{14}{24}$	$\frac{12}{24}, \frac{12}{24}$