Strategic outsourcing and optimal procurement

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Abstract

This article provides an explanation for outsourcing in situations where a seller's outsourcing decision can influence the buyer's procurement strategy and the other sellers' strategic behavior. I consider a procurement auction environment in which each seller can ex ante decide to become an intermediary by outsourcing production to a subcontractor. Outsourcing leads to a loss of information to the subcontractor and a need for subcontracting. I show that even though the procurement mechanism is designed by a strategic player who dislikes a softening of competition, outsourcing can be beneficial for its anticompetitive effects. In an industry with two sellers, the focal equilibrium can exhibit bilateral outsourcing. When a seller can extract his subcontractor's rent ex ante, the focal equilibrium does exhibit bilateral outsourcing. However, multilateral outsourcing can only arise in industries with a sufficiently small number of sellers.

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JEL classification: D44, D47, D82, L23

1. Introduction

What are sellers' optimal vertical structures when a seller's outsourcing decision can influence the buyer's procurement strategy and other sellers' strategic behavior? I show that even when outsourcing comes along with a loss of information and does not imply any direct positive effects, outsourcing can be beneficial for strategic reasons.

A firm's vertical structure is in the industrial organization literature commonly considered as a strategic long–term decision which is observable to other players. How two firms decide on this structure prior to engaging in a given mode of duopolistic competition is for example studied by Bonanno and Vickers (1988), Gal-Or (1992), Gal-Or (1992) and Liu and Tyagi (2011). Outsourcing can be beneficial for strategic reasons as it may soften competition. However, firms do often not compete in an exogenously given market but compete for the purchase order of a buyer with market power who dislikes competition to become softer.

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As an example, think of the large civil aircraft industry in which the sellers A and B compete for the purchase order of a large airline.[1] By outsourcing production, a seller loses knowledge and information to his subcontractor.[2] The outsourcing decisions are taken long before binding negotiations with the airline take place. The airline can affect how seller A competes with seller B. For example, it may prefer seller B unless seller A makes a sufficiently much better offer. The offer that a seller who outsourced production is willing to make depends on the outcome of negotiations with his subcontractor. The subcontractor of seller A may for instance agree to produce at a lower price when seller A submits in return an offer which results in a higher probability of obtaining the purchase order. What I investigate in this article is how the endogeneity of the mode of procurement and subcontracting affects the sellers' incentives to outsource.

I study this question from a mechanism design perspective. I consider an independent private cost procurement auction environment in which a buyer has to procure an object from one of two sellers and in which each seller can ex ante decide to become an uninformed intermediary by outsourcing. Outsourcing is not associated with any direct positive effects. The only direct consequence of outsourcing is a loss of information to a subcontractor and the need for subcontracting. After the outsourcing decisions are made, the buyer designs the procurement mechanism, sellers who outsourced production design subcontracting mechanisms, and the selected mechanisms are played.

I abstract from direct positive effects to explain in the clearest possible way why there exists a hidden but possibly very strong strategic effect which can render outsourcing an attractive management strategy.[3] The positive strategic effect is driven by the fact that outsourcing and optimal subcontracting make the distribution of cost for providing the object which the seller effectively faces more variable by stretching it. It is easy to construct examples where such stretching occurs also for procurement problems in which outsourcing implies also direct positive effects (e.g., cost savings). The effects analyzed in this article are thus also relevant for more complex procurement problems.[4]

My formulation of the problem involves four key assumptions: First, I follow the industrial organization literature by assuming that a firm's vertical structure is an observable long–term decision. Second, bargaining power lies downstream. That is, the seller has the bargaining power in the seller–subcontractor–relationship and the buyer has the bargaining power in the buyer–sellers–relationship. This reflects the fact that sellers have access to many potential subcontractors and that the buyer can exploit the competition between the sellers. Third, the subcontracting mechanism which governs a seller–subcontractor–relationships is private. According to Katz (1991), privacy of contracting is normally the most natural assumption.[5] It is not

[1] According to Newhouse (2008), "No airline will pay the list price for an airplane, if there is such a thing. The massive discounts offered to launch customers tend to establish the price, or come close to establishing it." Hence, although airlines typically face a sequence of buyers, the competition for a potential launch customer of a new aircraft is of particular importance.

[2] Newhouse (2008) cites a Boeing engineer who comments on the consequences of outsourcing as follows: "Over time, institutional learning and forgetting will put the suppliers in control of the critical body of knowledge, and Boeing will steadily lose touch which key technical expertise." Moreover, the production cost of an aircraft typically declines strongly over time. The subcontractor possesses private information regarding how fast he descends the learning curve. The elicitation of private information remains thus relevant when the sellers compete for the purchase order of other buyers later on.

[3] See Liu and Tyagi (2011) for a different strategic effect which can make outsourcing attractive.

[4] See Section 8 for a discussion of my results in the light of the large civil aircraft application in which much more complex effects are important than in my stylized model.

[5] "Even if there is an explicit agency contract, the other players may not be able to see it. Although the agent could show a contract to the other players in the game, the agent and his principal could have a later contract that supersedes the first one." See also Caillaud and Hermalin (1993).

important for my analysis whether the mechanism which governs this relationship is closed early at the time of outsourcing or late after the procurement mechanism is announced. Important is only that privacy implies that the procurement mechanism cannot condition on the sellers' subcontracting mechanisms, whereas a seller's subcontracting mechanism can condition on the procurement mechanism. Fourth, the buyer cannot force a seller who outsourced production to decide on participation in the procurement mechanism before his subcontracting mechanism is played. Such an assumption is natural when the buyer cannot control interactions between a seller and his privately informed subcontractor. It allows a seller who has outsourced production to earn a positive rent in equilibrium.[6] By contrast, considering the case in which a seller who outsources production can ex ante extract the expected rent of his subcontractor may be interesting. For example, a seller may be able to elicit competitive bids from still uninformed potential subcontractors for operating a disintegrated unit.[7] I will derive results for the case in which this kind of rent extraction is possible and for the case in which it is not.

1.1. Related literature

Outsourcing can be interpreted as a precommitment to behave differently in the buyer's procurement mechanism. 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. Caillaud and Hermalin (1993) show that delegation can allow the principal to commit to actions to which she could not commit if she played for herself and that the benefits of delegation can be increasing in the agency cost. I am interested in why and when a precommitment through outsourcing can be beneficial for my procurement problem.

McAfee and McMillan (1995) show that aggregating information along longer, exogenously given hierarchies is more costly. I investigate the endogenous emergence of multi–tier hierarchies in a setting in which the principal can purchase from competing hierarchies of endogenous length.

Mookherjee and Tsumagari (2004) and Severinov (2008) study the optimal organization of production by a principal when inputs are substitutes. The marginal production cost of each input is privately learnt by its producer. The principal prefers contracting with each producer separately to contracting with a merged producer who produces both inputs. A two–tier production network is never strictly optimal for the principal. By contrast, the structure of the production network arises through choices of the producers in my model. I show that the focal equilibrium can then exhibit a production network with a multi–tier structure.

[6]If the seller could not make his participation decision dependent on information he elicits from his subcontractor, the buyer could extract his entire expected rent through a participation fee. See Melumad et al. (1995) for a similar participation assumption as I impose. Similar effects are also implied when the seller has to decide on participation before he can elicit information and he is either protected by limited liability (McAfee and McMillan (1995)) or risk–averse (Faure-Grimaud and Martimort (2001)).

[7]The extraction of rents from a subcontractor may also happen indirectly such that it may not be directly visible for an outsider. Production often causes setup cost (because facilities have to be built, tools have to be constructed or workers have to be trained). When rent extraction is not possible, the seller reimburses his subcontractor for such cost. That is, the seller bears this cost irrespective of his outsourcing decision. When rent extraction is possible, he can indirectly extract rents by not fully reimbursing the setup cost.

In the literature studying strategic outsourcing prior to duopolistic competition in prices (Bonanno and Vickers (1988), Liu and Tyagi (2011)) and in quantities (Gal-Or (1992), Gal-Or (1999)), the structure of the production network arises through choices of competitive firms. As in my model, a firm's vertical structure is a strategic long–term decision to which it has to commit to before details are fixed (like wholesale prices, product design decisions or subcontracts) and which is observable to its competitor. Outsourcing can arise in equilibrium because it may induce softer competition by increasing marginal cost (like in Bonanno and Vickers (1988), Gal-Or (1992) and Gal-Or (1999)) or by leading to a higher product differentiation (like in Liu and Tyagi (2011)).[8] The effects in these articles rely on the producers' attempts to game an exogenously given mode of competition, whereas I show why outsourcing may even arise when the mode of competition is designed by a strategic player who tries to counteract such attempts.[9]

Finally, "outsourcing" and "subcontracting" are also important in the literature on the delegation of effort provision in exogenously given contest games (see Baik and Kim (1997), Wärneryd (2000) and Konrad et al. (2004)). Delegation reduces competitiveness by raising the cost of competition through incentive problems and limited liability. Whether bilateral delegation is stable depends strongly on the details of the contest game. In my model, delegation of production has a similar effect although it induces an adverse selection problem instead of a moral hazard problem. It reduces competitiveness by raising the cost of competition through informational rents that have to be left to the delegates. I am however interested in the effect of the delegation decisions on the design of the game by a strategic player and in the resulting incentives to delegate.

2. The game which is played after outsourcing decisions are made

A buyer can purchase a product either from seller 1 or from seller 2. I denote a generic seller by i and the other seller by $-i$. Each seller is characterized by whether he produces in–house ($\alpha_i = I$) or has outsourced production to a subcontractor ($\alpha_i = O$). α_i is observable and it is exogenous until I endogenize it in Sections 5 and 6. Each producer of the product is privately informed about his production cost c_i. That is, c_i is learnt by seller i if $\alpha_i = I$ and by seller i's subcontractor if $\alpha_i = O$. c_1 and c_2 are the realizations of independent and identically distributed random variables C_1 and C_2, respectively. C_i is distributed according to a cumulative distribution function $F(c_i)$ with density $f(c_i)$, support $[0, 1]$, $f(1) > 0$ and a differentiable and strictly increasing inverse reversed hazard rate $h(c_i) := F(c_i)/f(c_i)$.[10] Production takes place after the purchase decision is made. That is, only the product which is sold is actually produced and causes production cost.

I denote the buyer's value for the product by v, the probability with which she purchases it 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 subcontractor by s_i. The

[8] Gal-Or (1992) and Gal-Or (1999) consider problems in which outsourcing implies a loss of information. Whether bilateral outsourcing, unilateral outsourcing or bilateral in–house production arises in equilibrium depends strongly on the parameters of the given mode of competition.

[9] The mode of competition is also exogenously given in the literature studying the decision to make or to buy from a market. See Shy and Stenbacka (2003) and Buehler and Haucap (2006).

[10] As $\ln(F(c_i))'' = -h'(c_i)/h(c_i)^2$, the hazard rate assumption corresponds to assuming strict log–concavity of the distribution function. Such an assumption is standard in auction theory and it is satisfied for the most commonly used distributions. See Bagnoli and Bergstrom (2005). My distributional assumptions are for example satisfied for any power distribution function $F(c_i) = c_i^a$ with $a > 0$.

buyer's payoff is $(q_1 + q_2)v - t_1 - t_2$. If $\alpha_i = I$, seller i's payoff is $t_i - q_i c_i$. If $\alpha_i = O$, seller i's payoff is $t_i - s_i$ and his subcontractor's payoff is $s_i - q_i c_i$. I am interested in the case in which v is sufficiently large such that the buyer always wants to procure the product.[11]

A procurement mechanism $(\mathcal{B}_1, \mathcal{B}_2, q, t)$ consists of four components: a non–empty set $\mathcal{B}_i$ of possible messages for each seller; an allocation rule $q : \mathcal{B}_1 \times \mathcal{B}_2 \to \{(q_1, q_2) \in [0,1]^2 | q_1 + q_2 \leq 1\}$ which describes the probabilities with which the buyer purchases from each of the two sellers; and a payment rule $t : \mathcal{B}_1 \times \mathcal{B}_2 \to \mathbf{R}^2$ which describes her payments to each of the sellers. The subcontracting mechanism $(\mathcal{R}_i, b_i, s_i)$ of a seller i who has outsourced production consists of three components: a non–empty set $\mathcal{R}_i$ of possible messages for seller i's subcontractor; a rule $b_i : \mathcal{R}_i \to \mathcal{B}_i$ which describes how seller i will behave in the procurement mechanism; and a payment rule $s_i : \mathcal{R}_i \times \mathcal{B}_1 \times \mathcal{B}_2 \to \mathbf{R}$ which describes seller i's payments to his subcontractor. To better distinguish a seller's message in the procurement mechanism from a subcontractor's message in a subcontracting mechanism, I will refer to the former as *announcement* or *bid* and to the latter as *report*. At issue is how does the buyer design the procurement mechanism given the effect it will have on the sellers' subcontracting behavior.

I am interested in the case in which a seller's (resp. subcontractor's) participation in the procurement mechanism (resp. subcontracting mechanism) is voluntary and in which a seller can make his participation decision dependent on information he elicits from his subcontractor. Formally, I consider this case by assuming that each $\mathcal{B}_i$ contains an announcement $\emptyset$ (resp. each $\mathcal{R}_i$ contains a report $\emptyset$) which is to be interpreted as non–participation of seller i (resp. seller i's subcontractor) in the procurement mechanism (resp. subcontracting mechanism). When the announcement $\widehat{b}_i = \emptyset$ is chosen, seller i wins with probability zero, $q_i(\widehat{b}_1, \widehat{b}_2) = 0$, and he obtains a zero payment from the buyer, $t_i(\widehat{b}_1, \widehat{b}_2) = 0$. By choosing report $\emptyset$, seller i's subcontractor can enforce seller i's non–participation in the procurement mechanism, $b_i(\emptyset) = \emptyset$, and a zero payment from seller i, $s_i(\emptyset) = 0$.

The timing is as follows: First, the buyer designs and publicly announces a procurement mechanism $(\mathcal{B}_1, \mathcal{B}_2, q, t)$. Second, each seller i who has outsourced production chooses a subcontracting mechanism $(\mathcal{R}_i, b_i, s_i)$ which is only observed by seller i's own subcontractor. Third, each producer privately learns his production cost c_i. Fourth, the mechanisms are played: If $\alpha_i = I$, seller i chooses a bid $\widehat{b}_i \in \mathcal{B}_i$ directly. If $\alpha_i = O$, seller i's subcontractor chooses a report $\widehat{r}_i \in \mathcal{R}_i$ which determines seller i's bid $\widehat{b}_i = b_i(\widehat{r}_i)$ indirectly. Finally, payoffs realize. As equilibrium concept I adopt the notion of Perfect Bayesian equilibrium.

3. The one–seller–benchmark and its relation to the multi–seller–case

Before I start with the analysis of my model, I discuss in this section briefly the case in which the buyer can only purchase from a single seller, say seller 1, and in which procurement and subcontracting mechanisms correspond to posted price offers. This gives me a framework for motivating the effects in the case with multiple sellers and to explain how they differ from the one–seller–case. The imposed structure leaves me with a game which is as follows: If the seller produces in–house ($\alpha_1 = I$), the buyer posts a price $p_I \geq 0$ and trade takes place if the seller accepts this offer. If the seller has outsourced production instead ($\alpha_1 = O$), the buyer posts a price $p_O \geq 0$, the seller observes this price and asks his subcontractor in turn

[11] Formally, the assumption corresponds to assuming $v \geq 1 + (2 + h'(1))/f(1)$.

whether he is willing to produce the product at a price $p_S \geq p_O$. Trade takes place if the subcontractor accepts the seller's price p_S. Besides being well interpretable, the here considered posted price mechanisms will turn out to be optimal in the one–seller–case.[12]

What is the effect of the seller's outsourcing decision? In the situation where the seller produces in–house, he accepts the buyer's offer p_I whenever it exceeds his production cost c_1. As the buyer's value v is assumed to be so large that she always wants to procure, the buyer offers the lowest price which will always be accepted, $p_I^* = 1$. In the situation where production is outsourced, trade takes place if the seller's offer to his subcontractor p_S exceeds the subcontractor's production cost c_1. As the seller has however less to gain from trade taking place than the buyer (only $p_O < v$ instead of v), he is less eager to make an offer which is always accepted. In particular, if $p_O = 1$, the seller can only make a positive profit when he offers a price $p_S < 1$ which will be rejected with positive probability. Hence, in order to get acceptance with probability one, the buyer has to offer the seller a price which is larger than 1 although it is common knowledge that the real production cost are always smaller than 1.

Outsourcing serves in the one–seller–case as a precommitment for being less eager to accept the buyer's offer. It induces the buyer to offer a better price ($p_O^* > 1$ instead of 1), but it leaves the seller on the other hand with a higher cost for providing the object (1 instead of $c_1 \leq 1$). If a seller who outsources can extract his subcontractor's expected rent ex ante, the optimality of outsourcing follows directly from the buyer's better price offer. It turns however out that outsourcing is even optimal when the seller cannot extract his subcontractor's rent (see Appendix A for a proof). Crucial for the favorable effect of outsourcing on the buyer's procurement strategy which drives the optimality of outsourcing in the one–seller–case are two things: the buyer has a very strong incentive to obtain the object and there exists only a single source from which she can obtain it. In situations in which it is very important to procure, there exists however typically at least a second source (possibly installed by the buyer). This gives rise to the question what changes if there is more than one seller.

When there is more than one seller, outsourcing serves still as a precommitment to become weak, the implications of such a precommitment differ then however. As the buyer has the possibility to buy from other sources, it is in the multi–seller–case unclear whether the buyer will respond to a seller's decision to outsource by modifying her procurement strategy in his favor. I show below that the buyer may even respond by penalizing him (see my example in Section 7). That is, the favorable effect of outsourcing on the buyer's procurement strategy which drives the results in the one–seller–case may even turn around and become detrimental. On the other hand, when there is more than one seller, a seller's outsourcing decision can have an effect on the other sellers' strategic behavior. The literature studying outsourcing prior to engaging in a given mode of duopolistic competition (e.g., Bonanno and Vickers (1988), Gal-Or (1992), Gal-Or (1992)) indicates that outsourcing can still be beneficial as it may soften competition, but that it depends on the considered mode of competition and the parameters of the model whether this effect is strong enough to justify the increase in cost which comes along with outsourcing.[13]

I am in this article interested in problems where the mode of competition is not exogenously given but en-

[12]The case with a single seller corresponds basically to the version of my model in which the buyer can only choose among mechanisms with $q_2(b_1, b_2) = 0$. The optimality of posted price mechanisms follows then from my analysis in the next section.

[13]See also Fudenberg and Tirole (1984).

dogenously designed by a strategic player who strives for inducing the toughest competition. Outsourcing has in my model thus an effect on the buyer's procurement strategy (like in the discussed one–seller–benchmark) and on the other sellers' strategic behavior (like in the literature on outsourcing prior to engaging in an exogenously given mode of competition). I derive the optimal subcontracting and procurement mechanisms which determine how the sellers compete and I study the sellers' incentives to game this endogenous mode of competition by outsourcing.

4. Design of the optimal subcontracting and procurement mechanism

4.1. The optimal subcontracting mechanism

Suppose $\alpha_i = O$. Seller i's subcontracting problem is specified by the chosen procurement mechanism $(\mathcal{B}_1, \mathcal{B}_2, q, t)$ and the other seller's supposed bidding behavior $b_{-i}(c_{-i})$.[14] Thereby it is not important whether the other seller chooses bids directly or whether his bidding behavior derives indirectly from subcontracting. I take in this section any subcontracting problem of seller i as given and I derive seller i's optimal subcontracting mechanism $(\mathcal{R}_i, b_i, s_i)$.

Because a revelation principle applies to seller i's subcontracting problem, I can without loss of generality restrict attention to direct subcontracting mechanisms $([0,1] \cup \{\emptyset\}, b_i, s_i)$ for which it is optimal to truthfully report the production cost c_i. Define $\overline{q}_i(c_i) := \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]$ and $\overline{s}_i(c_i) := \mathbf{E}[s_i(C_i, b_1(C_1), b_2(C_2))|C_i = c_i]$. The subcontractor's reporting incentives depend then only through the interim expected values $\overline{q}_i(c_i)$ and $\overline{s}_i(c_i)$ on the design of the subcontracting mechanism (and the subcontracting problem). Optimality of truthful reporting consists of two parts, incentive compatibility and individual rationality. That is, $\overline{s}_i(c_i) - \overline{q}_i(c_i)c_i \geq \overline{s}_i(\widehat{c}_i) - \overline{q}_i(\widehat{c}_i)c_i$ for any $c_i, \widehat{c}_i \in [0,1]$ and $\overline{s}_i(c_i) - \overline{q}_i(c_i)c_i \geq 0$ for any $c_i \in [0,1]$. The notation with $\overline{s}_i$ and $\overline{q}_i$ demonstrates that the incentive compatibility and the individual rationality constraint correspond to standard constraints in Bayesian mechanism design. The subsequent lemma follows from standard reasoning à la Baron and Myerson (1982).

Lemma 1 *Consider any subcontracting problem of seller i. A direct subcontracting mechanism $([0,1] \cup \{\emptyset\}, b_i, s_i)$ is incentive compatible and 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 $\kappa \geq 0$.*

It follows from the lemma that any bidding behavior $b_i(c_i)$ which implies a non–increasing function $\overline{q}_i(c_i)$ can be supported by a payment rule $s_i(c_i)$. The interim expected payment from seller i to his subcontractor is up to a constant completely specified by the function $\overline{q}_i(c_i)$. It consists of three parts: First, seller i has to reimburse his subcontractor for his complete interim expected production cost $\overline{q}_i(c_i)c_i$. Second, seller i has to leave an information rent $\int_{c_i}^1 \overline{q}_i(c)\mathrm{d}c$ to his subcontractor in order to induce truthful revelation of the subcontractor's private information. Third, seller i can make any non–negative lump–sum payment κ to his subcontractor.

Seller i's expected payoff from truthful reporting by his subcontractor under a direct subcontracting mechanism $([0,1] \cup \{\emptyset\}, b_i, s_i)$ is given by $\mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - s_i(C_i, b_1(C_1), b_2(C_2))]$. Lemma 1 implies

[14] Seller $-i$'s bid conditional on the cost realization c_{-i} could in principle be a random variable. Whether $b_{-i}(c_{-i})$ is a value from $\mathcal{B}_{-i}$ or a random variable on $\mathcal{B}_{-i}$ does not matter for the analysis.

that this expression can be rewritten as

$$\mathbf{E}[\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i] - \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i]k(C_i) - \kappa] \tag{1}$$

with $k(c_i) := c_i + F(c_i)/f(c_i)$.[15] Using the mechanism design terminology introduced by Myerson (1981), $k(c_i)$ describes seller i's virtual cost of producing. $k(c_i)$ can be interpreted as seller i's marginal cost taking into account the effect which production at cost c_i has on the expected information rent he has to leave to his subcontractor.

Seller i's subcontracting problem corresponds to choosing a bidding behavior $b_i(c_i)$ and a constant $\kappa \geq 0$ such that (1) is maximized subject to the constraint that $\overline{q}_i(c_i) = \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]$ is non–increasing in c_i. By using that $\kappa = 0$ is optimal and by ignoring the monotonicity constraint, I obtain a relaxed subcontracting problem in which seller i chooses a bidding behavior $b_i(c_i)$ to maximize (1). Because the unconstrained maximum of (1) corresponds to the pointwise maximum, the bidding behavior $b_i(c_i)$ which solves the relaxed problem maximizes

$$\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i = c_i] - \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]k(c_i) \tag{2}$$

for any $c_i \in [0, 1]$. (2) corresponds to the interim expected payoff that seller i would obtain from bid $b_i(c_i)$ if he produced in–house and had production cost $k(c_i)$ instead of c_i. As the ignored monotonicity constraint holds for the solution of the relaxed problem, I obtain the following result:

Proposition 1 *Consider any subcontracting problem of seller i. The optimal subcontracting mechanism implies a bidding behavior $b_i(c_i)$ and an expected payoff of seller i which are as if seller i produced in–house but had production cost $k(c_i)$ instead of c_i.*

Proof. To complete the argument in the text, I have to verify that $\overline{q}_i(c_i) = \mathbf{E}[q_i(b_1(C_1), b_2(C_2))|C_i = c_i]$ is non–increasing in c_i when $b_i(c_i)$ corresponds to the optimal bidding behavior of a seller who produces in–house and who has production cost $k(c_i)$ instead of c_i. It is straightforward to show that such a seller chooses a bid which implies an at least weakly smaller interim winning probability $\overline{q}_i(c_i)$ when his production cost $k(c_i)$ is larger. Because the hazard rate assumption implies that $k(c_i)$ is strictly increasing, $\overline{q}_i(c_i)$ is non–increasing in c_i. q.e.d.

The virtual cost $k(c_i)$ play the same role for a seller who has outsourced production which the actual cost c_i play for a seller who produces in–house.[16] Because $k(0) = 0$ and $k'(c_i) > 1$ (which follows directly from the hazard rate assumption), the virtual cost of producing which a seller faces when he has outsourced production is stretched upwards compared to his actual cost of producing when he produced in–house instead. Thus, disregarding strategic effects on the buyer's procurement mechanism choice and the other seller's bidding behavior, outsourcing is purely wasteful for a seller.

4.2. The optimal procurement mechanism

Proposition 1 allows me to study the optimal procurement mechanism for the reduced game in which the subcontracting stage is reduced. A seller who has outsourced production is in this reduced game like

[15] The derivation of (1) is standard in mechanism design and can be found in Appendix A.

[16] This is similar to what is found by McAfee and McMillan (1995) for a setting with an ex ante participation constraint and limited liability.

a seller who produces in–house but who has production cost $k(c_i)$ instead of c_i. I will therefore henceforth use the denotation production cost for c_i if $\alpha_i = I$ and for $k(c_i)$ if $\alpha_i = O$. The only effect of outsourcing is then that the seller's production cost increase in a specific way. In particular, this means that it is as if he knows c_i. The buyer's procurement mechanism design problem can be handled like a standard procurement auction design problem with two possibly asymmetric sellers (see Myerson (1981)).

By the revelation principle, I can without loss of generality restrict attention to direct procurement mechanisms $([0,1] \cup \{\emptyset\}, [0,1] \cup \{\emptyset\}, q, t)$ for which it is optimal for each seller to truthfully announce c_i. Define $\overline{q}_i^d(c_i) := \mathbf{E}[q_i(C_1, C_2)|C_i = c_i]$ and $\overline{t}_i^d(c_i) := \mathbf{E}[t_i(C_1, C_2)|C_i = c_i]$. Seller i chooses then the announcement $\widehat{c}_i \in [0,1] \cup \{\emptyset\}$ 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 optimality of $\widehat{c}_i = c_i$ over any other $\widehat{c}_i \in [0,1]$ corresponds again to a standard incentive compatibility constraint and the optimality of $\widehat{c}_i = c_i$ over $\widehat{c}_i = \emptyset$ corresponds again to a standard individual rationality constraint. The derivation of the following lemma is thus like that of Lemma 1 standard.

Lemma 2 *A direct procurement mechanism $([0,1] \cup \{\emptyset\}, [0,1] \cup \{\emptyset\}, q, t)$ is incentive compatible and individually rational if and only if the following is true for each i: $\overline{q}_i^d(c_i)$ is non–increasing, $\overline{t}_i^d(c_i) = \overline{q}_i^d(c_i)c_i + \int_{c_i}^1 \overline{q}_i^d(c)dc + \kappa_i$ if $\alpha_i = I$, $\overline{t}_i^d(c_i) = \overline{q}_i^d(c_i)k(c_i) + \int_{c_i}^1 \overline{q}_i^d(c)k'(c)dc + \kappa_i$ if $\alpha_i = O$ and $\kappa_i \geq 0$.*

Two properties are important. First, a seller who has outsourced production is reimbursed his complete interim expected production cost $\overline{q}_i^d(c_i)k(c_i)$. That is, he is also reimbursed the informational rent he has to leave to his subcontractor. He is thus not directly hurt by the "wastefulness" of the outsourcing decision. Second, a seller's information rent under outsourcing differs by the factor $k'(c_i)$ from his information rent under in–house production. Because $k'(c_i) > 1$, outsourcing stretches the cost distribution a seller faces. Even though the stretching increases cost only, it has a positive effect on the information rent the seller can earn as it makes lying potentially more attractive. For the same interim winning probability function $\overline{q}_i^d$, outsourcing clearly increases a seller's information rent. However, I will find below that the "wastefulness" of the outsourcing decision has a clearly negative effect on this interim winning probability function.

The buyer's expected payoff from the truthful announcement of c_i by each seller under a direct procurement mechanism $([0,1]\cup\{\emptyset\}, [0,1]\cup\{\emptyset\}, q, t)$ is given by $\mathbf{E}[(q_1(C_1, C_2)+q_2(C_1, C_2))v - t_1(C_1, C_2) - t_2(C_1, C_2)]$. Lemma 2 and the fact that $\kappa_1 = \kappa_2 = 0$ is clearly optimal allows me to rewrite the buyer's expected payment to seller i as

$$\mathbf{E}[t_i(C_1, C_2)] = \mathbf{E}[q_i(C_1, C_2)J_O(C_i)] \text{ with } J_O(c_i) := c_i + \frac{F(c_i)}{f(c_i)} + \frac{F(c_i)}{f(c_i)}k'(c_i) \tag{3}$$

if $\alpha_i = O$ and as

$$\mathbf{E}[t_i(C_1, C_2)] = \mathbf{E}[q_i(C_1, C_2)J_I(C_i)] \text{ with } J_I(c_i) := c_i + \frac{F(c_i)}{f(c_i)} \tag{4}$$

if $\alpha_i = I$.[17] The buyer's expected procurement cost is thus given by $\mathbf{E}[\sum_i q_i(C_1, C_2)J_{\alpha_i}(C_i)]$. $J_{\alpha_i}(c_i)$ describes the buyer's virtual cost of purchasing from a seller with information c_i and vertical structure α_i. It is comprised of the actual production cost c_i, the effect that buying at cost c_i has on the producer's informational rent, $F(c_i)/f(c_i)$, and, in case production is outsourced, the effect that buying has on the

[17]The derivation of (3) and (4) is standard in mechanism design and can be found in Appendix A.

informational rent of the intermediary, $F(c_i)/f(c_i) \cdot k'(c_i)$. Because of the double marginalization of rents which arises under outsourcing, a seller's decision to outsource clearly increases the buyer's virtual cost of purchasing from him:

$$J_O(c_i) > J_I(c_i) \text{ for any } c_i > 0. \tag{5}$$

If the virtual cost functions J_I and J_O are both increasing (which is at least for J_I the case by the monotonicity of $h(c_i) = F(c_i)/f(c_i)$), standard reasoning implies that the buyer may only purchase from the seller with the lowest virtual cost. The discussion in the text and my assumption that the buyer always wants to procure the product implies the following result:

Proposition 2 *Suppose $J_O(c_i)$ is increasing.*[18] *Any direct procurement mechanism* $([0,1] \cup \{\emptyset\}, [0,1] \cup \{\emptyset\}, q, t)$ *where the allocation rule minimizes* $\sum_i q_i(c_1, c_2) J_{\alpha_i}(c_i)$ *and the payment rule satisfies the conditions in Lemma 2 with* $\kappa_i = 0$ *is optimal.*

The allocation rule favors in asymmetric situations the seller who produces in–house relative to the seller who has outsourced production. In symmetric situations, that is in situations in which either both sellers produce in–house or both sellers have outsourced production, no seller is favored. The seller with the lower c_i wins in both cases. As a seller obtains by Lemma 2 a higher information rent under outsourcing than under in–house production when the allocation rule is the same, both sellers strictly prefer bilateral outsourcing over bilateral in–house production.

Proposition 3 *Suppose $J_O(c_i)$ is increasing. A sellers's expected payoff is strictly higher under bilateral outsourcing than under bilateral in–house production.*

Proof. I first describe how a seller's expected payoff depends on his vertical structure for a given interim winning probability function $\overline{q}_i^d(c_i)$. By Proposition 1 and (3), the expected payoff of a seller who has outsourced production is

$$\mathbf{E}[t_i(C_1, C_2) - q_i(C_1, C_2)k(C_i)] = \int_0^1 \overline{q}_i^d(c_i) F(c_i) k'(c_i) \mathrm{d}c_i. \tag{6}$$

By (4), the expected payoff of a seller who produces in–house is

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

The sellers' expected payoffs under the optimal procurement mechanism follow from using the interim winning probability function $\overline{q}_i^d(c_i)$ which is implied by Proposition 2 in (6) and (7). Because $(\alpha_1, \alpha_2) = (I, I)$ and $(\alpha_1, \alpha_2) = (O, O)$ imply the same allocation rule and because $k'(c_i) > 1$ by the hazard rate assumption, I obtain the result. q.e.d.

Let me stress that what drives a seller's preference for bilateral outsourcing over bilateral in–house production is the *slope* of his cost function under outsourcing, $k(c_i)$, and not the *increase* in his cost.

[18] 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). I can write $J_O(c_i) = c_i + h(c_i) + h(c_i)(1 + h'(c_i))$. When h is twice differentiable, $J_O'(c_i) = 1 + 2h'(c_i) + (h'(c_i))^2 + h(c_i)h''(c_i)$. It follows from this that sufficient for J_O being increasing is $h''(c_i) > -(1 + h'(c_i))^2/h(c_i)$. The sufficient condition 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 power distribution function $F(c_i) = c_i^a$ with $a > 0$.

This effect survives thus modifications of my model where outsourcing reduces production cost as long as outsourcing makes the cost distribution faced by the seller in a certain sense more variable.

From the analysis so far I know the following: For a given vertical structure of the other seller, a seller faces a trade–off. On the one hand, outsourcing leads to a disfavoring through the allocation rule of the optimal procurement mechanism. It leads thus to a lower interim winning probability function. On the other hand, outsourcing leads to a higher information rent for a given interim winning probability function. Hence, although both sellers strictly prefer bilateral outsourcing over bilateral in–house production, it is a priori unclear whether bilateral outsourcing can be stable in an augmented game in which the outsourcing decisions are taken non–cooperatively.

4.3. Expected payoffs as a function of the sellers' vertical structures

I present in the next two sections two ways of endogenizing the sellers' outsourcing decisions. I augment the game analyzed in this section with two versions of an initial stage and I study under which conditions outsourcing occurs in equilibrium. The analysis in this section allows me to reduce the last stages of the considered augmented games. For the reduction, it is useful to introduce some additional notation.

Seller i's expected payoff under the optimal procurement mechanism is given by (6) if $\alpha_i = O$ and by (7) if $\alpha_i = I$ with the function $\overline{q}_i^d$ which derives from the allocation rule characterized in Proposition 2. The equilibrium payoffs depend through this allocation rule also on the other seller's vertical structure. For a given (α_1, α_2), I denote the expected payoff of a seller with vertical structure α_i by $\Pi_{\alpha_i}^{(\alpha_1,\alpha_2)}$. When seller i has outsourced production, also his subcontractor obtains an informational rent. By Lemma 1, the expected payoff of seller i's subcontractor is given by

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

Again, $\overline{q}_i^d$ follows from Proposition 2 and depends on (α_1, α_2). For a given (α_1, α_2) with $\alpha_i = O$, I denote the expected profit of seller i's subcontractor by $\Pi_S^{(\alpha_1,\alpha_2)}$.

For future reference, the following example describes the sellers' and the subcontractors' expected payoffs when C_i is distributed according to a power distribution function.

Example 1 *Suppose $F(c) = c^a$ with $a > 0$. As $k(c_i) = (1+a)/a \cdot c_i$, a seller who has outsourced production behaves as if his cost were linearly higher. I obtain $J_I(c_i) = (1+a)/a \cdot c_i$ and $J_O(c_i) = (1+a)^2/a^2 \cdot c_i$. The sellers' interim winning probability functions for the different outsourcing structures follow directly from these functions. By using those in (7) and in (6), I obtain the following expected payoffs:*

$$\Pi_I^{(I,I)} = \int_0^1 (1 - c_i^a)c_i^a\, dc_i = \frac{a}{1+a}\frac{1}{1+2a} \tag{9}$$

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

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

$$\Pi_O^{(I,O)} = \int_0^{a/(1+a)} (1 - \left(\frac{1+a}{a}c_i\right)^a)c_i^a \frac{1+a}{a}\, dc_i = \left(\frac{a}{1+a}\right)^a \frac{a}{1+a}\frac{1}{1+2a} \tag{12}$$

$$\Pi_S^{(O,O)} = \frac{a}{1+a}\Pi_O^{(O,O)} \text{ and } \Pi_S^{(I,O)} = \frac{a}{1+a}\Pi_O^{(I,O)} \tag{13}$$

Table 1: Structure of payoffs in the reduced outsourcing game without rent extraction

(a) Coordination game [$F(c) = c^{1/2}$]

	$\alpha_2 = I$	$\alpha_2 = O$
$\alpha_1 = I$	$\boxed{\frac{1}{6}}$, $\boxed{\frac{1}{6}}$	$\frac{1}{2}(\frac{4}{3} - \frac{1}{\sqrt{3}})$, $\frac{1}{\sqrt{3}}\frac{1}{6}$
$\alpha_1 = O$	$\frac{1}{\sqrt{3}}\frac{1}{6}$, $\frac{1}{2}(\frac{4}{3} - \frac{1}{\sqrt{3}})$	$\boxed{\frac{1}{2}}$, $\boxed{\frac{1}{2}}$

(b) Prisoner's Dilemma game [$F(c) = c^2$]

	$\alpha_2 = I$	$\alpha_2 = O$
$\alpha_1 = I$	$\boxed{\frac{18}{135}}$, $\boxed{\frac{18}{135}}$	$\boxed{\frac{33}{135}}$, $\frac{8}{135}$
$\alpha_1 = O$	$\frac{8}{135}$, $\boxed{\frac{33}{135}}$	$\frac{27}{135}$, $\frac{27}{135}$

5. The reduced outsourcing game without rent extraction

I first augment the model in Section 2 with an initial stage in which each seller i simultaneously chooses $\alpha_i \in \{I, O\}$.[19] After this choice is made, (α_1, α_2) becomes observable and the game described in Section 2 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 reduced outsourcing game without rent extraction and I am interested in pure strategy Nash equilibria of this reduced game.[20]

I characterize in this section the optimal outsourcing decisions for $F(c) = c^a$ with $a > 0$. As (9) is for any $a > 0$ strictly larger than (12), any seller has a strict incentive not to deviate from bilateral in–house production. That is, bilateral in–house production constitutes a strict Nash equilibrium of the reduced outsourcing game. Because both sellers strictly prefer bilateral outsourcing over bilateral in–house production by Proposition 3, the reduced outsourcing game can have only two possible structures. If bilateral outsourcing constitutes also a Nash equilibrium, it has a coordination game structure with bilateral outsourcing being the Pareto–dominant Nash equilibrium. This is for example the case when $a = 1/2$ (see Table 1(a)). If bilateral outsourcing constitutes not a Nash equilibrium, the reduced outsourcing game has a Prisoner's Dilemma structure. Bilateral in–house production constitutes then the only Nash equilibrium. This is for example the case when $a = 2$ (see Table 1(b)). The following proposition establishes that the reduced outsourcing game has a coordination game structure for any $a \in (0, 1]$ and a Prisoner's Dilemma structure for any $a \in (1, \infty)$.

Proposition 4 *Suppose $F(c) = c^a$ with $a > 0$. The reduced 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. (9), (12) and $(a/(a + 1))^a < 1$ imply that $\Pi_I^{(I,I)} > \Pi_O^{(I,O)}$ for any $a > 0$. This renders (I, I) is a strict Nash equilibrium. Moreover, it implies that there cannot exist an asymmetric Nash equilibrium. It remains to check under which conditions (O, O) also constitutes a Nash equilibrium. (10) and (11) imply that $\Pi_O^{(O,O)} \geq \Pi_I^{(I,O)}$ is equivalent to $a^{a-1} \geq (a + 1)^{a-1}$. As this inequality is true if and only if $a \in (0, 1]$, (O, O) constitutes a Nash equilibrium if $a \in (0, 1]$ but not if $a \in (1, \infty)$. Because (I, I) is the unique Nash equilibrium for $a \in (1, \infty)$, the Pareto–dominance result is trivial in this case. That (O, O) is the Pareto–dominant Nash equilibrium when $a \in (0, 1]$ follows from Proposition 3. q.e.d.

[19] It will follow from the analysis in this section that assuming that α_1 and α_2 are chosen simultaneously works against my result. Whenever bilateral outsourcing is an equilibrium of the simultaneous move game, then it is the unique equilibrium of the game where the outsourcing decisions are taken sequentially.

[20] For any outsourcing behavior which specifies a Nash equilibrium of the reduced game, the same behavior is part of a Perfect Bayesian equilibrium of the non–reduced game. Moreover, Nash equilibria in mixed strategies may exist but are not interesting. It turns out that there always exists a pure strategy Nash equilibrium which is very focal. When I consider the modified game in which the outsourcing decisions are taken sequentially, the focal pure strategy Nash equilibrium of the simultaneous move game becomes the unique Nash equilibrium in mixed strategies of the sequential move game.

By deviating unilaterally from bilateral outsourcing, a seller wins more often, but he obtains a smaller rent conditional on winning. The stability of bilateral outsourcing depends on the relative strength of the two effects. Intuitively, when it is relatively likely that the realization of C_i is high ($a > 1$), getting favored through the allocation rule is more attractive for a seller than getting a higher rent conditional on winning. Each seller has an incentive to deviate unilaterally from bilateral outsourcing. Bilateral in–house production constitutes the only Nash equilibrium. By contrast, when it is relatively likely that the realization of C_i is low ($a < 1$), getting a higher rent conditional on winning is more important for a seller than getting favored through the allocation rule. Bilateral outsourcing is stable and constitutes the focal Nash equilibrium.

6. The reduced outsourcing game with rent extraction

I consider now the reduced game which is like the reduced game in Section 5, 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 $\Pi_O^{(\alpha_1,\alpha_2)}$. That is, a seller who outsources production can now extract his subcontractor's expected rent ex ante. I refer to this reduced game as reduced outsourcing game with rent extraction.

Recall that seller i's trade–off in the reduced 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 ability to extract his subcontractor's rent makes the higher rent conditional on winning under outsourcing even higher. It turns out that this makes outsourcing sufficiently more attractive such that bilateral outsourcing constitutes a Nash equilibrium for any distribution satisfying the regularity condition.

Proposition 5 *Suppose $J_O(c_i)$ is increasing. (O,O) is the Pareto–dominant Nash equilibrium of the reduced outsourcing game with rent extraction.*

Proof. Under bilateral outsourcing, the interim winning probability function is $\overline{q}_i^d(c_i) = (1 - F(c_i))$. By using this in (6) and (8), I obtain that each seller's expected payoff under bilateral outsourcing is given by

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

The third equality follows from partial integration. Note that $F(c_i)/f(c_i)$ is bounded from below as it is non–negative and that is bounded from above as it is increasing and $f(1) > 0$. Boundedness of $F(c_i)/f(c_i)$ implies $[(1 - F(c_i))F(c_i)F(c_i)/f(c_i)]_{c_i=0}^{c_i=1} = 0$. The fourth equality follows from this and from simplifying.

Suppose now seller i deviates unilaterally to in–house production and denote his interim winning probability function in this case by $\overline{q}^d$. By (7), his expected payoff is given by $\Pi_I^{(I,O)} = \int_0^1 \overline{q}^d(c_i)F(c_i)\mathrm{d}c_i$. Because this is for any interim winning probability function $\overline{q}_i^d$ at least weakly smaller than $\int_0^1 F(c_i)\mathrm{d}c_i$, seller i cannot have a strict incentive to deviate unilaterally from bilateral outsourcing. Although bilateral

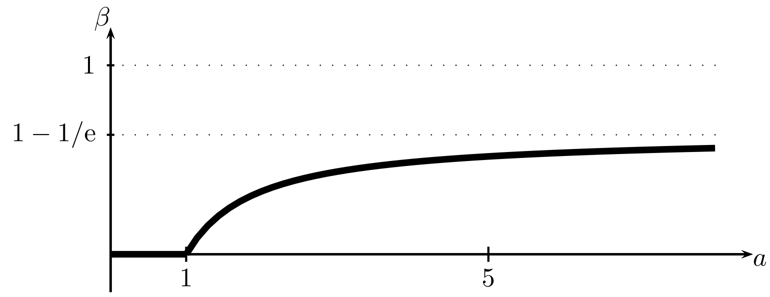

Figure 1: Fraction of a subcontractor's rent which needs to be extractable to render bilateral outsourcing stable [$F(c) = c^a$]

in–house production may constitute a further Nash equilibrium, it follows from Proposition 3 that bilateral outsourcing constitutes in any case the Pareto–dominant Nash equilibrium. q.e.d.

The technique of proof requires the complete extraction of a subcontractor's rent. However, the proof makes only use of a very rough upper bound of the expected payoff attained by deviating unilaterally from bilateral outsourcing. Normally the extraction of a much smaller part of a subcontractor's rent suffices to render bilateral outsourcing a Nash equilibrium of the reduced outsourcing game.

I can compute the part of the rent that needs to be extractable explicitly for $F(c) = c^a$ with $a > 0$. Suppose the payoff of a seller who outsources production is now $\Pi_O^{(\alpha_1,\alpha_2)} + \beta\Pi_S^{(\alpha_1,\alpha_2)}$ with $\beta \in [0,1]$. By Proposition 4, (O,O) constitutes a Nash equilibrium even for $\beta = 0$ when $a \in (0,1]$. Consider thus $a > 1$. I need to compute the smallest β such that $\Pi_O^{(O,O)} + \beta\Pi_S^{(O,O)} \geq \Pi_I^{(I,O)}$. By using (10), (13) and (11), I obtain $\beta = 1 - (a/(1+a))^{a-1}$ after simplifying. Figure 1 illustrates how β depends on the parameter a. Because $1 - (a/(1+a))^{a-1}$ is increasing with limit $1 - 1/\mathrm{e} < 2/3$, the extraction of two third of a subcontractor's rent suffices for any $a > 0$ to render bilateral outsourcing stable.

Proposition 5 holds for general distributions satisfying the regularity condition but it requires that there are only two sellers. However, I can show for any distribution $F(c) = c^a$ with $a > 0$ that the result breaks down when there are sufficiently many sellers. The existence of a Nash equilibrium with multilateral outsourcing has thus to be seen as a result for industries with a small number of sellers. Suppose that there are n sellers and denote a seller's payoff when each seller outsources production by $\Pi_O^{(O,O,\ldots,O)} + \Pi_S^{(O,O,\ldots,O)}$ and his payoff from deviating unilaterally to in–house production by $\Pi_I^{(I,O,\ldots,O)}$. The behavior in the game that is played after the outsourcing decisions are taken follows straightforwardly from the analysis so far. The expected payoffs are still given by (6), (8) and (7), but the interim winning probabilities $\overline{q}_i^d(c_i)$ change. Seller i's 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. I obtain the following result:

Proposition 6 *Suppose $F(c) = c^a$ with $a > 0$. There exists n' such that for any $n \geq n'$ $(O,\ldots,O)$ is not a Nash equilibrium of the reduced outsourcing game with rent extraction.*

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

$$\Pi_O^{(O,O,\ldots,O)} + \Pi_S^{(O,O,\ldots,O)} = (2 + 1/a)\int_0^1 (1 - F(c_i))^{n-1} F(c_i)\mathrm{d}c_i. \tag{14}$$

This follows from (6) and (8) 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 distributions. If a seller deviates unilaterally to in–house production, his expected payoff is

$$\begin{aligned}\Pi_I^{(I,O,\ldots,O)} &= \int_0^1 (1-F(a/(1+a)\cdot c_i))^{n-1}F(c_i)\mathrm{d}c_i \\ &= (1+1/a)^{1+a}\int_0^{a/(1+a)}(1-F(x))^{n-1}F(x)\mathrm{d}x. \qquad (15)\end{aligned}$$

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 distributions. The second equality follows from applying the substitution $x = a/(1+a)\cdot c_i$ and from using that $F((1+a)/a\cdot z) = (1+1/a)^a F(z)$ for the considered distributions. The result in the proposition follows from comparing (15) with (14) and the following two observations: First, $(1+1/a)^{1+a}/(2+1/a) > 1$ for any $a > 0$. Second, $\lim_{n\to\infty}\int_0^{a/(1+a)}(1-F(c_i))^{n-1}F(c_i)\mathrm{d}c_i/\int_0^1(1-F(c_i))^{n-1}F(c_i)\mathrm{d}c_i = 1$ for any $a > 0$.

The proof of the first observation works as follows: I have to show that $(1+1/a)^{1+a} > (2+1/a)$. By multiplying both sides of the inequality with a^{1+a}, I obtain $(1+a)^{1+a} > 2a^{1+a} + a^a$. By subtracting a^{1+a} from both sides and by using the notation $g(x) := x^{1+a}$, the inequality can be written as $(g(1+a) - g(a))/((1+a)-a) > (1+a)a^a$. As the left–hand side is the slope of a secant of the strictly convex function g, it is strictly larger than $g'(a) = (1+a)a^a$. This implies the first observation.

Crucial for the second observation is that $\psi_n(c_i) := (1-F(c_i))^{n-1}F(c_i)/\int_0^1(1-F(c_i))^{n-1}F(c_i)\mathrm{d}c_i$ specifies a density function on $[0,1]$ which becomes more and more concentrated at zero as n increases. Let Ψ_n be the cumulative distribution which is implied by this density function. The quotient under consideration is then $\Psi_n(a/(1+a))$. The concentration property implies that $\lim_{n\to\infty}\Psi_n(a/(1+a)) = 1$ for any given $a > 0$. This is the second observation. q.e.d.

By deviating unilaterally from multilateral outsourcing, a seller wins more often, but he obtains a smaller rent conditional on winning. The stability of multilateral outsourcing depends on the relative strength of the two effects. Proposition 6 states that the first effect overwhelms the second effect when the number of sellers is sufficiently large. A rough intuition is that the first effect gets stronger and stronger as the number of sellers increases (because a seller who deviates is favored over more and more competitors) whereas the second effect is not affected by the number of sellers (because the rent conditional on winning is always by the same factor $1+1/a$ larger when the seller does not deviate).

It remains the question how fast the equilibrium in which each seller outsources production ceases to exist. When C_i is uniformly distributed, it still exists for $n = 3$ but it does not exist for more than three sellers (this follows from (14) and (15) with $a = 1$). This shows that although the result holds under quite general conditions for $n = 2$, it can break down quite fast when the number of sellers grows.

7. Strategic effects for reverse first–price auctions

I used direct mechanisms to derive my theoretical results. A seller's outsourcing decision affects for such mechanisms the buyer's procurement mechanism design but not the way this mechanism is played.[21] This made the strategic effects implied by a seller's outsourcing decision particularly transparent, but it made them also technical. I discuss in this section the strategic effects which are implied by a seller's outsourcing decision when the buyer uses a reverse first–price auction with potentially a bonus for one of the sellers to

[21] For any incentive compatible and individual rational direct mechanism, playing the game corresponds basically to each player announcing the realization of C_i. In that respect, the play of the game is independent of the design of the mechanism.

implement the optimal procurement mechanism.[22] A seller's outsourcing decision affects then how the buyer designs the bonus as well as the other seller's strategic behavior in the auction. This makes the resulting effects less transparent, but it allows for interesting interpretations. In particular, I can discuss how a seller's outsourcing decision affects favoritism in the buyer's procurement auction and the fierceness of competition between the sellers.

I consider the different games which are played after (α_1, α_2) is chosen. Whether rent extraction was possible at the initial stage does not matter for the behavior at later stages in which I am interested in now. For being able to compute the bonus and the sellers' bidding behavior explicitly, I consider uniformly distributed C_i.[23] Moreover, as my focus is on the sellers' behavior and on the design of the auction, I consider the game in which the subcontracting stage is reduced. Recall that in this reduced game the only consequence of outsourcing is that the seller's cost is $k(c_i) = 2c_i$ instead of c_i.

Symmetric cases. Suppose $(\alpha_1, \alpha_2) \in \{(I, I), (O, O)\}$. In both symmetric cases a reverse first–price auction without a bonus implements the optimal procurement mechanism. Although bilateral outsourcing and bilateral in–house production imply the same auction design, the aggressiveness of the induced bidding behavior differs. Under bilateral in–house production both sellers bid according to $b_I^{(I,I)}(c_i) = (1 + c_i)/2$, whereas they bid according to $b_O^{(O,O)}(c_i) = 1 + c_i$ under bilateral outsourcing. That is, bidding is much less aggressive under bilateral outsourcing. This is because outsourcing makes losing less harmful for a seller as it saves on informational rents he has to leave to his subcontractor. As a consequence, both sellers are less eager to win and competition is less fierce. On the other hand, both sellers face under bilateral outsourcing higher cost. Because $b_O^{(O,O)}(c_i) - 2c_i = 1 - c_i$ and $b_I^{(I,I)}(c_i) - c_i = (1 - c_i)/2$, bilateral outsourcing leads to a higher rent conditional on winning than bilateral in–house production. That is, the less aggressive bidding behavior overcompensates for the higher cost.

Asymmetric cases. Suppose now $(\alpha_1, \alpha_2) \in \{(I, O), (O, I)\}$. I denote the seller who produces in–house by I and the seller who has outsourced production by O. A reverse first–price auction with a bonus for the stronger seller I is then optimal. Seller I obtains an additional payment of $B(b_I) = (1 - b_I)/(3 - 2b_I)$ when he wins with the bid $b_I \in [0, 1]$. The bonus set by the buyer can be interpreted as a reward for a unilateral deviation from bilateral outsourcing. At first glance, seller I seems to be clearly better off relative to the case in which both sellers have outsourced production: He faces lower cost and he gets favored through the buyer's auction design by the bonus payment. However, both effects entail a more aggressive bidding behavior by the other seller.[24] In particular, as the bonus is decreasing and concave in seller I's bid, it sets a stronger incentive for seller I to bid more aggressively when he intends to submit a less aggressive bid. This gives rise to a flatter bidding behavior by seller I which induces in turn a more

[22] In a reverse first–price auction both sellers simultaneously submit real–valued bids. The seller with the lowest bid wins and he is paid his bid. When there is a bonus for one of the sellers, this seller is paid the bonus in addition to his bid when he wins.

[23] I describe in this section the optimal first–price auction and the implied bidding behavior for each possible outsourcing structure (α_1, α_2). The bidding behavior follows for the considered case with uniformly distributed C_i easily from the stated auction rules. It can be verified by solving each seller's profit maximization problem given the other seller's bidding behavior. The optimality of the stated auction rule follows from the Revenue Equivalence Theorem and from showing that the bidding behavior implies the optimal procurement contract allocation as derived in Subsection 4.2.

[24] 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 my (reverse) auction problem when there is no bonus for the strong bidder. This can be used to show that both factors, the asymmetry and the bonus, make competition fiercer.

aggressive bidding behavior by seller O. The equilibrium bidding behavior is $b_I^{(I,O)}(c_I) = (1+c_I)/2$ for seller I and $b_O^{(I,O)}(c_O) = 1/2 + c_O$ for seller O. Seller O bids exactly $1/2$ less compared to the bilateral outsourcing case whereas seller I bids at least $1/2$ less. Because seller I reduces his bidding behavior stronger, he wins more often relative to the bilateral outsourcing case. On the other hand, seller I's rent conditional on winning under bilateral outsourcing is $b_O^{(O,O)}(c_I) - 2c_I = 1 - c_I$ whereas it is in the asymmetric case only $b_I^{(I,O)}(c_I) + B(b_I^{(I,O)}(c_I)) - c_I = 1/2 \cdot (1 - c_I) + 1/2 \cdot (1 - c_I)/(2 - c_I) < 1 - c_I$. That is, although seller I obtains a bonus payment and has lower cost when he wins in the asymmetric situation, his rent conditional on winning is lower compared to the bilateral outsourcing case. Responsible for this is that competition gets much fiercer when at least one seller produces in–house.

Discussion. This section demonstrates two things. First, the higher rent conditional on winning associated with outsourcing derives for interesting indirect implementations from less fierce competition and not from a payment rule which favors weaker sellers. The force which makes outsourcing attractive for the sellers is thus hidden for an outsider who observes only the outsourcing decisions and the favoritism through the auction design. Second, effects are very transparent when the optimal procurement mechanism is implemented directly, whereas effects are more involved and seem more surprising for interesting indirect implementations. The here considered indirect implementation suggests that a unilateral deviation from bilateral outsourcing is at first glance very attractive for a seller in the reduced outsourcing game without rent extraction. By deviating, a seller gets favored through the auction rules and faces lower cost. Endogeneity of the procurement mechanism design seems thus to make it even less likely that bilateral outsourcing can be stable. However, a seller's decision to deviate to in–house production provokes a much more aggressive bidding behavior by the other seller. The here discussed case with uniformly distributed C_i is the knife–edge case for which the three effects exactly offset each other. This renders bilateral outsourcing stable.

8. Discussion in the light of the large civil aircraft industry

The large civil aircraft industry is the duopoly of Airbus and Boeing. Both firms engaged in massive outsourcing in the production of their new models, the A350 and the Boeing 787 Dreamliner, whereas they outsourced very little in the production of previous models.[25] The decisions to outsource were driven by many factors and had many consequences. Among the reasons were guaranteed sales, risk–sharing with subcontractors, lower production cost and the speeding up of R&D and production. Important consequences were a loss of information as well as quality problems and repeated delays.[26]

Assessing the outsourcing decisions of firms like Boeing and Airbus in their entirety lies beyond the scope of this article. However, this article points at an additional effect which comes along with the loss of information and the need for subcontracting: For whatever reason the outsourcing decisions were taken, bilateral outsourcing can induce less fierce competition. I demonstrated that the anticompetitive effect of outsourcing may not be very visible at first glance and that the incentive to deviate from bilateral outsourcing

[25] 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."

[26] See Newhouse (2008) or Allon (2012).

may be weak even when the mode of competition is designed by a strategic player who rewards deviations from it. This article adds thus to the discussion of outsourcing decisions in practice that there could be an additional effect which seems not to be included in the current discussion.

9. Conclusion

Under the presumption that outsourcing leads to a loss of information and a need for subcontracting, I have studied sellers' optimal outsourcing decisions when a seller's outsourcing decision can influence the buyer's procurement mechanism choice and the other seller's strategic behavior. I have established that each seller faces generally a trade–off between a higher winning probability (in–house production) and a higher rent conditional on winning (outsourcing). I have then shown for an industry with two sellers that each seller's incentive to deviate from bilateral outsourcing is often weak even when there are no direct positive effects associated with outsourcing. By contrast, the incentive to deviate from multilateral outsourcing is strong for industries with many sellers.

In practice, outsourcing decisions are typically affected by factors from which I have abstracted in my stylized model. However, as the positive "higher rent conditional on winning"–effect which comes along with outsourcing in my stylized model relies basically only on outsourcing making the distribution of cost for providing the object which the seller faces more variable, it is robust with respect to extensions which maintain this property. In particular, the effect survives when outsourcing implies also cost savings. Adding such positive direct effects to outsourcing makes the case for outsourcing thus even stronger. Although the positive "higher rent conditional on winning"–effect associated with outsourcing may for interesting indirect implementations of the optimal procurement mechanism be not very obvious at first glance, it may nevertheless be strong and should be taken into account in the assessment of more complex outsourcing problems in practice.

Appendix A.

Proof that outsourcing is in the one–seller–case optimal even when the buyer cannot extract his subcontractor's rent. If the buyer offers a price $p_O = 1 + F(1)/f(1)$, the seller chooses p_I to maximize $F(p_I)(1 + F(1)/f(1) - p_I)$. $p_I = 1$ solves the first–order condition $f(p_I)[1 - p_I + F(1)/f(1) - F(p_I)/f(p_I)] = 0$ and it constitutes a maximum as the bracketed expression is strictly decreasing by the hazard–rate assumption. As $p_O = 1 + F(1)/f(1)$ is the lowest offer which induces $p_I = 1$, it constitutes the buyer's equilibrium offer. That is, $p_O^* = 1 + F(1)/f(1)$ and $p_I^* = 1$. The seller's expected profit is thus $p_O^* - p_S^* = F(1)/f(1)$ under outsourcing and $p_I^* - \mathbf{E}[C_1] = 1 - \int_0^1 c_1 \mathrm{d}F(c_1)$ under in–house production. By applying integration by parts, the latter profit can be written as $\int_0^1 F(c_1)\mathrm{d}c_1$. It follows that $p_O^* - p_S^* > p_I^* - \mathbf{E}[C_1]$ is equivalent to $F(1)/f(1) > \mathbf{E}[F(C_1)/f(C_1)]$. As the hazard rate assumption implies that this must be true, I obtain the optimality of outsourcing even when the seller is not able to extract rents from his subcontractor. q.e.d.

Derivation of (1). I have

$$\begin{aligned}
& \mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - s_i(C_i, b_1(C_1), b_2(C_2))] \\
= \; & \mathbf{E}[\mathbf{E}[t_i(b_1(C_1), b_2(C_2))|C_i] - \overline{s}_i(C_i)] \\
= \; & \int_0^1 \left(\int_0^1 t_i(b_1(C_1), b_2(C_2)) f(c_{-i})\mathrm{d}c_{-i} - \overline{q}_i(c_i)c_i - \int_{c_i}^1 \overline{q}_i(c)\mathrm{d}c - \kappa \right) f(c_i)\mathrm{d}c_i
\end{aligned}$$

$$
\begin{aligned}
&= \int_0^1 \left(\int_0^1 t_i(b_1(C_1), b_2(C_2)) f(c_{-i}) \mathrm{d}c_{-i} - \overline{q}_i(c_i) \left(c_i + \frac{F(c_i)}{f(c_i)} - \kappa \right) \right) f(c_i) \mathrm{d}c_i \\
&= \int_0^1 \int_0^1 \left(t_i(b_1(C_1), b_2(C_2)) - q_i(b_1(c_1), b_2(c_2)) \left(c_i + \frac{F(c_i)}{f(c_i)} - \kappa \right) \right) f(c_{-i}) \mathrm{d}c_{-i} f(c_i) \mathrm{d}c_i \\
&= \mathbf{E}[t_i(b_1(C_1), b_2(C_2)) - q_i(b_1(C_1), b_2(C_2)) k(C_i)] - \kappa.
\end{aligned}
$$

The first equality follows from applying the Law of Iterated Expectations and from using the definition of $\overline{s}_i$. The second equality follows from Lemma 1 and from writing the expected values as integrals. The third equality follows from applying partial integration. The fourth equality follows from using the definition of $\overline{q}_i$. The fifth equality follows from writing the integrals as expected values again. q.e.d.

Derivation of (3) and (4). Suppose first that $\alpha_i = O$. I have then

$$
\begin{aligned}
\mathbf{E}[t_i(C_1, C_2)] &= \mathbf{E}[\mathbf{E}[t_i(C_1, C_2)|C_i]] = \mathbf{E}[\overline{t}_i^d(C_i)] \\
&= \int_0^1 \left(\overline{q}_i^d(c_i) k(c_i) + \int_{c_i}^1 \overline{q}_i^d(c) k'(c) \mathrm{d}c \right) f(c_i) \mathrm{d}c_i \\
&= \int_0^1 \overline{q}_i^d(c_i) \left(k(c_i) + \frac{F(c_i)}{f(c_i)} k'(c_i) \right) f(c_i) \mathrm{d}c_i = \mathbf{E}[q_i(C_1, C_2) J_O(C_i)].
\end{aligned}
$$

The first equality follows from applying the Law of Iterated Expectations. The second equality follows from using the definition of $\overline{t}_i^d$. The third equality follows from Lemma 2 with $\kappa_i = 0$ and from writing the expected value as an integral. The fourth equality follows from partial integration. The fifth equality follows from writing the integral as an expected value and from using that $J_O(c_i) = k(c_i) + F(c_i)/f(c_i) \cdot k'(c_i)$. Suppose now that $\alpha_i = I$. The derivation of the expected transfer to seller i is like the derivation for $\alpha_i = O$ but with $k(c_i)$ replaced by c_i. q.e.d.

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