Precontractual Investment and Modes of Procurement

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Abstract

Consider a repeated game in which a buyer must decide whether to procure goods whose design may prove defective through auctions or negotiations. To reduce the likelihood of failure, the buyer must motivate the potential suppliers to make a precontractual investment. Because the noisy signal of the supplier's investment is non-verifiable the buyer can induce the suppliers to invest only through relational contracts. I find that auctions may not enable the buyer to implement a surplus-increasing relational contract even when the players are very patient. Therefore, negotiations may be adopted, since they are more effective in stimulating the supplier's investment.

Keywords: Auctions, Negotiations, Precontractual Investment, Procurement, Relational Contracts.
JEL: D82, D86, L14, L22

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Preprint submitted to European Economic Review

1. Introduction

Procuring a good whose design turns out to be defective can be extremely costly. This is especially so if the procurer is not the final user of the good. Consider, for instance, all the problems Boeing has experienced with the failure in the design of its new 787 Dreamliner. In January 2013, after two distinct cases of overheating involving the lithium-ion batteries, the planes had been grounded by the authorities. These batteries were one of the components Boeing had procured from its suppliers. The aircrafts were allowed to fly only several months later, when the causes of the problems were fixed.[1]

Adjusting the design of a good ex-post may thus have dire consequences: recalls, delays, the need to undo some works or redesign some other components, the possibility of disputes, the loss of reputation with customers.[2] To reduce the probability of having a defective design, the procurer of a sophisticated good, such as a building or a car's or an aircraft's part or component, may seek the involvement of the supplier at the planning stage. The supplier's know-how and skills can indeed be crucial to improve the initial design of the good provided by the buyer. A critical issue is that the supplier's involvement often requires a costly precontractual investment for it may entail a careful inspection of all the details of the project as well as the development of prototypes or technical drawings.

The purpose of this paper is to investigate the buyer's choice of the procurement mode when there is uncertainty about the suitability of the design of the good. I show that the horizon of the relationship affects the buyer's choices of auctions versus negotiations and of the delegation of the design task to the suppliers. In particular, when avoiding design failures is important and the interaction between the parties is repeated, negotiations are preferred and the design of the good is delegated to the suppliers. In contrast, when the interaction is one-shot or the quality of the design is of secondary importance, auctions are preferred and the design task is retained by the buyer.

I consider a repeated game in which a buyer selects a supplier to produce a good in each period. There is ex-ante uncertainty as to whether or not the design of the good will turn out to be correct. Initially, I assume that only the suppliers can provide the technical drawings (or develop a prototype) for the good the buyer wants to procure. Each solicited supplier independently decides how much to invest in developing their own technical drawings. The technical drawings improve the design of the good and reduce the likelihood of failure if the selected supplier's investment has been high. The investment choice is private and is made before a supplier knows exactly how much it would cost him to produce that specific good. The suppliers differ with respect to the production costs, which also vary over time. Their cost of production is private knowledge which makes it valuable for the buyer to screen the potential suppliers in every period. The buyer chooses the award mechanism, i.e. auctions or negotiations. In an auction at least two firms bid on the price to produce the good according to their own technical drawings, whereas in a negotiation only one firm is solicited to develop the technical drawings.

I assume that each supplier's investment is project-specific, which leads to the well-known hold-up problem (see Klein et al., 1978 and Williamson, 1975), and the value of a supplier's contribution cannot be assessed in a court-enforceable contract.[3] In this environment, only repeated interaction can create the conditions for the suppliers to undertake the investment, whereas formal incentives are ineffective. Thanks to repeated interaction it is possible to use *relational contracts*, namely informal agreements that can be sustained by the parties' concern about the future.

When the interaction between the buyer and the suppliers is not repeated, the buyer anticipates that the suppliers will not invest in developing the drawings of the good. The buyer will then focus on minimizing

[1] The potential penalties for late deliveries that Boeing could be asked to pay to its customers will increase the already higher than anticipated cost that the development of the new wide-body jet has brought about. Boeing initially planned to spend around $5 billion, but conservative estimates made by Barclays Capital say that the programme will end up costing around $14 billion. See "*The Two Men Behind the 787*", in The Wall Street Journal, January 24, 2013.

[2] The faults that have plagued the development and the delivery of the 787 may have cost Boeing its dominance in the Japanese aviation industry. See "*Turning Japanese*", The Economist, October 12, 2013.

[3] Even ex-post, it is often difficult for a court to determine whether the good meets all the buyer's desired specifications and who is to blame for a design failure. In the Boeing 787 case, the ultimate cause of the battery failure has never been determined.

the cost of production. To this end, she will procure the good through an open auction, that is an auction in which all the potential suppliers in the market are solicited to submit a bid.

When the interaction is repeated, I find that negotiations are more effective than auctions in stimulating the investment. Auctions are ineffective in inducing the suppliers to invest because an essential feature of competitive bidding is that any reward promised by the buyer for delivering a flawless design is competed away at the bidding stage. Therefore, a supplier may be willing to invest only if the expected value of the information rent, which is all he can expect to obtain if he wins the auction, is larger than the investment cost. I call this condition the *bidding-competition* constraint. Furthermore, auctions augmented with relational contracts suffer from a severe credibility problem. This occurs because they may require an excessively expensive reward that the buyer may not credibly promise to pay. Consider that, even if the value of the expected informal payment is incorporated in the bids, the buyer must promise a reward for a successful design so as to avoid that the potential suppliers decide to remain idle. The reward can be particularly high in auctions for two reasons. First, when a supplier invests there is uncertainty as to whether or not he will be awarded the contract. Second, by remaining idle a supplier obtains a positive payoff, whose size is inversely related to that of the reward itself. Inviting fewer bidders may not generate enough rents to prompt the investments and, as a result, the buyer may find it profitable to relinquish the benefits of auctions and directly negotiate with one supplier. Negotiations augmented with relational contracts do not require the bidding-competition constraint and need a lower reward to induce the investment, since the supplier must just receive the standard moral-hazard rent.

If the buyer can provide the technical drawings of the good herself, she will prefer to retain the design task and delegate only the production of the good to the suppliers when the interaction is not repeated. In contrast, when the interaction is repeated the buyer may be better off delegating the design of the good to the suppliers for they can be prompted to invest. As a result, the model provides some important predictions about firms' procurement practices in the private sector. It suggests that we should observe that buyers use open auctions when they entirely develop the design of the good in-house while they use restricted auctions and direct negotiations when they delegate the design of the good to their suppliers.

The paper can account for a number of findings in the management literature concerning buyer-supplier relationships. It seems especially suitable to explain the sharp differences between the supply-chain practices in the Japanese and the U.S. manufacturing industry in the early 1980s and the subsequent adoption of Japanese-style procurement practices in the U.S.. Specifically, American car manufacturers used to develop the specification of the good entirely by themselves and select suppliers through open bidding. In doing so, they hardly received any ideas from the suppliers on how to improve the design of the car parts or components. In contrast, Japanese car manufacturers traditionally delegate the design of the good to their suppliers, who are selected through auctions with a limited number of firms in which the incumbent is strongly favoured, so that the selection procedure closely resembles a negotiation. The model suggests that such practices are particularly valuable when obtaining high-quality designs of the goods is essential and inducing the suppliers' investment requires frequent interaction. Consistently, U.S. assemblers embraced Japanese-style procurement practices in the second half of the 1980s, when vehicles became technically complex and car models proliferated. The predictions of the paper also appear to be consistent with the procurement practices adopted in other industries, such as sophisticated electronics (Burt, 1989) and construction industry (Bajari et al., 2009). In the latter case, the authors find that more complex projects, for which the suppliers' insight is more valuable, are procured through negotiations or restricted auctions.

Related Literature. This paper is part of the burgeoning literature on relational contracts whose foundations have been laid by Bull (1987), MacLeod and Malcomson (1989), Baker et al. (1994, 2002), and Levin (2003) (see Malcomson, 2012, for a recent survey). Recently, several papers in the economics and management literatures have analysed the use of relational contracts in procurement (among others, see Tunca and Zenios, 2006, Taylor and Plambeck, 2007a,b, and Corts, 2012).

In this strand of the literature, the articles which are more closely linked to my paper are those by Andrews and Barron (2016), Board (2011), Calzolari and Spagnolo (2009), and Calzolari et al. (2019). Andrews and Barron (2016) develop a repeated moral-hazard problem between one buyer and many suppliers in the presence of imperfect private monitoring. They find that the buyer rewards a supplier who performs well with additional contracts (i.e., success is rewarded) and that this favoured supplier loses future business only if, in a period in which he does not produce, the replacement performs well (i.e., failure is tolerated). Board (2011) analyses a principal who must invest in one of many suppliers in each period. He shows that relational contracts can mitigate the hold-up problem and induce loyalty, in the sense that those trading parties with whom the principal has dealt in the past will be favoured over the outsiders when new contracts are awarded. The role of the award mechanism is not examined and it is assumed that the principal cannot extract the suppliers' expected rents. Like me, Calzolari and Spagnolo (2009) study the procurement mode chosen by the buyer in a repeated setting. They also find that the buyer may be willing to restrict competition when the interaction with suppliers is frequent. However, a-priori there is no reason why the two papers should reach such a similar conclusion given that they analyse sharply different settings: A supplier chooses investment after selection and the relational contract is enforced by bilateral punishments in Calzolari and Spagnolo (2009), whereas a supplier invests before the contract is awarded and the relational contract is enforced by multilateral punishments in the present model.[4]

I depart from this literature by analysing an ex-ante moral-hazard problem in which there is a non-observable project-specific investment to be made *before* the contract is awarded and there is a non-verifiable noisy signal of performance. In this context, I show that auctions can provide incentives to invest only if a bidding-competition constraint is satisfied. Furthermore, I provide clear predictions as to when the buyer will be willing to retain or delegate the design task. Calzolari et al. (2019) also investigate how relational contracting can induce precontractual investment in a procurement setting. These authors empirically study the interplay between trust, competition, and investment using survey data on buyer-supplier relationships in the German automotive industry. In their model, Calzolari et al. (2019) shed light on how the allocation of bargaining power between the buyer and the suppliers can explain the differential impact of trust on competition and investment as a function of the technological sophistication of the supplied part that they find in their empirical analysis.[5]

The paper is also related to recent work by Herweg and Schmidt (2017, 2019) who consider a procurement setting in which the suppliers may be ex-ante informed about a superior design of the project. Suppliers are willing to withhold such information to extract rents ex-post in a bilateral renegotiation with the buyer. Herweg and Schmidt (2017) show that a bilateral negotiation may outperform an auction because the supplier is already in a situation of bilateral monopoly with the buyer and, as a consequence, does not benefit from revealing information ex-post. Herweg and Schmidt (2019) look for the optimal mechanism to induce suppliers to reveal design flaws. Like them, I assume that the good may be plagued by design flaws and, akin to Herweg and Schmidt (2017), I compare bilateral negotiations to auctions. Unlike them, I focus on relational contracting and I assume that renegotiation to adopt a superior design does not take place by analysing a setting in which the good has already been delivered when uncertainty resolves. Moreover, I do not assume that suppliers are better informed about design flaws but can invest to reduce the likelihood of failure.

Finally, I also investigate the interplay between the procurement mode and the buyer's initial investment in the design of the good, which is a dimension that has not been analysed in the above papers. In developing a model of endogenous design incompleteness, I draw on Bajari and Tadelis (2001) who were the first to put forward the idea of an initial investment into planning which reduces the likelihood that the design of the good fails. Bajari and Tadelis (2001) study a one-shot procurement game between a buyer and a seller and highlight the tension between ex-ante cost-reduction incentives, which call for a high-powered incentive scheme (i.e. a fixed-price contract), and ex-post transaction costs, which call for a low-powered incentive scheme (i.e. a cost-plus contract). They do not allow for a (partial) delegation of the design to the supplier and do not focus on potential heterogeneities among different suppliers.

[4]See also the paper by Albano et al. (2017) who show how the buyer should use handicaps to induce the firms to provide the required level of non-verifiable quality.

[5]In addition to the different objectives, the two papers also have noteworthy modeling differences. For instance, in Calzolari et al. (2019) the buyer can select a supplier to produce a part according to the technical drawings developed by a different firm, thereby depriving the latter of his IPR. Moreover, the buyer observes the project-specific investment of the selected supplier, as well as those of all the other suppliers invited in the development phase, once production is completed. Conversely, I assume that the buyer observes a signal imperfectly correlated with the investment of the selected supplier and I allow for informal bonuses that can be used to provide the suppliers with incentives to invest.

Outline. The remainder of the paper proceeds as follows. In the next section I set up the model. In Section 3, I compare auctions and negotiations in the absence of repeated interaction. In Section 4, I study procurement modes when relational contracts can be used and I discuss how the results of the model may provide an explanation for the different procurement practices adopted in the manufacturing industry. In Section 5, I analyse several variants of the model to check the robustness of the main results and provide additional insights. In Section 6, I conclude. All proofs and technicalities are in the appendices.

2. The Model

Players. Consider a risk-neutral buyer who, in each period $t = 1, 2, 3...$, wants to procure a good from one of $N \geq 2$ risk-neutral potential suppliers. The buyer is female while the suppliers, indexed by $i \in \{1, ..., N\}$, are male. Buyer's and supplier i's utility functions are denoted by u and π_i, respectively. The players discount future payoffs using the same discount factor $\delta \leq 1$ and the overall payoffs are multiplied by $1 - \delta$ to obtain per-period averages. The buyer and the suppliers have outside options giving 0.

Design Failure. There is uncertainty as to whether or not the design of the good will turn out to be correct. The buyer derives utility v if the design is correct and $v - k$ if it is flawed. The parameter $k > 0$ is meant to capture both the loss of utility the buyer incurs if she markets a defective product, such as the loss of reputation and the penalties associated with delays, and the increased cost of producing the good, e.g. the cost of fixing the defective design. I assume that a design failure is observed by all the players of the game but that a court-enforceable contract contingent on this event cannot be written. Consistently, the buyer's payoff is assumed to be observable but non-verifiable. The probability with which the initial specification of the project is flawed is $1 - \beta$. I assume that β is known to all the players of the game and, for tractability reasons, is the same for all the goods procured by the buyer.

Timing. In every period, the sequence of events is summarized in Figure 1 and is extensively described below.

In stage 0, the buyer issues a request for business proposals. A proposal includes the development of the technical drawings of the good, which are essential for production, as well as a price request.[6] The buyer selects a subset of suppliers $\mathcal{N}_t \subseteq \{1, ..., N\}$ who are solicited to submit their business proposals. I denote by n_t the cardinality of $\mathcal{N}_t$, $n_t \equiv |\mathcal{N}_t|$. The buyer also sets a participation fee $f_t \in \mathbb{R}$ that a solicited supplier must pay to see the details of the project and the reserve price $\bar{b} \in \mathbb{R}$. I distinguish between two polar procurement modes:

(a) *Auctions*, wherein $n \geq 2$ suppliers are solicited to submit a price bid b along with the technical drawings. I assume that a second-price reverse auction is held and, as a result, the selected supplier receives the value of the second lowest bid once production is complete.[7]
(b) *Direct negotiations*, wherein the buyer asks a single supplier to supply the technical drawings and the price required to carry out production.

In stage 1, the suppliers who have been solicited to submit the proposal decide whether or not to accept to participate. A supplier's choice of trade is publicly observed and is denoted by $d_{i,t} \in \{0, 1\}$. Each supplier who accepts to participate independently and privately decides how much to invest in preparing their proposals. I assume that this investment is binary, i.e. $e_i \in \{0, 1\}$. The cost of the investment is ge_i, with $g > 0$. The technical drawings supplier i can provide at time t are *superior* if $e_{i,t} = 1$ and *standard* if $e_{i,t} = 0$. While standard drawings do not affect the probability of an ex-post failure, superior drawings reduce it to $(1 - \beta)(1 - \rho)$. Thus, $\rho \in (0, 1)$ captures the probability that superior drawings correct existing

[6] Instead of the technical drawings, one may think of the buyer asking the potential suppliers to develop a prototype of the good.

[7] Most of the results of the analysis would not change if the buyer held a first-price reverse auction as the conditions of the Revenue-Equivalence Theorem are satisfied, i.e., bidders are risk-neutral and their types are independently and identically distributed (see Myerson, 1981). I consider second-price auctions in the analysis for tractability reasons.

flaws in the initial specification of the good. I assume that the buyer cannot detect whether $e_{i,t} = 0$ or $e_{i,t} = 1$ from observing i's proposal. This implies that a supplier could pretend that his standard drawings are in fact efficiency enhancing without incurring any cost and the buyer would not be able to distinguish them from ones which are effectively superior. This is why the buyer only evaluates price bids and not also the technical drawings.

In stage 2, each supplier learns his own cost of production $c_{i,t}$, which I assume to be independently and identically distributed according to the continuous distribution $\Phi(c)$, with density $\phi(c)$, on the interval $[\underline{c}, \bar{c}] \subset \mathbb{R}_+$, with $\bar{c} > \underline{c}$. While the cost distribution is publicly known, a supplier is privately informed about his own cost of production.

In stage 3, the participating suppliers submit their proposals. Subsequently, the buyer observes the proposals and signs the contract according to the rules of the chosen procurement mode. The suppliers' bids and the buyer's choice of the supplier is public. The latter is denoted by $q_t = \{q_{i,t}\}_{i=1}^N$, with $q_{i,t} \in \{0, 1\}$, and $\sum_{i=1}^N q_{i,t} \leq 1$.

In stage 4, the good is produced according to the drawings of the winning supplier at an unverifiable cost $c_t = \sum_{i=1}^N q_{i,t} c_{i,t}$.

Between stage 4 and stage 5 uncertainty is resolved, and payoffs are realised in stage 5.

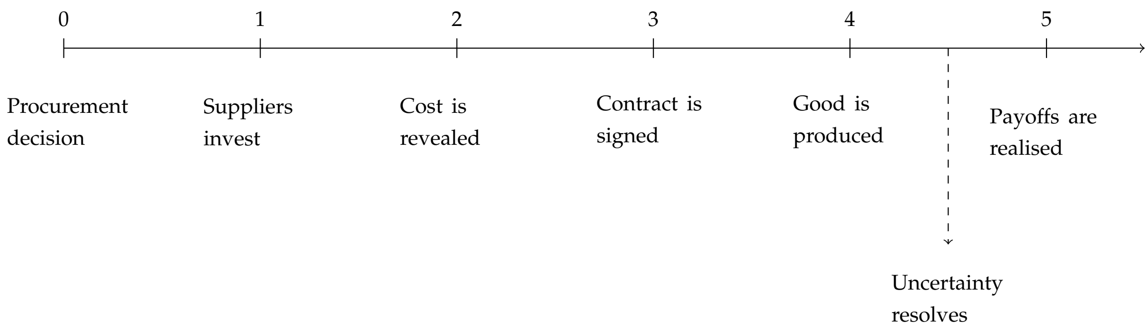

Figure 1: Sequence of Events

Equilibrium and parametric assumptions. In the analysis, I look for the equilibrium that maximises the buyer's expected utility.[8] This is equivalent to maximising ex-ante total surplus, since utility is transferable between the buyer and the suppliers through the participation fees and the former sets the terms of the procurement modes.

Throughout, I assume that it is efficient that a supplier undertakes the investment.

Assumption 1. *The following condition holds:*

$$(1 - \beta)\rho k > g.$$

The above inequality says that the benefits of superior technical drawings, namely the reduction in the probability that the buyer incurs the loss of utility due to a design failure, outweigh the investment cost. Moreover, I make the following assumption that implies that it is socially efficient (i) to produce the good even when the probability of a design failure is one and (ii) to select a supplier who has invested over one who has not, irrespective of their costs of production.

Assumption 2. *The following conditions hold:*

(i) $v - k \geq \bar{c}$;

[8]Details on the equilibrium concepts and the players' strategies are provided in the next sections.

(ii) $(1-\beta)\rho k > \bar{c} - \underline{c}$.

Discussion. I conclude this section by commenting on some of the modelling assumptions. Firstly, a design failure is assumed to be non-verifiable. Problems occurring after the production of the good may cause delays and disputes and, as a result, are difficult to conceal. At the same time, it may be difficult for a court to assess whether the good produced is not exactly as conceived by the contracting parties or whether either of them is claiming the presence of non-existing flaws.[9]

Secondly, the supplier learns exactly how much it would cost him to produce the good according to his own drawings, $c_{i,t}$, only after having invested. Before investing, a supplier only knows the cost distribution. This can be due to the great uncertainty about the costs of production that suppliers face before examining the details of a project and developing the technical drawings. In construction procurement, for instance, sources cited by Bajari and Tadelis (2001, page 390) maintain that reasonable cost targets can be established only when project engineering is $40\% - 60\%$ complete.[10]

Thirdly, the assumption that the production cost is project-specific can be justified by the wide variety of goods that a buyer typically procures, each with their own specific features.[11]

Lastly, Assumption 2 (ii) implies that the model focuses on an environment where procuring superior technical drawings is critical as its benefits outweigh the maximum gains from competition, i.e. the maximum cost differential. As a result, the buyer will not mind restricting competition if this leads the solicited suppliers to choose a high investment. This assumption helps convey the main message of the paper, that is, the ineffectiveness of auctions in stimulating the suppliers' investment even when this is surplus-increasing. However, this assumption is admittedly restrictive and is relaxed in Section 5.4. where it is shown that auctions suffer from the same drawbacks, but may be preferred because of the expected reduction in the production cost of the selected supplier.

3. One-time Procurement

I begin by analysing the procurement mode the buyer adopts in the absence of repetition. First note that in the one-stage game the suppliers' investment to provide superior drawings of the good cannot be encouraged, irrespective of the chosen procurement mode: Since the design failure is non-verifiable and the cost a supplier bears in preparing his own proposal is sunk, choosing $e_i = 0$ is a dominant strategy for each $i \in \mathcal{N}$.

In a one-shot auction, the buyer's expected utility if production always takes place is given by:

$$u^{auc} = v - (1-\beta)k - EP(b) + \sum_{i \in \mathcal{N}} d_i f_i,$$

where $EP(b)$ denotes the expected payment made to the winning bidder, which is a function of the bids. In a second-price auction, $EP(b)$ is equal to the expected value of the second-smallest bid. Let c^n_m be the expected value of the m-th highest order statistic of n draws from the distribution Φ on $[\underline{c}, \bar{c}]$.[12] I now formally define the *expected information rent* which plays a crucial role throughout the analysis.

[9] Even if available, third-party enforcement could be very costly, which may prompt a buyer to rely on reputational enforcement mechanisms to induce performance. I refer the reader to the work of economists and legal scholars on network governance (e.g., Lippert and Spagnolo, 2011 and Bernstein, 2015).

[10] I may also assume that the type of drawings supplied can affect the cost of production. For instance, supplier i's cost of production may be augmented by an additive parameter $\epsilon_{i,t} e_{i,t}$ with mean $\mu_\epsilon = 0$ and small variance. This would not change the results of the analysis.

[11] In construction procurement, the specificities of a project are related to the location, the size (e.g. the number of stories in a building), the type of material to be used. In manufacturing, the characteristics of the components and the parts that assemblers procure vary from one good to another. For instance, in the automotive industry, the chassis, the engine, or the brakes are markedly different depending on the model (e.g. a city-car, a sedan, or a sports car).

[12] In defining the order statistics, I follow the auction theory literature which customarily rearranges the draws from the highest to the lowest, in contrast to the statistic notation and terminology which conventionally rearranges the draws from the smallest to the highest.

Definition 1. *The expected information rent accruing to a supplier in an auction with n bidders is:*

$$\frac{1}{n}I(n) \equiv \frac{1}{n}(c^n_{n-1} - c^n_n).$$

The expected information rent is given by the product of the ex-ante probability of winning the auction, which is $\frac{1}{n}$ as the suppliers are ex-ante identical, and the difference between the two smallest order statistics, $c^n_{n-1} - c^n_n$, which, as will be shown momentarily, coincides with the expected gain from winning the auction.

The following lemma characterises the suppliers' equilibrium behaviour and the choices of the reserve price, the participation fee, and the number of solicited bidders which maximise the buyer's expected utility in an auction.

Lemma 1. *In a one-shot auction, it is a weakly dominant strategy for each supplier $i \in \mathcal{N}$ to choose $d_i = 1$ if $f_i \leq \frac{1}{n}I(n)$ and $d_i = 0$ otherwise, $e_i = 0$, and $b_i = c_i$, whereas the buyer optimally sets $\bar{b}^{auc} \geq \bar{c}$, $f^{auc}_i = f^{auc} = \frac{1}{n}I(n)$ for all $i \in \mathcal{N}$, and $n^{auc} = N$.*

In a second-price reverse auction, it is a weakly dominant strategy for each solicited supplier to bid their true cost of production. The buyer finds it profitable to set the reserve price in such a way that production always takes place. Since the lowest-cost supplier is awarded the contract and receives a price equal to the second-lowest bid, it follows that $EP(b) = c^n_{n-1}$. Hence, to guarantee the suppliers' participation in the auction and fully extract their expected information rent, the buyer optimally sets a participation fee $f^{auc} = \frac{1}{n}I(n)$. Finally, as the buyer's expected utility is increasing in the number of bidders, the buyer holds an *unrestricted or open auction*, that is, she solicits bids from all N potential suppliers. Therefore, the buyer's expected utility from procuring a good through an auction is given by:

$$u^{auc} = v - (1-\beta)k - c^N_N. \quad (1)$$

Lemma 2 characterises the selected supplier's equilibrium behaviour and the choices of the reserve price and participation fee that maximise the buyer's expected utility in a direct negotiation.

Lemma 2. *In a one-shot negotiation, it is a weakly dominant strategy for a selected supplier to choose $d = 1$ if $f \leq \bar{b} - E(c)$ and $d = 0$ otherwise, $e = 0$, and $b = \max\{\bar{b}, c\}$, whereas the buyer optimally sets $\bar{b}^{neg} \geq \bar{c}$ and $f^{neg} = \bar{b}^{neg} - E(c)$, where $E(c) = \int_{\underline{c}}^{\bar{c}} x\phi(x)dx$.*

In a direct negotiation, the selected supplier will ask for the buyer's maximum acceptable price. However, in expectation the supplier does not earn any rent: since there are many potential suppliers among whom the buyer can select the producer of the good, she does not need to give up any margin in a bilateral negotiation. The buyer's expected utility is given by:

$$u^{neg} = v - (1-\beta)k - E(c). \quad (2)$$

Comparing (1) and (2) it is straightforward to see that in the one-shot game auctions outperform negotiations: the former always select the least-cost supplier, whereas the latter do so with probability $\frac{1}{N}$. Therefore in the buyer-preferred sequential equilibrium of the one-shot game an open auction is held and (1) represents the outcome to which the buyer will revert if she fails to sustain an efficiency-enhancing informal agreement in the repeated game.[13]

[13]It is worth noticing that in the one-shot game the buyer cannot improve upon the outcome achieved with an open auction by devising a more general mechanism to procure the good. First, since suppliers' investment decisions are privately observed and a design failure is non-verifiable, $e_i = 1$ for at least some i cannot be induced. Second, the open auction described in Lemma 1 maximises the buyer's expected utility as it guarantees that the lowest-cost supplier always wins the contract and that the buyer extracts all the suppliers' expected surplus.

4. Repeated Interaction and Relational Contracts

I now consider the infinitely repeated version of the buyer's problem. Repeated interaction enables the buyer to use informal incentives to induce the desired action from the suppliers provided that the punishment each party faces if they deviate is severe enough.

In this setting, the buyer might be able to induce the supplier's investment by promising different payoffs following the resolution of uncertainty between stages 4 and 5. In particular, the supplier can be rewarded if the design of the good turns out to be correct and punished otherwise. Formally, the stage game of the previous section is enriched in the following way. In every period t, the buyer agrees to pay the selected supplier a discretionary reward r, which I assume to be solely contingent on the realisation of $\xi \in \{S, F\}$ at stage 5 where $\xi = F$ if the design fails and $\xi = S$ if it "succeeds".[14]

To describe the informal contracts that govern the relationship between the buyer and the set of N potential supplier I follow the literature on relational contracts, and more specifically Levin (2002, 2003). Consider a *multilateral relational contract* describing a complete plan for the relationship between the buyer and the N suppliers. The relational contract also prescribes parties' behaviour following a deviation, for instance if either the buyer refuses to pay or a supplier refuses to accept the contingent reward. Crucially, I assume that market participants are able to identify which party has deviated. Namely, a buyer's deviation is detected by all the players of the game, included those suppliers who have not been invited to submit their proposals in that period. The suppliers react by ceasing to trust the buyer's proposed non-enforceable rewards. As is standard in this literature, I say that the multilateral relational contract is *self-enforcing* if it describes a Perfect Public Equilibrium (PPE) of the repeated game.[15]

The fact that relational contracts are sustained by a multilateral punishment appears realistic. Many procuring firms themselves promote suppliers' associations, which ease information sharing among market participants (for Toyota, among others, see Roberts, 2004, pp. 204-206). In the model, the problem of identifying who deviated is dramatically simplified because ξ and r are assumed to be observed by all suppliers. However, as shown in Section 5.4, the results of the paper carry through to a setting in which only the buyer and the selected supplier observe whether or not the design fails. Intuitively, there is other "public information", such as the trade decision, that the other suppliers can use to infer whether the buyer followed through on her promised reward. Because the suppliers can coordinate punishments, if the buyer reneges, her reputation (goodwill) is tarnished. Similarly to Baker et al. (1994, 2011), in what follows I assume that the parties can only use formal contracts in future periods after a deviation. Thus, if the buyer deviates in period t, she cannot attain more than the one-shot open auction payoff thereafter. If a supplier deviates, the bilateral relationship ends with probability one and the buyer will optimally decide whether or not to blacklist the deviant supplier, who will no longer be asked to submit his proposal.[16]

I analyse the use of relational contracts in augmented auctions and augmented negotiations, separately, and I then determine the procurement mode the buyer prefers. To simplify the analysis of optimal contracts, I turn to the well-known result of Levin (2003) on the optimality of stationary contracts.[17] Furthermore, I focus on symmetric pure-strategy equilibria.

[14] Note that the parties cannot gain from making the discretionary reward dependent on other observable variables as they would not provide additional information about the selected supplier's investment choice, given that ξ is available.

[15] A strategy is public if it depends only on public history, and not on a player's private history. A PPE is a profile of public strategies that form a Nash Equilibrium from t onwards for any public history h^t (see Fudenberg et al., 1994).

[16] With auctions, the choice is non-trivial only when $n = N$ so that the buyer must decide whether to hold augmented auctions with $N - 1$ suppliers or revert to auctions with N suppliers and no informal contracts. Conversely, if $n < N$, the buyer can costlessly replace the deviant supplier.

[17] Levin (2003, Theorem 2) shows that present compensation and future payoffs are substitutable instruments to provide incentives when the parties are risk neutral and the performance measure is observed by both the principal and the agent. When this is the case, an incentive scheme that uses continuation payoffs to reward/punish the agent may be replicated by a scheme only based on immediate compensation. As a result, in searching for optimal contracts, it suffices to focus on contracts which are stationary, namely that involve the same compensation schedule and the same effort in every period. The conditions of the theorem are satisfied by the present model and the players can use the participation fee to transfer utility between one another. In the proof of Lemma 3, I show that the buyer cannot gain from adopting non-stationary contracts.

4.1. Augmented Auctions

Suppose that the buyer wants to hold an auction in every period to select the supplier and wishes to employ informal incentives to complement the formal contract so as to improve upon the outcome of the stage game. Specifically, the buyer holds *augmented auctions* wherein she uses contingent rewards to induce the investment. Below I determine the conditions under which augmented auctions induce the suppliers to invest. Technical details concerning histories, the features of the multilateral relational contract, the suppliers' and the buyer's expected utilities are reported in the appendix. Let $SW^A(n)$ be the surplus that can be achieved in augmented auctions in which n suppliers are solicited to submit a proposal and which implement $e_{i,t} = 1$ for each invited supplier i and $t = 1, 2, ..$, namely:

$$SW^A(n) = v - (1-\beta)(1-\rho)k - c_n^n - ng. \tag{3}$$

I denote by n^* the surplus maximising number of solicited suppliers, which is monotone nonincreasing in the investment cost g.[18] Intuitively, augmented auctions entail wasteful investments as some suppliers costly develop superior drawings which are not used in the production of the good. Therefore, when the investment cost g is higher, it is socially optimal to limit the number of solicited suppliers.

To achieve $SW^A(n)$, each supplier must prefer to invest rather than remain idle. Consider that in the investment stage the suppliers play a non-cooperative Nash game taking into account the bidding equilibrium. While other equilibria may exist, I focus on the weakly dominant strategy equilibrium of the second-price auction in which each solicited supplier i bids his true production cost, $c_{i,t}$, minus the expected value of the discretionary payment he will receive if he wins the auction, which is a function of i's investment and is denoted $R(e_{i,t})$.

When each supplier invests, $EP(b) = c_{n-1}^n - R(1)$, which implies that the suppliers compete away at the bidding stage the expected value of the discretionary payment associated with $e = 1$. Therefore, at the investment stage, the only rent a supplier expects to obtain is the information rent associated with his private knowledge of his cost of production. Then, a necessary condition for a supplier to be willing to invest is that the expected information rent is large enough so as to compensate him for the investment cost. I call this condition the *bidding competition constraint* (BCC):

$$\pi_{i,t}(e_{i,t} = 1 | e_{-i,t} = 1) = \frac{1}{n} I(n) - g \geq 0. \tag{BCC}$$

Augmented auctions with n bidders cannot induce each supplier to invest when the above constraint is not satisfied at that n. This is so even if they increase surplus relative to the static outcome. This stands in contrast to the rest of the literature in relational contracting in which surplus improving relational contracts can always be self-enforced when the players are patient enough.

Only if the (BCC) is satisfied, the buyer can motivate the suppliers to invest. However, this is not sufficient to induce investment. To this end, the buyer must create a wedge between $R(1)$ and $R(0)$ so that a supplier who remains idle has a lower expected payoff. Provided that the (BCC) holds, it is always possible to set the differential $R(1) - R(0)$ large enough so as to induce all the suppliers to invest. However, there is a credibility problem since a higher $R(1) - R(0)$ translates into a higher reward that the suppliers must credibly expect the buyer to pay. For this reason, the buyer finds it profitable to choose the smallest such differential. Consider that the multilateral relational contract is self-enforcing only if, in addition to participation and incentive compatibility constraints, it satisfies suppliers' and buyer's dynamic enforcement constraints which ensure that neither the suppliers nor the buyer, respectively, are willing to back out on their promises. Thus, by setting the lowest rewards which satisfy the supplier's dynamic enforcement and incentive compatibility constraints, the buyer minimises her maximum temptation to renege on the relational contracts. I define $B(n, g)$ as the minimum differential $R(1) - R(0)$ such that $e_i = 1 \; \forall i \in \mathcal{N}$ is the only equilibrium in the investment stage. $B(n, g)$ is always strictly larger than the investment cost g. This is because a supplier who invests is uncertain as to whether or not he will be awarded the contract.

[18] To see this, note that SW^A exhibits nondecreasing differences in $(n, -g)$ and, as a result, n^* is monotone nonincreasing in g.

Moreover, by remaining idle a supplier can attain a positive payoff whose magnitude decreases as $B(n,g)$ grows large. In addition, when the difference between the expected information rent and the investment cost is positive but small, $B(n,g)$ must be very high to induce the investment.[19]

I can now determine under what conditions augmented auctions which generate $SW^A(n)$ can be sustained.

Lemma 3. *Augmented auctions that obtain $SW^A(n)$ and yield the buyer utility $u^A(n)$ are self-enforcing if the (BCC) and the following buyer's dynamic enforcement constraint hold:*

$$\frac{\delta}{1-\delta}\underbrace{[(1-\beta)\rho k - ng - (c_n^n - c_N^N)]}_{u^A(n)-u^{auc}} \geq r_S^A = \frac{B(n,g)}{(1-\beta)\rho}. \qquad (BDE^A)$$

When there is higher uncertainty about the suitability of the design of the goods the buyer procures, sustaining the relational contract is easier. There are two reasons why a lower β helps implement $e = 1$ in augmented auctions. First, a supplier's investment is more valuable when there is a higher likelihood that the good is ex-ante defective, increasing the surplus generated by relational contracting. Second, the observation of ξ better informs the buyer about the supplier's investment when β is lower, thereby reducing the cost of providing incentives. Likewise, a higher ρ helps obtain $e = 1$. In contrast, a higher investment cost has a negative impact on the possibility of obtaining $SW^A(n)$. This is because a higher g makes it harder to satisfy the bidding-competition constraint, reduces the buyer's surplus from relational contracting, and increases the temptation to renege.

The buyer is better off setting $\bar{b}^A \geq \bar{c} - R(1)$ and the participation fee equal to the suppliers' expected information rent net of the investment cost, i.e. $f^A = \frac{1}{n}I(n) - g$. The buyer's expected utility in augmented auctions which obtain $SW^A(n)$ is

$$u^A(n) = v - (1-\beta)(1-\rho)k - c_n^n - ng. \qquad (4)$$

The following remark describes the buyer's optimal number of solicited bidders in augmented auction, that is denoted n^A.

Remark 1. *In augmented auctions, the buyer sets $n^A = n^* < N$ only if (BCC) and (BDE^A) and both satisfied at n^*.*

If augmented auctions can be sustained at n^*, social and buyer's incentives are perfectly aligned. The buyer may find it profitable to solicit bids from a number of bidders different from n^* if this is necessary to sustain the relational contracts. However there are limits to the buyer's ability to use this instrument to induce the suppliers' investment in an auction environment as moving away from n^* gives rise to a tension between the bidding-competition and the reneging constraint. Specifically, restricting competition may be helpful to sustain $e = 1$ in augmented auctions thanks to its positive effect on the bidding competition constraint. Competing with fewer rivals increases the probability of being the lowest cost bidder as well as the magnitude of the information rent, relaxing (BCC). Restricting competition may have negative effects on the buyer's dynamic enforcement constraint, though, since it decreases the surplus of relational contracting and has an ambiguous effect on $B(n,g)$.

4.2. Augmented Negotiations

Augmented auctions suffer from two main drawbacks. First, $e = 1$ can be attained only if the expected information rent is higher than the investment cost. Second, there is a severe credibility problem as the magnitude of the reward the buyer must promise in case of a success may need to be excessively large. Restricting competition in auctions may not be an effective means to approach these problems as it may fail to generate information rents sufficiently large relative to the investment cost.

[19] In the appendix, I characterise the lower and the upper bounds of $B(n,g)$.

The two drawbacks mentioned above are ultimately caused by an essential feature of competitive bidding, namely bidders compete away the expected rewards at the bidding stage. Therefore, when competition for the contract prevents investment, moving away from auctions may be a viable alternative. Since in a direct negotiation the expected discretionary payment $R(e_i)$ is not incorporated in a bid, the buyer can always promise the supplier a reward scheme which induces the investment. Moreover, the absence of competition for the contract reduces the size of the reward for a flawless design and, as a result, the temptation to renege on the relational contract is always strictly lower under augmented negotiations. When a supplier invests in an auction there is uncertainty as to whether or not he will be selected to produce. Moreover, the payoff associated with remaining idle is positive, unless the reward for a correct design is so large that an idle supplier does not stand a chance of winning the auction when at least one rival supplier invests. Thus, while auctions better cope with the screening problem, negotiations may turn out to be more effective in stimulating the supplier's investment.

Under augmented negotiations, a multilateral relational contract specifies the (i) features of the procurement mode $(f_t, \bar{b}_t)$, (ii) chosen supplier's acceptance d_t, investment e_t, and price b_t decisions, (iii) contingent reward $r_t(\xi_t)$. I continue to restrict attention to stationary contracts. The buyer's expected utility under augmented negotiations which induce $e = 1$ in every period is:

$$u^{AN} = v - (1-\beta)(1-\rho)k - \bar{b} - R(1) + f. \tag{5}$$

By contrast a supplier expects to get $\bar{b} + R(1) - E(c) - g - f$ in every period in which he is selected and invests. The buyer's problem is to choose rewards, the participation fee and the reserve price so as to maximise (7), subject to participation, incentive, and dynamic enforcement constraints. The next lemma shows under what condition augmented negotiations that attain $e = 1$ in every period can be implemented.

Lemma 4. *Augmented negotiations that obtain $e = 1$ are self-enforcing if the following buyer's dynamic enforcement constraint holds:*

$$\frac{\delta}{1-\delta} \underbrace{[(1-\beta)\rho k - g - (E(c) - c_N^N)]}_{u^{AN} - u^{auc}} \geq r_S^{AN} = \frac{g}{(1-\beta)\rho}. \tag{BDE^{AN}}$$

The buyer sets the participation fee and the reserve price in such a way as to fully extract the supplier's surplus. Namely, $f^{AN} = \frac{\beta g}{(1-\beta)\rho} + \bar{b}^{AN} - E(c)$ and $\bar{b}^{AN} \geq \bar{c} - R(1)$. Thus, the buyer's expected utility in a negotiation can be rewritten as follows:

$$u^{AN} = v - (1-\beta)(1-\rho)k - c_1^1 - g. \tag{6}$$

As a result, it does not matter if the buyer switches trading party in every period as the supplier does not attach any weight to the possibility of being granted additional contracts.[20]

4.3. Choice of the Procurement Mode

I can now compare augmented auctions and augmented negotiations. To this end, let $\delta^A(n)$ be the threshold level of the discount factor above which (BDE^A) is satisfied when $n \geq 2$ bidders are invited to take part in augmented auctions. Let δ^{AN} be the corresponding threshold level for (BDE^{AN}). I distinguish between two scenarios, which differ depending on whether the bidding competition constraint holds or not for some $n \geq 2$.

Proposition 1. *Suppose (BCC) does not hold for any $n \geq 2$. Then, in the buyer-preferred PPE of the game*

[20] By contrast, if the buyer were unable to fully extract the supplier's surplus through the participation fee, it might be profitable to condition both rewards and the probability of renewing the contract on current performance. The renewal option would allow the buyer to sustain the relational contract more easily, since deferring some of the moral-hazard rent to future periods would reduce the per-period reward following a good outcome. In such a different setting, the relational contract may not be stationary, as shown by Board (2011).

(a) *an augmented negotiation that induces* $e_i = 1$ *for all* $i \in \mathcal{N}$ *is held in any period if* $\delta \geq \delta^{AN}$, *whereas*
(b) *an open auction that induces* $e_i = 0$ *for all* $i \in \mathcal{N}$ *is held in any period if* $\delta < \delta^{AN}$.

Proposition 2. *Suppose (BCC) holds for all n up to some* $\tilde{n} \geq 2$ *and let*

$$\hat{n} \in \arg\max_{2 \leq n \leq \tilde{n}} \quad \frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] - \frac{B(n,g)}{(1-\beta)\rho}.$$

Then, in the buyer-preferred PPE of the game

(a) *either an augmented negotiation or an augmented auction that induces* $e_i = 1$ *for all* $i \in \mathcal{N}$ *is held in any period if* $\delta \geq \min\{\delta^A(\hat{n}), \delta^{AN}\}$, *whereas*
(b) *an open auction that induces* $e_i = 0$ *for all* $i \in \mathcal{N}$ *is held in any period if* $\delta < \min\{\delta^A(\hat{n}), \delta^{AN}\}$.

Several remarks are worth making. As long as augmented negotiations which implement $e = 1$ are strictly profitable for the buyer, i.e. $u^{AN} > u^{auc}$, there always exists a threshold level of the discount factor δ above which they can be sustained. This may not be the case for augmented auctions, since the suppliers can be induced to invest only if the expected information rent is larger than the investment cost. Therefore, if the investment cost g is sufficiently large as compared to the information rent, the (BCC) never holds and the buyer will either adopt augmented negotiations which implement $e = 1$ or open auctions which implement $e = 0$, depending on the value of δ, as shown in Proposition 1. This is more likely to occur when firms should make substantial precontractual investments and their costs of production are similar.

As shown in Proposition 2, when the (BCC) holds for some n, the buyer will also be able to use augmented auctions to implement $e = 1$, provided that δ is sufficiently high. Even when this occurs and augmented auctions generate a higher surplus than augmented negotiations, the buyer may need to adopt the latter procurement mode, since it entails a strictly lower temptation to renege as $\frac{g}{(1-\beta)\rho} < \frac{B(n,g)}{(1-\beta)\rho}$. This is so because under augmented negotiations a supplier does not face any uncertainty as to whether or not he will be chosen to produce the good and he must just be provided with a moral-hazard rent. When high investment can be induced with both augmented negotiation and augmented auctions, the buyer will choose the procurement mode which yields the highest surplus.

Lastly, the model shows how the optimal procurement mode critically depends on the horizon of the relationship: while unrestricted auctions are optimal in the one-shot game, restricted auctions or direct negotiations may be optimal when the players interact frequently.[21] Furthermore, stiffer competition may not benefit the buyer: a higher number of potential suppliers N increases the attractiveness of spot auctions and, as a result, may render superior relational contracts non-sustainable. It must be noticed that this latter result crucially rests on the assumption that parties revert to spot contracting after a buyer's deviation. It does not arise if the suppliers react to a breach of the relational contract by refusing to trade with the buyer and taking their outside options thereafter, which is the worst possible equilibrium punishment for the buyer and, as a result, is an optimal punishment to deter her uncooperative behaviour (see Abreu, 1988).[22] A decrease in k makes the use of open auctions where no supplier invests more likely because it reduces the surplus that can be achieved with relational contracting.

Up to now, I have maintained the assumption that the buyer always delegates the task of designing the good to the suppliers. However, the buyer may be able to provide the technical drawings of the good herself. Then, if the game is not repeated or an efficiency-enhancing relational contract cannot be sustained, the buyer might find it profitable to develop the design of the good in-house and only delegate its production to a supplier. In the manufacturing industry, this practice is often referred to as *drawings supplied*. In

[21] This result can be reminiscent of Baker et al. (2011) and Che and Yoo (2001) in which the optimal governance structure and incentives for teams, respectively, are affected by the weight contracting parties place on the future of the relationship.

[22] Note that the other results of the model remain qualitatively unaltered under this alternative assumption. The main difference concerns the buyer's dynamic-enforcement constraint, which becomes easier to satisfy under both procurement modes. This is because the buyer would be more willing to adhere to the relational contract if she were to attain 0 rather than u^{auc} in each period following a deviation.

contrast, when relational contracts that induce the investment are sustainable, the buyer can provide the interested suppliers with a list of the required performances, and rely on them to deliver the final design of the good. This practice is often called *black-box* or *drawings approved*. In contrast, in construction procurement, under the Design-Bid-Build project-delivery system the buyer only delegates the building phase to the supplier while under Design-Build the supplier also provides the design of the building.

The model predicts that when the task of designing the goods is delegated to the suppliers, a buyer tends to adopt either restricted auctions or direct negotiations. This is both desirable, because it is not efficient to have many suppliers bear the investment cost, and necessary, because it encourages the investment by creating enough information rent or reduces the size of the reward for a successful design. In contrast, when a buyer supplies the technical drawings herself, one should expect her to procure goods through open bidding. As the suppliers' investment does not have to be motivated, there is no use in restricting competition.

4.4. *Empirical Evidence and Discussion*

This section has highlighted how the buyer's objectives of selecting the most efficient supplier and solving the hidden-action problem may be conflicting. The buyer faces a trade-off: Unrestricted auctions guarantee that the lowest cost supplier will produce the good, whereas limiting competition is desirable when the potential suppliers must be motivated to undertake a project-specific investment. When there is more uncertainty about the correct specification of the good the supplier's investment is more critical. In the economics literature, this uncertainty is often interpreted as an indication of the *complexity* of a project (see, for instance, Bajari and Tadelis, 2001, and Chakravarty and MacLeod, 2009). Therefore, one testable implication is that one should observe a more extensive use of negotiations or restricted auctions whenever goods are more complex. This prediction seems to be supported by empirical evidence on the construction industry. Bajari et al. (2009) analyse private sector building contracts awarded in Northern California during the years 1995-2000 and find that more complex projects are more likely to be negotiated. They also estimate an ordered logit which shows an inverse relationship between the complexity of the project and the competitiveness of the award procedure.[23]

The results of the model can help provide some insight on the stark differences between the buyer-supplier relationships in the Japanese and American car manufacturing industry up to the end of the 1980s and the subsequent adoption of Japanese-like supply-chain practices by the U.S. car makers.[24,25]

In the U.S., the buyer-supplier relationships had historically been adversarial. There the assemblers' engineers normally designed most of the parts and components of a car themselves. Then, the assemblers provided the suppliers with detailed drawings of the parts they needed to procure and asked them to submit a price bid. In doing so, they received no significant insight from the suppliers on how to improve the goods specification. Competitive bidding was open to a large number of suppliers and selection occurred solely on a price basis. This is in line with the predictions of my model: when the buyer does not expect the suppliers to make the investment, she does not restrict competition, chooses the lowest cost supplier, and develops the design of the good by herself.

In sharp contrast, Japanese can manufacturers had built a good-faith long-term relationship with their suppliers. The suppliers were normally given just performance specifications and were told to develop a prototype before getting a production order.[26] Supplier were usually selected by restricted competition and they faced a limited number of competitors. Moreover, price had a marginal role in the selection

[23]As proxies for complexities the authors use the (log) value of the project (engineers' estimated cost), the (log) square feet of the project, and the number of divisions which indicate the number of subcategories of work required to complete the project.

[24]In the discussion that follows I draw on a number of sources, such as Asanuma (1989); McMillan (1990, 1994); Dyer (1996); Roberts (2004); Womack et al. (2007).

[25]Compelling evidence on the German automotive industry is provided by Calzolari et al. (2019) who also develop a model that is better suited to explain the interesting interplay between trust, competition, investment, and technological sophistication of parts that they uncover for that industry.

[26]The figures reported in Clark (1989, Table 1) help grasp the difference between Japanese and U.S. assemblers. While U.S. assemblers were delegating detail-engineering (i.e., the process of producing the drawings of a part) only for 16% of the parts in their cars, Japanese assemblers were resorting to the suppliers' engineers to supply the drawings for 62% of their car parts.

choice while more weight was attached to other aspects, such as performance record and past relationships. As discrimination tended to act in favour of the incumbent, this selection procedure closely resembles augmented negotiations.[27] Furthermore, suppliers were not dismissed when their performance did not meet the expectations (Womack et al., 2007, pg.157), consistently with the finding of Lemma 3 and 4 where I show that design failures are tolerated and a supplier is not blacklisted provided that the he accepts a penalty.[28] The model suggests that Japanese assemblers restricted competition or adopted negotiation procedures to successfully delegate the design of the goods to their suppliers. Expecting the buyers to honour their informal promises to reward successful performances, suppliers were willing to undertake the project-specific investments.

As many observers argue, each system of relationships was probably optimal in its environment (see McMillan, 1994 and Roberts, 2004): The strategy pursued by the U.S. car makers had allowed them to dominate the industry for decades. Arguably, the increasing technical complexity of vehicles made valuable the involvement of the suppliers in the design of car parts and components.[29] In my model this would translate into a lower level of β that, as Lemma 3 and 4 highlight, increases the appeal of delegating the design to the suppliers.

Relative to the Big Three, the Japanese car makers were better positioned to receive some insight from their suppliers: They were producing more distinct products and were replacing models at a faster pace.[30] This more frequent interaction would imply a higher value associated with continuing the long-term informal relationship.

One of the triggers for the adoption of similar good-faith relationships between buyers and suppliers in the U.S. was the fierce competition from the Japanese car makers in the 1980s. The different supply-chain practices can, at least to some extent, account for the competitive advantage that Japanese car manufactures had over their US counterparts during those years, as reported in the comprehensive study by Womack et al. (2007).[31] The adoption of Japanese-style supplier relations was accompanied by technological developments that dramatically shortened the time needed to redesign products and led to a proliferation of car models, which implied a higher value of a good-faith relationship also in the U.S. automotive industry.[32],[33]

A similar pattern is observed in sophisticated electronics (Burt, 1989). At the end of the 1970s the share of worldwide copier revenues accruing to Xerox was falling rapidly. Relative to its Japanese competitors, Xerox had high manufacturing costs and slow product development. At that time, Xerox engineers designed almost all the copier components whose manufacture was typically outsourced to suppliers which included over 5,000 firms. Among the steps taken to turn around the company there was the restriction of the supplier base to 400 firms and the delegation of the design task to the suppliers who were required to

[27]As reported by McMillan (1990), a 1987 survey of small Japanese manufacturers found a considerable stability in the buyer-supplier relationship: 68% never changed their parent companies and only 7% changed three or more times.

[28]While in the Japanese buyer-supplier system the business was temporarily and partially shifted to a competitor, in the model the penalty takes a monetary form which allows the parties to settle at the end of each period.

[29]This was at least in part due to the growing use of electronic components which began in the 1970s and continues to the present day.

[30]See Womack et al. (2007), in particular Figure 5.2 and Figure 5.6. On the differences between the product lines of Toyota and Ford, see also Roberts (2004) (pp 38-39).

[31]Suppliers' performance was unambiguously superior in Japan as can be seen, for instance, by the lower number of parts defects per car: 0.24 instead of 0.33 (Womack et al., 2007, Figure 6.1).

[32]The broad-ranging technological developments (e.g. computer-aided design) are documented in Milgrom and Roberts (1990), while for the proliferation of car models sold and produced in North America as well as the increased variety in body styles and chassis configurations see, for instance, the figures reported in Van Biesebroeck (2007).

[33]Other explanations for the change in the supplier relations in the U.S. automotive industry are provided in Legros and Newman (2008) and Taylor and Wiggins (1997). Legros and Newman (2008) show how shocks that initially affect only few firms can have widespread repercussions on the design of organisations in an entire industry. Then, the fall in revenues that the U.S. assemblers experienced because of the stiffer Japanese competition might have caused a decrease in the degree of control that buyers had in their relationship with their suppliers over several aspects of product and process development. Taylor and Wiggins (1997) argue that the drop in the cost of setting up a production run favoured the adoption of the Japanese-style mode of procurement in the U.S.. They maintain that a distinguishing trait of Japanese-style procurement is that firms buy small lots more frequently and threat to cut off those suppliers who turn out to have provided low quality goods rather than inspect up-front large deliveries and refuse to buy the lots if the quality is deemed unsatisfactory, like the American firms traditionally do.

provide blueprints. This was followed by a considerable fall in new product development time and costs and a reduction of net production costs.

To conclude this section, it must be acknowledged that several assumptions and findings of the model do not accurately reflect features of real-world procurement. However, at least in some cases, this imperfect match can be attributed to modeling simplifications that can be relaxed, without significantly affecting the conclusions of the paper.

Firstly, while ex-ante transfers are often exchanged between a buyer and her prospective suppliers, these do not usually take the form of participation fees. The transfer received by the buyer in the model, f, turns out to be always positive in equilibrium, which justifies the use of the term "participation fees". However, $f > 0$ in equilibrium due to the normalisation that delivering standard drawings is costless for a supplier. If, as it is plausible, some minimum level of investment cost must be borne by a supplier, f might be negative.[34]

Secondly, ex-post discretionary payments appear to be seldom used between firms. Instead of informal payments, buyers can resort to a variety of methods to reward their performing suppliers, such as awarding supplementary or ancillary contracts, or making generous agreements to share the profits resulting from the sale of the final products to the market. The discretionary bonus r is a modeling shortcut which is meant to broadly capture the monetary value of these rewards. Moreover, in the model, if the buyer cannot use discretionary bonuses in stage 5, she could reward a supplier with a reduction in future participation fees. For instance, consider augmented auctions and suppose that supplier i was awarded the contract in period $t-1$. The (possibly negative) participation fee that supplier i would be asked to pay in period t would be contingent on the realisation of ξ_{t-1}. That is,

$$f_{i,t} = \begin{cases} \frac{1}{n} I(n) - g, & \text{if } q_{i,t-1} \neq 1, \\ \frac{1}{n} I(n) - g - \frac{r(\xi_{t-1})}{\delta}, & \text{if } q_{i,t-1} = 1, \end{cases}$$

where $r(F) = 0$ and $r(S) = \frac{B(N,g)}{(1-\beta)\rho}$.

Lastly, in reality, buyers carefully select the suppliers they invite and their identity is crucial. In the simplest version of my model, the identity of the suppliers is not critical: With stationary contracts, the parties can settle in every period. However, there are several complementary mechanisms which can make the identity of the supplier play a more relevant role. One of these mechanisms has just been illustrated: If the buyer uses f to reward a supplier, then a performing supplier must be reinvited in order to receive his prize. This can provide a first justification for the empirical observation that few, regular suppliers are invited in real-world private procurement of sophisticated goods. A second justification is provided in Section 5.4, where I discuss the implications of relaxing the informational assumption that ξ is observed by all the players of the game. There, I show that the buyer may prefer to invite the same pool of favourite suppliers to allow the coordination of punishments.

5. Extensions and Robustness Checks

In this section I consider several extensions and robustness checks. First, I assume that the buyer is able to invest in the initial specification of the good and I study the relationship between this investment and the procurement mode. Second, I assume that the buyer can infer the suppliers' investment from observing the technical drawings so as to understand the role of hidden-action in determining the results. Last, I relax other relevant assumptions of the model to check the robustness of the findings.

5.1. Buyer's Investment in the Design of the Good

In this extension, I build on the earlier discussion on the buyer's ability to provide the design of the good herself. I assume that the buyer can decide the extent to which the design of the good is delegated to

[34]It must be added that the buyer may find it profitable to restrict competition in one-shot auctions if the minimum level of investment is large enough. Alternatively, the buyer could supply the drawings herself and use open auctions.

a supplier. In particular, I consider the case in which the buyer can make an investment at the beginning of each period which affects the probability β that the specification of the good will be ex-post free from defects. In doing this, I draw on Bajari and Tadelis (2001) who were the first to envision an initial buyer's investment into planning that affects the likelihood that the design of a good is ex-post correct. A similar approach has since then been adopted by other authors, such as Ganuza (2007), Chakravarty and MacLeod (2009), and Tirole (2009). In particular, Tirole (2009) develops this idea further and provides the alternative interpretation of an investment in the completeness of the contract to which I might also adhere.

Formally, the buyer chooses the value of $\beta \in [0,1]$ at a cost given by the function $T(\beta)$ which is strictly increasing, $T^{'}(\beta) > 0$, strictly convex, $T^{''}(\beta) > 0$, and with $T'(0) = 0$, and $T'(1) = \infty$ so that there is always a positive probability that the specification of the project initially worked out by the buyer turns out to be defective. The buyer's investment in the specification of the good is known to all the players of the game and is made before the procurement mode is announced.

The optimal buyer's specification of the good clearly depends on whether or not the supplier invests. The socially efficient level of specification is such that the marginal social benefit of a more accurate specification of the good, i.e. the avoidance of k when the buyer's specification is correct, equals its marginal cost. First, I define β^* as the socially efficient specification of the good when the supplier incurs the investment cost:

$$\beta^* \equiv \arg\min_{\beta\in[0,1]} (1-\beta)(1-\rho)k + T(\beta)$$

Thus, $T'(\beta^*) = (1-\rho)k$. Analogously, I define $\hat{\beta}$ as the socially efficient specification of the good when the supplier does not make the investment:

$$\hat{\beta} \equiv \arg\min_{\beta\in[0,1]} (1-\beta)k + T(\beta)$$

Thus, $T'(\hat{\beta}) = k$. The buyer's specification of the good is more complete when no supplier is expected to invest. This is what happens in the one-shot game, irrespective of the adopted procurement mode, since the buyer must compensate for the lack of the supplier's investment. Thus, $T'(\beta^{auc}) = T'(\beta^{neg}) = T'(\hat{\beta}) = k$.

To make the problem interesting, I continue to assume that the supplier's investment is desirable also when the buyer can affect the likelihood of a design failure. To this end, I need to adapt Assumption 1 to the new setting by imposing that the social loss due to a failure of the design is minimised when the supplier invests, given the buyer's optimal specification of the good.

Assumption 3. *The following condition holds:*

$$(1-\hat{\beta})k + T(\hat{\beta}) > g + (1-\beta^*)(1-\rho)k + T(\beta^*).$$

In the repeated game, the buyer's investment becomes part of the relational contract as it affects the incentives provided to the suppliers to undertake the investment.

The following proposition describes the optimal choice of β in augmented auctions and augmented negotiations and shows how this crucially depends on whether or not the buyer's dynamic enforcement constraint binds.

Proposition 3. *The optimal buyer's investment in the specification of the good in augmented auctions and augmented negotiations are*

$$T'(\beta^A) = \max\left\{(1-\rho)k - \mathbb{1}\{\frac{1-\delta}{\delta}\frac{B(n,g)}{(1-\beta^A)^2\rho}\}, 0\right\}$$

$$T'(\beta^{AN}) = \max\left\{(1-\rho)k - \mathbb{1}\{\frac{(1-\delta)}{\delta}\frac{g}{(1-\beta^{AN})^2\rho}\}, 0\right\}$$

where the indicator function $\mathbb{1}$ takes value 1 if the buyer's dynamic enforcement constraint binds and 0 otherwise.

The above proposition shows that the buyer makes the socially optimal investment in the specification of the good as long as her dynamic enforcement constraint (BDE) is slack. Conversely, when the (BDE) binds, the buyer's choice of β is distorted away from efficiency. To provide an intuition for this result, consider that a more complete specification of the good increases the cost of incentives because of the moral-hazard problem: if the design turns out to be correct, the buyer does not know whether this is due to the adequacy of her specification of the project or the supplier's technical drawings. As long as the (BDE) is slack, the positive relationship between the reward and β does not affect the buyer's investment choice. In contrast, when the (BDE) binds, the buyer finds it profitable to reduce the cost of incentives by under-investing in the specification of the good. When the incentive problem is especially severe, the buyer may decide to provide a totally opaque specification of the project.

When the supplier's reward for delivering successful drawings is very high, the buyer must distort β away from efficiency to sustain $e = 1$. As I have shown previously, the credibility problem may be more severe under augmented auctions and therefore the buyer may decide to adopt augmented negotiations in order to mitigate the distortion of the investment in the specification of the goods.

A significant investment in the specification of the good can be best interpreted as the buyer providing the design of the good, detailing the materials and the methods to be used and only outsourcing its manufacture to the supplier. In contrast, a small buyer's investment can be seen as a mere specification of the desired performance requirements that the good should meet.[35] In the stage game the buyer expects to receive no insight from the suppliers on how to better design the good. For this reason, she will have to make a very significant investment in its specification. In the presence of frequent interaction, the buyer can provide the potential suppliers with a more general specification of the good and Proposition 3 shows that she may find it profitable to strategically under-specify the design of the good as the incentive problem becomes more severe.[36]

Given that auctions are always used in the absence of repeated interaction while negotiations are more likely to be used when interaction is frequent, the model suggests a relationship between the buyer's choice of the procurement mode and her investment in the specification of the good. Namely, goods procured through auctions should be more specified than goods procured through negotiations.

Taking into account the buyer's investment into planning, the model also provides a complementary explanation to the finding of Bajari et al. (2009) that more experienced procurers are more likely to select contractors through auctions. The authors maintain that more experienced buyers have lower administrative costs as they are more familiar with the bureaucratic procedures associated with auctions. Through the lens of my model, a buyer with more experience might incur a lower cost to draw up a more complete contract. The equilibrium level of β would subsequently be higher allowing the buyer to focus on the screening problem as a design failure is less likely to occur.

5.2. Observable Investment

The model presents elements typical of both the hold-up literature, i.e. a non-verifiable project-specific investment, and of the principal-agent literature, i.e. the investment is non-observable. To understand which dimension has driven the results, in this section I assume the moral-hazard problem away by positing that the buyer can perfectly infer a supplier's investment from observing his drawings, though I maintain its non-verifiability by a court. The ex-post noisy signal of investment, which is also solely observable, is no longer needed to set the informal payments.

In the stage-game the literature on research contests has shown that the suppliers' investment can be attained only under contests (e.g., see Che and Gale, 2003). As there is no legally verifiable piece of information which can be used to induce the suppliers to invest, it is not possible to solve the hold-up problem

[35] I could have modelled the buyer's investment in the specification of the good as binary, so as to make the correspondence between such investment and the choice of delegating the design to a supplier more evident. However, by doing so, I would have missed the different incentives the buyer faces when she decides how much to specify the goods depending on the tightness of the BDE.

[36] Also in Tirole (2009) it is shown that relational contracting is associated with more incomplete contracts. In that paper the result is due to the possibility that the supplier may refrain from holding up the buyer after a design failure, whereas in my setting the buyer under-invests as she knows that she can profitably delegate the design of the good to the supplier.

in one-shot negotiations. In contrast, $e_i = 1$ for each $i \in \mathcal{N}$ may constitute an equilibrium of the one-stage auction game provided that the bidding competition constraint holds at n. This is because the buyer has an incentive to select the supplier who offers her the largest surplus. Therefore a supplier who has invested is rewarded. Below I show that in the presence of repeated interaction both auctions and negotiations can stimulate the investment. Furthermore, I find that the temptation to renege is always lower under augmented negotiations which may then better address the hold-up problem.

In the repeated game, the buyer can promise to pay the selected supplier a reward, r, contingent on e. As a result, the absence of competition does not prevent negotiations from encouraging investment, which is a significant difference from the literature on research contests. Relative to the non-observability case, the condition to sustain the relational contract is also milder:

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - g - (E(c) - c_N^N)] \geq g \tag{7}$$

In augmented auctions, the bidding-competition constraint no longer prevents surplus-increasing relational contracts from being sustained. This represents the most remarkable difference with the hidden-action case and is due to the buyer's ability to reward a supplier who has invested even if he has not won the auction.

Below I expand the space of contracts to allow the buyer to exchange transfers r_i with each supplier after the investment decisions are made. By doing so, the buyer adopts an *employment contract*. Expressions (3) and (4) on the suppliers' and the buyer's utility functions change as follows:

$$\pi_{i,t} = (1-\delta)E\sum_{\tau=t}^{\infty}\delta^{\tau-t}\{[P(b_\tau) - c_{i,\tau}]q_{i,\tau}(b_\tau) + r_{i,\tau}e_{i,\tau} - ge_{i,\tau} - f_{i,\tau}\}\mathbb{1}_{i,\tau} \tag{8}$$

For all $i \in \{1, ..., N\}$ and

$$u_t = (1-\delta)E\sum_{i=1}^{N}\sum_{\tau=t}^{\infty}\delta^{\tau-t}\{[v - (1-\beta)(1-\rho e_{i,\tau})k - P(b_\tau)]q_{i,\tau} - r_{i,\tau}e_{i,\tau} + f_{i,\tau}\}\mathbb{1}_{i,\tau} \tag{9}$$

As the following remark shows, since augmented auctions entail a higher reneging temptation than augmented negotiations, the former may be harder to sustain than the latter even when they generate a higher surplus.

Remark 2. *Augmented auctions that attain $SW^A(n)$ are self-enforcing if the following buyer's dynamic enforcement constraint holds:*

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] \geq ng. \tag{10}$$

If the buyer cannot adopt the employment contract, it is still possible to sustain $e = 1$ by reimbursing those suppliers who have invested at time t through the participation fee paid at time $t+1$. This clearly makes it harder to sustain the relational contract because the temporal lag further increases the buyer's temptation to renege.

5.3. Informational Assumptions

In the model, it has been assumed that, in every period, the performance signal ξ_t is publicly observable and that all players of the game can observe whether the buyer pays the promised reward $r(\xi_t)$ and whether the selected supplier accepts or not such reward. These stylized informational assumptions enable suppliers to straightforwardly detect a buyer's deviation from the relational contract. However, the results of the model continue to hold even if only the supplier selected for production and the buyer observe the realisation of the performance signal as well as the buyer's payment of the bonus and whether the selected supplier accepts the bonus or not. This requires amending the relational contract so as to enable the other suppliers to infer the identity of the breacher from the off-the-equilibrium history and react accordingly. Stated differently, this amended relational contract must prescribe that buyer's and supplier's deviations from on-the-equilibrium behavior trigger continuation equilibria that can be distinguished by the other players. Coordinating punishments against a deviant buyer simply requires that the other suppliers rationally form their belief about the identity of the breacher off-the-equilibrium path from the observation of the continuation game that is being played. To form such beliefs, suppliers can use the information provided by those actions that are commonly observed by all the players of the game, like the decision to trade or not with the buyer, i.e., the decision d. It is important to point out that the buyer will be eager to write such a relational contract because, in equilibrium, she benefits from the suppliers' ability to coordinate punishments.

In Appendix B, I provide illustrative examples of relational contracts for both augmented auctions and augmented negotiations that capitalize on this public information to coordinate punishments against a reneging buyer. Interestingly, these relational contracts introduce an element of *loyalty*, that is, the same pool of suppliers are invited to participate in augmented auctions (respectively, the same supplier is chosen in augmented negotiations) in every period, as this facilitates other suppliers' detection of deviations. The solutions entail minimal changes with respect to the outcomes characterised in Lemma 3 and 4. One of the chief implications is that discretionary bonuses are credible even if auctions are not open to all N suppliers.

Next, suppose that, akin to Andrews and Barron (2016), the game has imperfect private monitoring as a supplier only observes his bilateral relationship with the buyer. Namely, a supplier i's choice of trade, $d_{i,t}$ is observed only by supplier i and the buyer. Likewise, supplier i's bid, $b_{i,t}$ is observed only by supplier i and the buyer. Then, if the buyer deviates with supplier i, there is no public information that suppliers $j \neq i$ can use to infer whether the buyer reneged on her promise. It follows that multilateral punishments cannot be carried out and a discretionary bonus would be bounded above by the surplus that the bilateral relationship with a supplier generates. If a buyer uses restricted auctions or negotiations, a supplier can always be replaced at no cost and, as shown by Calzolari and Spagnolo (2009), positive bonuses are not credible. The buyer would have to give up rents to the suppliers to stimulate investment and could find it profitable (i) to restrict competition so as to sufficiently reward a supplier and (ii) to condition the future supplier's invitation on current performance.

Yet, if suppliers could communicate with one another, the results of the paper could be restored. It would suffice to extend the space of actions by introducing a costless message that the selected supplier in period t sends to the other suppliers in the market. The message just reveals whether the buyer paid or not the promised reward. Since his continuation payoff would be the same, a supplier would have no incentive to lie and the other suppliers could thus be informed about the buyer's trustworthiness. In this respect, Barron and Powell (2019) have recently shown how the imperfect public monitoring outcome can be replicated in the presence of bilateral monitoring if agents can exchange costless messages with one another at the end of each period.[37]

To summarise, in the environment studied in the present paper, discretionary bonuses can be credible unless suppliers cannot observe each other's participation or bidding decisions and cannot communicate with each other. The availability of public information about actions taken by suppliers appears reasonable especially for the procurement of sophisticated goods as there are typically a limited number of known suppliers able to carry out production: There, a supplier's refusal to trade with the buyer would hardly go unnoticed. Moreover, communication among suppliers seems common and is often promoted by the buyers themselves, like in the case of Toyota. Therefore, it would not be surprising if a disgruntled supplier informed the other market players of a buyer's unreliability.

5.4. Competition and Quality

The analysis has so far focused on an economic environment where the quality of the technical drawings plays a predominant role. Because of Assumption 2 (ii), the buyer always prefers to select a supplier who

[37] Like in my paper, in Barron and Powell (2019) agents are held to their punishment payoff both on the equilibrium path and following an agent's deviation. Each agent reports the outcome he has privately observed in the period and they do not have an incentive to lie because their continuation payoffs are unaffected by the messages they exchange. This allows the suppliers to coordinate punishment against a reneging principal. It must also be noticed that if the selected supplier could commit to a bonus-contingent public message before receiving the bonus, cooperation could be destroyed as shown by Barron and Guo (2019).

has chosen $e = 1$ over one who has chosen $e = 0$, no matter the cost difference. In this subsection, I show the implications of relaxing this assumption, that is, I suppose that $(1-\beta)\rho k \in (0, \bar{c} - \underline{c}]$.

I begin by noticing that the buyer may not want to induce all suppliers to invest when Assumption 2 (ii) is not satisfied. Specifically, the buyer might prefer to hold auctions where only a subset of the solicited bidders are asked to provide superior drawings. This is because the buyer may now prefer to select a low-cost supplier who has not invested over a high-cost supplier who has invested. I formally show this claim in Appendix B. Thus, I now consider modified augmented auctions with M solicited suppliers, of whom only m will be asked to provide superior drawings, with $1 \leq m \leq M$ and $2 \leq M \leq N$. Interestingly, the management literature has long emphasised that buyers must often decide whether to procure high-quality parts from trusted suppliers or cheaper parts in the open market, such as the electronic marketplace (see and Grey et al., 2005 and Tunca and Zenios, 2006). When procuring high-quality goods becomes more important, i.e., the parameter k takes higher values, I find that the surplus-maximising number of suppliers who are asked to provide superior drawing increases, but that of the invited suppliers decreases. Stated differently, higher quality calls for (i) restricting competition and (ii) focusing on high-investment suppliers.

Remark 3. *The surplus-maximising number of high-investment (respectively, low-investment) suppliers increases (decreases) in k.*

Since the buyer cannot write court-enforceable agreements with the suppliers and does not observe the quality of the supplied drawings, the issue of inducing some suppliers to make high investments arises. Without loss of generality, I suppose that bidders from 1 to m are asked to provide superior drawings, whereas bidders from $m+1$ to M are asked to supply standard drawings, i.e., $e_i = 1$ for $i \in \{1, ..., m\}$ and $e_j = 0$ for $j \in \{m+1, ..., M\}$. To select the winning bidder, the buyer prefers a high-investment supplier to a low-investment supplier only if the difference between their bids is lower than or equal to $(1-\beta)\rho k - R(1)$, which is the expected quality differential, net of the expected discretionary payment a high-investment supplier receives.[38]

$$\min_{i \in \{1,...,m\}} b_i \leq \min_{j \in \{m+1,...,M\}} b_j + (1-\beta)\rho k - R(1). \tag{11}$$

In the proposition below, I characterise the choice of the procurement mode when Assumption 2 (ii) does not hold. To this end, let $\delta^A(m, M)$ be the threshold level of the discount factor above which the buyer's dynamic enforcement constraint is satisfied when M suppliers are invited and m make a high investment in modified augmented auctions. Furthermore, define (i) $IR(m, M)$ as the expected information rent for a high-investment supplier in the modified augmented auctions, which is decreasing in both m and M, (ii) $B(m, M, g)$ as the minimum differential $R(1) - R(0)$ such that $e_i = 1$ for $i \in \{1, ..., m\}$ is the only equilibrium in the investment stage, and (iii) $\alpha\left(\frac{m}{M}\right)$ as the probability that a high-investment supplier is selected.[39]

Proposition 4. *Let $(1-\beta)\rho k \leq \bar{c} - \underline{c}$ and*

(a) *suppose $IR(m, M) < g$ for all (m, M). Then, in the buyer-preferred PPE of the game, an augmented negotiation that induces $e_i = 1$ for all $i \in \mathcal{N}$ is held in every period if $\delta \geq \delta^{AN}$, whereas an open auction that induces $e_i = 0$ for all $i \in \mathcal{N}$ is held in every period if $\delta < \delta^{AN}$;*

(b) *suppose $IR(m, M) \geq g$ up to some $(\tilde{m}, \tilde{M})$, with $\tilde{M} \in \{\max\{2, \tilde{m}\}, N\}$ and let*

$$(\hat{m}, \hat{M}) \in \arg \max_{\tilde{m} \geq m \geq 1; \tilde{M} \geq M \geq 2} \frac{\delta}{1-\delta}\left[\alpha\left(\frac{m}{M}\right)(1-\beta)\rho k - mg\right] - \frac{\delta}{1-\delta}\left[\alpha\left(\frac{m}{M}\right)c_m^m + \left(1-\alpha\left(\frac{m}{M}\right)\right)c_{M-m}^{M-m} - c_N^N\right] - \frac{B(m, M, g)}{(1-\beta)\rho}.$$

Then, in the buyer-preferred PPE of the game either an augmented negotiation that induces $e_i = 1$ for all $i \in \mathcal{N}$ or an augmented auction that induces $e_i = 1$ for all $i \in \{1, ...m\}$, and $e_i = 0$, otherwise, is held in any period if

[38] Clearly, only high-investment suppliers are promised rewards as a function of the realisation of ξ.

[39] More details about $IR(m, M)$, $B(m, M, g)$, and $\alpha\left(\frac{m}{M}\right)$ are provided in the Proof of Proposition 4.

$\delta \geq \min\{\delta^A(\hat{m}, \hat{M}), \delta^{AN}\}$, whereas an open auction that induces $e_i = 0$ for all $i \in \mathcal{N}$ is held in every period if $\delta < \min\{\delta^A(\hat{m}, \hat{M}), \delta^{AN}\}$.

A decrease in k makes it more likely that an open auction in which $e_i = 0$ for all $i \in \mathcal{N}$ is held in every period.

This proposition is the analog of Proposition 1 and 2 for the case in which the cost-saving benefits of competition may outweigh the benefits of inducing an investment in superior drawings. Because the expected rewards promised by the buyer to the high-investment suppliers are competed away at the bidding stage, only the lure of getting the information rent can motivate the suppliers to choose $e_i = 1$. The buyer can overcome this problem by using negotiations, under which high investment can always be induced provided that the parties are patient enough. However, if k is too small, the buyer will not find advantageous to forego the benefits of competition to obtain superior drawings and will opt for open auctions instead of augmented negotiations. Thus, if k is small, the buyer uses open auctions where $e_i = 0$ for all i. Only if k is large enough the buyer might use restricted auctions or negotiations to procure the goods.[40]

6. Conclusions

In this paper I have examined the problem of a buyer who must induce her supplier(s) to undertake a project-specific non-observable investment prior to sign the contract. I have highlighted a trade-off between alternative procurement modes: while auctions better address the screening problem, negotiations are more effective in stimulating the supplier's investment.

The model suggests that the buyer's choice of retaining/delegating the design task is related to the procurement mode. When the design of the good is delegated, one should observe restricted auctions or direct negotiations. In contrast, the in-house development of the design should be associated with unrestricted auctions.

In the model, I have assumed away any learning process which could improve the quality of the match between the buyer and the suppliers with whom she has previously interacted. Plausibly, if the same supplier is repeatedly hired, he will become more experienced and better able to meet the buyer's specific needs, which is an argument against the use of auctions. In the model, I have shown that such learning effects are not necessary for a buyer to prefer negotiations to auctions: even in their absence, negotiations can emerge as the buyer's preferred procurement mode because they can more effectively motivate precontractual investments.

In the paper, I have not allowed for the possibility of collusion among suppliers in augmented auctions. In a related setting, Calzolari and Spagnolo (2009) show that the buyer can be better off if the suppliers are able to sustain a collusive agreement aimed at inflating the price paid to the awardee, since she can obtain higher quality goods. Likewise, in my set-up the buyer can benefit from collusion in prices among suppliers. This is because the suppliers may be more willing to make the precontractual investment as the awardee's expected payoff is larger than the information rent obtained in the absence of collusion. The buyer would not be concerned about the higher price paid to the winning bidder as she could extract the suppliers' expected rents through the participation fees.

I have studied suppliers' precontractual investments that are "cooperative" in the sense of Che and Hausch (1999) and Che and Chung (1999), for they increase the buyer's expected value of the project whereas they do not have any significant effect on the cost of production. This approach can be regarded as complementary to that of other authors who have studied precontractual investments that are "selfish", for their effect is to shift to the left the suppliers' cost distribution with no impact on the expected value of the project to the buyer (see Tan, 1992, Laffont and Tirole, 1993, and, more recently, Loertscher and Riordan, 2018). In this latter case, repeated interaction is not necessary to stimulate investment.

[40] For the case of post-contractual investments and bilateral punishments, Calzolari and Spagnolo (2009) also find a negative relationship between competition and quality.

Appendix A

Proof of Lemma 1

In the second-price reverse auction, each bidder submits a bid b_i and the lowest bid wins the contract. Suppose that $\bar{b} \geq \bar{c}$. At the time of submitting his bid, supplier i's payoff is:

$$\pi_i = \begin{cases} \min_{j \neq i} b_j - c_i, & \text{if } b_i < \min_{j \neq i} b_j \text{ or if } b_i = \min_{j \neq i} b_j \text{ and } i < j; \\ 0, & \text{otherwise.} \end{cases}$$

Given that a supplier's bid only affects the probability of winning the auction and not also the payment he receives, for each supplier it is a weakly dominant strategy to reveal their cost of production. Thus, $b_i = c_i \leq \bar{b}$. The lowest cost supplier wins the auction and his expected cost of production is c_n^n. The expected payment to the winning bidder amounts to the value of the second-smallest bid, that is $EP(b) = c_{n-1}^n$. Substituting these values in the buyer's expected utility function I attain:

$$u^{auc} = v - (1 - \beta)k - c_{n-1}^n + \sum_{i \in \mathcal{N}} f_i. \tag{A1}$$

The buyer chooses f_i and the number of solicited suppliers to maximise (A1), subject to the suppliers' participation constraint. First, note that she charges $f_i^{auc} = f^{auc} = \frac{1}{n} I(n)$ to induce the invited suppliers to accept to participate and fully extract their expected information rent. This yields

$$u^{auc} = v - (1 - \beta)k - c_n^n, \tag{A2}$$

which is monotonically increasing in n, hence $n^{auc} = N$. Finally, note that the buyer cannot gain from setting $\bar{b} < \bar{c}$. In this case, bidding one own's cost of production continue to be a weakly dominant strategy. However, setting $\bar{b} < \bar{c}$ may lead to underproduction which is always detrimental because of Assumption 2 (i).

□

Proof of Lemma 2

In a bilateral negotiation, the selected supplier will always ask for the maximum reserve price $\bar{b}$ if $\bar{b} \geq c$. If $\bar{b} < c$, it is a weakly dominant strategy for the supplier to ask for c, in which case production will not take place. Anticipating this, the buyer chooses the reserve price and the participation fee to maximise her expected utility:

$$[v - (1 - \beta)k - \bar{b}]\Phi(\bar{b}) + f,$$

subject to the supplier's participation constraint:

$$\int_{\underline{c}}^{\bar{b}} (\bar{b} - x)\phi(x)dx - f \geq 0.$$

In stage 1, the supplier chooses whether to participate knowing the reserve price and the participation fee, but before learning his cost of production.

The buyer will set

$$f^{neg} = \int_{\underline{c}}^{\bar{b}} (\bar{b} - x)\phi(x)dx = \int_{\underline{c}}^{\bar{b}} \Phi(x)dx$$

to ensure participation, i.e. $d = 1$, and give up no rent to the supplier. The optimisation problem can be rewritten as:

$$\max_{\bar{b}} \quad [v - (1 - \beta)k - \bar{b}]\Phi(\bar{b}) + \int_{\underline{c}}^{\bar{b}} \Phi(x)dx.$$

Maximisation yields:

$$-\Phi(\bar{b}) + [v - (1-\beta)k - \bar{b}]\phi(\bar{b}) + \Phi(\bar{b}) = 0.$$

Hence, $\bar{b} = v - (1-\beta)k > \bar{c}$ because of Assumption 2 (i). Now note that whenever $\bar{b}^{neg} \geq \bar{c}$, the buyer's expected utility is:

$$v - (1-\beta)k - \bar{b} + \underbrace{\bar{b} - \int_{\underline{c}}^{\bar{c}} x\phi(x)dx}_{f^{neg}} = v - (1-\beta)k - E(c).$$

□

Augmented Auctions: Preliminaries

Under augmented auctions, *public history* at time t is $h_t = \{\mathcal{N}_t, f_t, \bar{b}_t, \{d_{i,t}\}, \{b_{i,t}\}, q_t, \xi_t, \{q_{i,t}r_{i,t}\}\}$. Public history up to t is $h^t = \{h_1, ..., h_{t-1}\}$. For each player $i \in \{1, ..., N\}$ private history also contains information on i's own investment decision, $e_{i,t}$, and cost realisation, $c_{i,t}$, when i has been invited and has accepted to submit a proposal, i.e. when $i_t \in \mathcal{N}_t$ and $d_{i,t} = 1$, for $t = 1, 2, ...$

For any period t and any history h^t, the *multilateral relational contract* specifies (i) the features of the procurement mode $(\mathcal{N}_t, f_t, \bar{b}_t)$, (ii) the invited suppliers' acceptance and investment decisions, d_t and e_t, as well as the bids b_t as function of their own realised cost, (iii) supplier's choice, $q_{i,t}$, as function of the bids, and (iv) discretionary bonuses $r_{i,t}$ contingent on the realisation of ξ_t. The multilateral relational contract is *self-enforcing* if it describes a Perfect Public Equilibrium (PPE) of the repeated game.

Supplier i's expected utility at time t is the following discounted sum of the stream of payoffs:

$$\pi_{i,t} = (1-\delta)E\sum_{\tau=t}^{\infty}\delta^{\tau-t}\{[P(b_\tau) - c_{i,\tau} + R_\tau(e_{i,\tau})]q_{i,\tau}(b_\tau) - ge_{i,\tau} - f_{i,\tau}\}d_{i,\tau}\mathbb{1}_{i,\tau}. \quad \text{(A3)}$$

where (i) the expected utility is computed over the sequences of n-profiles of production costs $c_{i,\tau}$ for $i_\tau \in \mathcal{N}_{\ll}$ and $\tau = t, t+1, ...$; (ii) $\mathbb{1}_{i,\tau} = 1$ if supplier $i_\tau \in \mathcal{N}_\tau$, that is if i is invited to participate in the auction at time τ, and $\mathbb{1}_{i,\tau} = 0$ otherwise; and (iii) $R_\tau(e_{i,\tau})$ is the expected value of the discretionary payment a winning supplier receives at time τ if he has invested $e_{i,\tau}$.[41]

The buyer's expected utility at time t is given by:

$$u_t = (1-\delta)E\sum_{i=1}^{N}\sum_{\tau=t}^{\infty}\delta^{\tau-t}\{[v - (1-\beta)(1-\rho e_{i,\tau})k - P(b_\tau) - R_\tau(e_{i,\tau})]q_{i,\tau} + f_{i,\tau}\}d_{i,\tau}\mathbb{1}_{i,\tau}. \quad \text{(A4)}$$

By restricting attention to stationary contracts, $f_t = f$, $\bar{b}_t = \bar{b}$, $n_t = n$, $d_t = d$, $e_t = e$, $b_{t,c_t} = b_{c_t}$, $q_t = q$, and $r_{t,\xi_t} = r_{\xi_t}$ in every period t.

Proof of Lemma 3

I split the proof in three parts. In Part 1, I show that (BCC) is a necessary condition to have an equilibrium in augmented auctions in which $e_i = 1\ \forall i \in \mathcal{N}$ and I characterise $B(n, g)$. In Part 2, I show that augmented auctions that achieve $SW^A(n)$ are self-enforcing only if (BCC) and (BDE^A) hold. In Part 3, I show that the buyer cannot gain from adopting non-stationary contracts.

[41] As the suppliers are all identical with respect to their ability to deliver superior drawings, the buyer offers the same discretionary reward schedule to each seller she interacts with and therefore I can drop the index i at $R_{i,\tau}$. Note that I report the equation of $R_{i,\tau}$ in the proof of Lemma 3.

Part 1

I first show that if $\frac{1}{n}I(n) < g$, $e_i = 1\ \forall i \in \mathcal{N}$ cannot be achieved. Suppose i's $n-1$ rival suppliers are investing. If supplier i remains idle, his expected payoff is at least 0. If he invests, his expected payoff at the investment stage is:

$$E\pi_i(e_i = 1|e_{-i} = 1) = \frac{1}{n}I(n) - g.$$

Then $\frac{1}{n}I(n) \geq g$ is a necessary condition for the suppliers to invest in a pure-strategy symmetric equilibrium. It does not guarantee investment, though. To this end, the buyer must set $R(1) > R(0)$ so as to reduce the expected payoff of an idle supplier.

In what follows I assume that (BCC) is satisfied. Now I show that for a sufficiently large $R(1) - R(0)$ the buyer can always induce all the suppliers to invest.

Recall that as the buyer holds second price auctions, it is a weakly dominant strategy for bidder i to bid $b_i = c_i - R(e_i)$. Suppose that i remains idle when at least one rival supplier j invests. Supplier i has no chance of winning the auction and his expected payoff is then 0 if $\min b_i(e_i = 0) > \max b_j(e_j = 1)$, that is if $\underline{c} - R(0) > \bar{c} - R(1)$, which can be rewritten as $R(1) - R(0) > \bar{c} - \underline{c}$. If this inequality holds and i invests, he wins if $c_i < \min_{j \neq i} c_j$ for $j \in \mathcal{N}$ such that $e_j = 1$. Suppose that there are $m - 1 \leq n - 1$ investing bidders. Then, i's expected payoff from investing when $R(1) - R(0) > \bar{c} - \underline{c}$ is:

$$E\pi_i(e_i = 1|m-1 \text{ rivals invest}) = \frac{1}{m}I(m) - g.$$

Therefore i is willing to invest when $m-1$ rivals invest if and only if $\frac{1}{m}I(m) \geq g$. Note that the left-hand side of this inequality reaches its minimum when all i's $n-1$ rivals invest. In that case, the inequality becomes $\frac{1}{n}I(n) \geq g$, which is satisfied whenever (BCC) holds. In addition, note that if $\underline{c} - R(0) = \bar{c} - R(1)$, an idle supplier may win the auction when at least one of his rivals invests, but his expected payoff conditional on winning is 0. Therefore, if $R(1) - R(0) \geq \bar{c} - \underline{c}$, it is a weakly dominant strategy for each supplier i to invest when at least one rival invests.

However, setting $R(1) - R(0) \geq \bar{c} - \underline{c}$ may not be enough when *all* i's rivals remain idle. In that case i's expected payoff from remaining idle is:

$$E\pi_i(e_i = 0|e_{-i} = 0) = \frac{1}{n}I(n).$$

If i invests, his expected payoff is:

$$E\pi_i(e_i = 1|e_{-i} = 0) = c^{n-1}_{n-1} - R(0) - (c^1_1 - R(1)) - g,$$

where $c^{n-1}_{n-1} - R(0)$ is the expected value of the smallest bid of i's rivals and c^1_1 is i's expected cost of production. Then, for i to be willing to invest, it must also be that:

$$R(1) - R(0) \geq \frac{1}{n}I(n) + g + (c^1_1 - c^{n-1}_{n-1}). \tag{A5}$$

Note that $c^1_1 \geq c^{n-1}_{n-1}$ for any $n \geq 2$. Hence, if the buyer sets $R(1) - R(0) \geq \max\{\bar{c} - \underline{c}, \frac{1}{n}I(n) + g + (c^1_1 - c^{n-1}_{n-1})\}$, she ensures that a supplier i is willing to invest independently of what his rivals do.

To minimise her temptation to renege on the relational contracts, the buyer sets the minimum difference $R(1) - R(0)$ which guarantees that $e_i = 1$ for all $i \in \mathcal{N}$ is the only equilibrium in the investment stage. I have denoted such minimum difference by $B(n, g)$. Now, I show that:

$$g < B(n, g) \leq \max\{\bar{c} - \underline{c}, g + \frac{1}{n}I(n) + c^1_1 - c^{n-1}_{n-1}\}.$$

The upper bound of $B(n,g)$ is reached when the (BCC) binds, that is when $\frac{1}{n}I(n) = g$. To see this, consider that in that case i's expected payoff from investing when all the other suppliers are investing is:

$$E\pi_i(e_i = 1|e_{-i} = 1) = \frac{1}{n}I(n) - g = 0.$$

As a result, i is willing to invest also if what he expects to earn by remaining idle is 0, which requires $R(1) - R(0) \geq \bar{c} - \underline{c}$. Then to avoid that $e_i = 0$ for all $i \in \mathcal{N}$ is an equilibrium, the buyer must also make sure that $R(1) - R(0) \geq \frac{1}{n}I(n) + g + (c_1^1 - c_{n-1}^{n-1})$.

To show that $B(n,g) > g$, it is convenient to focus on the simplest case in which supplier i must be motivated to invest when all his $n-1$ rivals remain idle.[42] Notice that irrespective of whether $e_i = 1$ or $e_i = 0$, with probability $\frac{1}{n}$, i is the lowest-cost supplier and gets the information rent $I(n)$. As a result, i's willingness to invest cannot depend on the expected information rent. Supplier i may be willing to invest to collect the prize $B(n,g)$ when he is awarded the contract. When i invests, he wins the auction also when $c_i > \min_{j \neq i} c_j$ and $\min_{j\neq i} c_j < c_i < \min_{j \neq i} c_j + B(n,g)$, in which case i's payoff is $B(n,g) - (c_i - \min_{j\neq i} c_j)$, that is the actual prize he collects is reduced by the fact that his cost of production is not the lowest one. Hence, i's surplus from investing when everyone else remains idle is:

$$B(n,g)Pr(c_i < \min_{j \neq i} c_j + B(n,g)) - (c_i - \min_{j\neq i} c_j)Pr(\min_{j\neq i} c_j < c_i < \min_{j\neq i} c_j + B(n,g)) - g.$$

Supplier i weakly prefers to invest when all his rivals remain idle if

$$B(n,g)Pr(c_i < \min_{j \neq i} c_j + B(n,g)) \geq g + (c_i - \min_{j\neq i} c_j)Pr(\min_{j\neq i} c_j < c_i < \min_{j\neq i} c_j + B(n,g)). \tag{A6}$$

On the left-hand side of the above inequality, $B(n,g)$ is multiplied by a probability which takes value 1 when $B(n,g) \geq \bar{c} - \underline{c}$ and is lower than 1 otherwise. On the right-hand side, the second addendum is always positive whenever $B(n,g) > 0$. Hence, I can conclude that $B(n,g) > g$ whenever $g > 0$.[43]

I conclude Part 1 by pointing out that the relationship between $B(n,g)$ and the number of solicited suppliers n is ambiguous. When fewer suppliers participate in the auction the probability that i wins increases. However, this is so irrespective of whether i himself invests or not. The magnitude of the positive change in the probability of winning depends, among other things, on the total number of bidders and the distribution Φ. Therefore, holding the differential $R(1) - R(0)$ constant, it might be that supplier i is not more motivated to invest when one less bidder participates in the auction.

Part 2

Augmented auctions with n suppliers which obtain $SW^A(n)$ in expectation with surplus division $\hat{u}$ and $\hat{\pi}_i$ for each i are self-enforcing if the following conditions hold:

1. The buyer's and the supplier i's participation constraint for all $i = 1, 2, ..., N$:

$$\hat{u} \geq u^{auc}; \qquad \hat{\pi}_i \geq 0.$$

2. The bidding-competition constraint

$$\frac{1}{n}I(n) \geq g. \tag{BCC}$$

[42] In a more general case a subset of i's rivals invest. There, i's expected payoff depends on whether his strongest rival has invested or not. The case on which I focus suffices to show that $B(n,g) > g$ and it is more clear-cut.

[43] Formally, let Φ_L be the distribution of the lowest order statistic of $n-1$ draws, i.e. the distribution of the strongest rival i faces. Taking into account i's expectation over c_i and $\min_{j\neq i} c_j$, i is willing to invest when all his rivals remain idle if:

$$B(n,g)\left[\int_{\underline{c}}^{\bar{c}}\left(1 - \int_{\underline{c}}^{c} d\Phi_L(x - B(n,g))\right) d\Phi_i(c)\right]$$
$$\geq g + \int_{\underline{c}}^{\bar{c}}\left(\int_{x}^{x+B(n,g)} (c-x)d\Phi_i(c)\right) d\Phi_L(x).$$

3. The supplier's incentive compatibility constraint:

$$R(1) - R(0) \geq B(n,g),$$

where

$$R(e) \equiv \begin{cases} [\beta + (1-\beta)\rho]r_S + (1-\beta)(1-\rho)r_F & \text{if } e = 1 \\ \beta r_S + (1-\beta)r_F & \text{if } e = 0. \end{cases}$$

4. The buyer's dynamic enforcement constraint which ensures that the buyer is always willing to honour her promised rewards:

$$-r_\xi + \frac{\delta}{1-\delta}\hat{u} \geq u_d(\xi) + \frac{\delta}{1-\delta}u^{auc},$$

where u_d represents the deviation payoff a buyer attains if she refuses to make the discretionary payment. The above constraint must hold for all $\xi \in \{S, F\}$.

5. Supplier i's dynamic enforcement constraint which ensures that supplier i is always willing to accept the buyer's discretionary rewards:

$$r_\xi + \frac{\delta}{1-\delta}\hat{\pi} \geq \pi_d(\xi),$$

where π_d is the deviation payoff the supplier gets if he refuses the buyer's discretionary payment. This constraint must hold for all i and $\xi \in \{S, F\}$.

Augmented auction attaining $SW^A(n)$ give the buyer an expected utility $u^A(n)$:

$$u^A(n) = v - (1-\beta)(1-\rho)k - EP^A(b) - R(1) + \sum_{i \in \mathcal{N}} f_i,$$

where $EP^A(b)$ is the expected value of the second-smallest bid in augmented auctions attaining $SW^A(n)$ and is equal to $c^n_{n-1} - R(1)$. Then the buyer's expected utility in augmented auctions is

$$u^A = v - (1-\beta)(1-\rho)k - c^n_{n-1} + \sum_{i \in \mathcal{N}} f_i,$$

while supplier i's expected profit at the beginning of each period is:

$$\pi^A_i(n) = \frac{1}{n}I(n) - g - f_i.$$

The buyer will optimally set $f_i = \frac{1}{n}I(n) - g$ for all $i \in \mathcal{N}$ so as to extract all the suppliers' expected surplus from participating in augmented auctions. Furthermore, the buyer will set $\bar{b} \geq \bar{c} - R(1)$ to ensure participation. Substituting f_i into the buyer's expected utility, I attain:

$$u^A = v - (1-\beta)(1-\rho)k - c^n_n - ng = SW^A(n).$$

Note that the rewards promised to the suppliers do not affect directly the buyer's utility. However, promising an excessively high reward increases the buyer's temptation to renege. The incentive compatibility constraint guarantees that in every period t each supplier prefers $e = 1$ to $e = 0$. The constraint can be rewritten as follows:

$$[\beta + (1-\beta)\rho]r_S + (1-\beta)(1-\rho)r_F \geq \beta r_S + (1-\beta)r_F + B(n,g).$$

The above condition boils down to

$$r^A_S \geq \frac{B(n,g)}{(1-\beta)\rho} + r^A_F.$$

To determine the relevant supplier's dynamic enforcement constraint, note that if supplier i rejects the buyer's reward, he gets 0 irrespective of ξ, i.e. $\pi_d = 0$ for $\xi \in \{S, F\}$. Moreover, r_S needs to be strictly higher than r_F to encourage the investment. The relevant constraint is then:

$$\frac{\delta}{1-\delta}\pi^A \geq -r_F^A.$$

By the same token, the relevant buyer's dynamic enforcement constraint is associated with the occurrence of $\xi = S$, in which case the buyer should pay a higher reward:

$$\frac{\delta}{1-\delta}[u^A(n) - u^{auc}] \geq r_S^A, \tag{BDE^A}$$

where $u_d(S) = u_d(F) = 0$ as the buyer does not get or lose any utility in a period if she refuses to make a discretionary payment. Since r_S^A increases in r_F^A, to facilitate the implementation of the augmented auctions yielding SW^A it is efficient to set r_F^A and r_S^A in such a way that the supplier's incentive compatibility and dynamic enforcement constraints bind. Since a supplier does not expect to obtain any rent from participating in an auction, the buyer cannot impose any discretionary penalty on a supplier following a failure:

$$r_F^A = 0.$$

Therefore, after a success the supplier gets:

$$r_S^A = \frac{B(n,g)}{(1-\beta)\rho}.$$

These rewards are set in such a way that the BDE can be more easily satisfied. By promising a higher reward, the utility of the buyer would not be altered but it would be harder to satisfy the BDE constraint. Knowing the optimal promised rewards r_ξ^A and observing ξ and r_ξ, the suppliers who are not selected in a given period to produce are able to detect a deviation and determine the identity of the player who has cheated. □

Part 3

I now show that the buyer cannot gain from adopting non-stationary contracts if she wants to use augmented auctions to induce each supplier $i \in \mathcal{N}$ to choose $e_i = 1$ in every period. Akin to Levin (2003), consider a relational contract that in the first period specifies $(\mathcal{N}, f, \bar{b}, d, de = d, b, q(b), r_\xi)$. If no deviation occurs, the relational contract entails continuation per-period payoffs u_ξ and $\pi_{i,\xi}$ for each i as a function of the observed outcome ξ. Any deviation triggers reversion to the buyer-preferred equilibrium of the one-shot game, under which the buyer attains u^{auc} and each supplier gets 0.

Let $\hat{u}$ and $\hat{\pi}_i$ be the parties' expected payoffs under this relational contract:

$$\hat{u} \equiv (1-\delta)E\sum_{i\in\mathcal{N}}\{[v - (1-\beta)(1-\rho)k - P(b) - R_\xi]q_i + f_i\}d_i + \delta u_\xi,$$
$$\hat{\pi}_i \equiv (1-\delta)E\{[P(b) - c_i + R_\xi]q_i - g - f_i\}d_i + \delta\pi_{i,\xi},$$

for all $i \in \mathcal{N}$. Suppose that the relational contract selects the supplier with the lowest production cost, then the expected surplus is:

$$\widehat{SW}(n) \equiv (1-\delta)\underbrace{[v - (1-\beta)(1-\rho)k - c_n^n - ng]}_{SW^A(n)} + \delta SW(n)_\xi,$$

where $SW(n)_\xi = u_\xi + \sum_{i\in\mathcal{N}}\pi_{i,\xi}$. For the relational contract to be self-enforcing it must be that (i) the participation constraint is satisfied, i.e., $\hat{u} \geq u^{auc}$, and $\hat{\pi}_i \geq 0$ for all i; (ii) the invited suppliers are willing to invest, which requires that the (BCC) is satisfied and the incentive-compatibility constraint is met:

$$(1-\beta)\rho\left[r_S + \frac{\delta}{1-\delta}\pi_{i,S}\right] \geq B(n,g) + (1-\beta)\rho\left[r_F + \frac{\delta}{1-\delta}\pi_{i,F}\right];$$

(iii) the parties are willing to pay/accept the discretionary payments, for all $\xi \in \{S, F\}$, for all $i \in \mathcal{N}$:

$$-r_\xi + \frac{\delta}{1-\delta} u_\xi \geq -u_d(\xi) + \frac{\delta}{1-\delta} u^{auc},$$
$$r_\xi + \frac{\delta}{1-\delta} \pi_{i,\xi} \geq \pi_d(\xi);$$

(iv) lastly, for each ξ, for each $i \in \mathcal{N}$, u_ξ and $\pi_{i,\xi}$ are obtained from a self-enforcing relational contract that begins in the next period.

Consider two results, closely tied to Theorem 1 and Lemma 1 in Levin (2003). Firstly, suppose that the relational contract is self-enforcing. Changing f in the first period does not affect the surplus and, as long as it satisfies the parties' participation constraints, the altered contract will continue to be self-enforcing, since conditions (ii)-(iv) do not depend on f. Secondly, $SW^A(n)$ is the maximum surplus that can be achieved in augmented auctions with n solicited suppliers and which implement $e_i = 1$ for all $i \in \mathcal{N}$. Then, efficiency requires that $SW(n)_\xi = SW^A(n)$ for all realization of ξ. Otherwise, it would be possible to increase the expected surplus $\widehat{SW}(n)$ by increasing u_ξ up to $u_\xi = SW^A(n) - \sum_{i\in\mathcal{N}} \pi_{i,\xi}$. This would relax the buyer's participation and dynamic-enforcement constraints, is consistent with a self-enforcing continuation relational contract, and does not affect the suppliers' incentives to invest.

Now note that $u_d(\xi) = \pi_d(\xi) = 0$ for all ξ: if a player refuses to accept or make a discretionary payment, nothing else occurs in that period. Therefore setting $r_F + \frac{\delta}{1-\delta}\pi_{i,F} = 0$ helps satisfy incentive compatibility without compromising dynamic enforcement. Thus, the incentive compatibility constraint can be rewritten as:

$$(1-\beta)\rho \left[r_S + \frac{\delta}{1-\delta} \pi_{i,S} \right] \geq B(n, g).$$

Consider now the buyer's dynamic-enforcement constraint and note that $u_\xi = SW^A(n) - \sum_{i\in\mathcal{N}} \pi_{i,\xi}$. This constraint can be rewritten as:

$$-r_\xi + \frac{\delta}{1-\delta}[SW^A(n) - \sum_{i\in\mathcal{N}} \pi_{i,\xi}] \geq \frac{\delta}{1-\delta} u^{auc}.$$

As shown earlier, $u^A(n) = SW^A(n)$. As a result:

$$\frac{\delta}{1-\delta}[u^A(n) - u^{auc}] \geq r_\xi + \frac{\delta}{1-\delta}\pi_{i,\xi} + \frac{\delta}{1-\delta} \sum_{j\neq i, j\in\mathcal{N}} \pi_{j,\xi} \geq \frac{B(n,g)}{(1-\beta)\rho},$$

because $\pi_{j,\xi} \geq 0$ for all $j \in \mathcal{N}$ and all ξ. Therefore, relaxing the restriction on stationary contracts does not relax the conditions under which augmented auctions that induce $e_i = 1$ for all i and in all periods can be sustained.

Proof of Remark 1

In augmented auctions, the buyer chooses the number of solicited bidders $2 \leq n \leq N$ to maximise (4), subject to (BCC) and (BDE^A). Several cases can be contemplated. First, note that $n^A = n^*$ if (BCC) and (BDE^A) are satisfied at n^* because (4) coincides with (3).

Second, if (BDE^A) is satisfied for all $2 \leq n \leq n^*$, whereas (BCC) is not satisfied at n^*, then the buyer will set $n^A < n^*$ if there exists $n^A \geq 2$ such that $\frac{1}{n^A} I(n^A) \geq g$. This is because restricting competition increases the expected information rent, thereby helping to satisfy this constraint. If such n^A does not exist, the buyer chooses $n^A = N$ and it follows that $e_{i,t} = 0$ for all $i \in \mathcal{N}$ and for all periods t.

Third, if (BCC) is satisfied for all n, whereas (BDE^A) is not satisfied at n^*, the buyer sets $n^A \neq n^*$. Meeting this constraint can require setting n^A either higher or lower than n^* because the relationship between $B(n, g)$ and n is ambiguous, as pointed out in the proof of Lemma 3. If it is not possible to satisfy this constraint, the buyer chooses $n^A = N$ and it follows that $e_{i,t} = 0$ for all $i \in \mathcal{N}$ and for all periods t.

Finally, notice that the two constraints are interlinked: reducing n to satisfy (BCC) may make it harder to satisfy (BDE^A). Likewise, increasing n to satisfy (BDE^A) may make (BCC) more unlikely to be satisfied. □

Proof of Lemma 4

The buyer will be willing to implement augmented negotiation if they enable her to improve upon *spot* auctions, that is, if $u^{AN} \geq u^{auc}$. The buyer chooses the rewards to maximise (7) subject to the suppliers' participation, incentive and dynamic enforcement constraints, her participation and dynamic enforcement constraints.

The supplier's incentive compatibility constraint ensures that each selected supplier is willing to make the unobservable investment. To determine this and the other constraints, note that the participation fee allows the buyer to extract the entire supplier's moral-hazard rent. Then a supplier does not attach any value to the future relationship with the buyer. The incentive compatibility constraint takes the following form:

$$[\beta + (1-\beta)\rho]r_S + (1-\beta)(1-\rho)r_F - g \geq \beta r_S + (1-\beta)r_F.$$

Unlike an auction, the expected discretionary payment $R(e_i)$ is not incorporated in any bid. It is straightforward to retrieve the optimal payments:

$$r_F^{AN} = 0; \qquad r_S^{AN} = \frac{g}{(1-\beta)\rho}.$$

The fee f^{AN} and the reserve price $\bar{b}^{AN}$ can be optimally set equal to $\frac{\beta g}{(1-\beta)\rho} + \bar{c} - E(c)$ and $\bar{c}$, respectively, to ensure the supplier's participation. Buyer's utility in augmented negotiations can be written as follows:

$$u^{AN} = v - (1-\beta)(1-\rho)k - c_1^1 - g, \tag{A7}$$

where $c_1^1 = E(c) = \int_{\underline{c}}^{\bar{c}} x d\Phi_(x)$. The supplier's dynamic enforcement constraint is trivially satisfied while the buyer's dynamic enforcement constraint takes the following form:

$$\frac{\delta}{1-\delta} \underbrace{[(1-\beta)\rho k - g - (c_1^1 - c_N^N)]}_{u^{AN} - u^{auc}} \geq r_S^{AN} = \frac{g}{(1-\beta)\rho}. \tag{BDE^{AN}}$$

Off-the-equilibrium path, it must be that the buyer is willing to exclude a supplier who has reneged on the relational contract. The threat of excluding the supplier is credible as it does not affect the buyer's utility: the expected cost of production will continue to be c_1^1. Finally, by following a proof strategy similar to that pursued in the proof of Lemma 3, it would be possible to show that the buyer would not benefit from using a non-stationary relational contract in augmented negotiations. □

Proof of Proposition 1

Suppose (BCC) does not hold at $n = 2$. Then, it will not hold for any $n > 2$ because the expected information rent $\frac{1}{n}I(n)$ is decreasing in n. It follows that augmented auctions that induce $e_{i,t} = 1$ for all $i \in \mathcal{N}$ and for all periods t cannot be implemented. If $\delta \geq \delta^{AN}$, the buyer will hold an augmented negotiation that induces $e_i = 1$ for all $i \in \mathcal{N}$ in every period as this is self-enforcing and is always preferred to an open auction because of Assumption 2. □

Proof of Proposition 2

Suppose (BCC) holds for all n up to some $\tilde{n} \geq 2$. This means that $\frac{1}{\tilde{n}}I(\tilde{n}) \geq g$, whereas $\frac{1}{\tilde{n}+1}I(\tilde{n}+1) < g$. Because the expected information rent $\frac{1}{n}I(n)$ is higher when n is smaller, (BCC) will hold for all $2 \leq n \leq \tilde{n}$. It follows that there exists a level of the discount factor δ above which some augmented auctions that induce $e_{i,t} = 1$ for all $i \in \mathcal{N}$ in every period t can be implemented on-the-equilibrium path. To determine the minimum level of the threshold level of δ, I take the number of bidders that have a higher chance of satisfying (BDE^A). This is given by any $\hat{n}$ that satisfies the (BCC) and maximises:

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] - \frac{B(n,g)}{(1-\beta)\rho}.$$

If δ is greater than the minimum between $\delta^A(\hat{n})$ and δ^{AN}, both augmented negotiations and some augmented auctions that induce $e_i = 1$ for all $i \in \mathcal{N}$ in every period are self-enforcing. These are always preferred to the infinite repetition of the buyer-preferred equilibrium of the stage game, namely, an open auction in which $e_i = 0$, for all i. If $\delta < \min\{\delta^A(\hat{n}), \delta^{AN}\}$, the buyer will revert to her preferred equilibrium of the one-shot game. □

Proof of Proposition 3

In augmented auctions the expected buyer's utility when $SW^A(n)$ is attained and β is affected by her investment is given by the following modified version of equation (6):

$$u^A(n,\beta) = v - (1-\beta)(1-\rho)k - c_n^n - ng - T(\beta) \tag{6'}$$

To attain this expected utility, a modified version of the buyer's dynamic enforcement constraint must hold. This allows for potential differences in both the buyer's investment cost, $T(\beta)$, and in the optimal level of specification of the good, β, between the repeated and the stage game:

$$\frac{\delta}{1-\delta}\underbrace{[(1-\beta)\rho k + (\beta-\hat{\beta})k + T(\hat{\beta}) - T(\beta) - ng - (c_n^n - c_N^N)]}_{u^A(n)-u^{auc}} \geq r_S^A \tag{A8}$$

where

$$r_S^A = \frac{B(n,g)}{(1-\beta)\rho}$$

Moreover, also the bidding-competition constraint $\frac{1}{n}I(n) \geq g$, which is unaffected by the choice of β, must hold. At stage 1 the buyer chooses a non-negative value of β to maximise this programme.

Let λ be the Karush-Kuhn-Tucker multiplier of (A8). The Lagrangian can be written as follows:

$$\begin{aligned} L(\beta;\lambda) = {} & v - (1-\beta)(1-\rho)k - c_n^n - ng - T(\beta) \\ & + \lambda\{\frac{\delta}{1-\delta}[(1-\beta)\rho k + (\beta-\hat{\beta})k + T(\hat{\beta}) - T(\beta) - ng - (c_n^n - c_N^N)] \\ & - \frac{B(n,g)}{(1-\beta)\rho}\} \end{aligned} \tag{A9}$$

As a first case, suppose that at the optimum $\lambda^A = 0$, that is the buyer's dynamic enforcement constraint is slack. Then the derivative of the Lagrangian with respect to β yields:

$$\frac{\partial L}{\partial \beta}(\beta^A;\lambda^A) = (1-\rho)k - T'(\beta^A) \leq 0$$

As β^A takes a positive value, the optimal investment in augmented auctions when the BDE constraint is slack is:

$$T'(\beta^A) = (1-\rho)k \tag{A10}$$

which is socially efficient, since the suppliers make the investment $e = 1$.

Then, consider what happens when the BDE constraint binds. The value of β^A can be retrieved from the BDE:

$$\begin{aligned} T(\beta^A) = {} & (1-\beta^A)\rho k + (\beta^A - \hat{\beta})k + T(\hat{\beta}) - (c_n^n - c_N^N) - ng \\ & - \frac{1-\delta}{\delta}\left[\frac{B(n,g)}{(1-\beta)\rho}\right] \end{aligned} \tag{A11}$$

Taking the derivative with respect to β I obtain:

$$T'(\beta^A) = (1-\rho)k - \frac{1-\delta}{\delta}\frac{B(n,g)}{(1-\beta^A)^2\rho} \tag{A12}$$

which takes a positive value for δ sufficiently high.

To conclude, putting together ($A10$) and ($A12$) I obtain that in augmented auctions the buyer's investment is given by the following expression:

$$T'(\beta^A) = \max\left\{(1-\rho)k - \mathbb{1}\{\frac{1-\delta}{\delta}\frac{B(n,g)}{(1-\beta^A)^2\rho}\}, 0\right\} \tag{A13}$$

where the indicator function $\mathbb{1}$ takes value 1 if the BDE binds and 0 otherwise.

Note that the objective function is concave and the constraint is convex so that the necessary conditions are also sufficient for optimality.

In augmented negotiations, the buyer's expected utility is

$$u^{AN} = v - (1-\beta)(1-\rho)k - E(c) - g - T(\beta) \tag{A14}$$

subject to the buyer's dynamic enforcement constraint:

$$\frac{\delta}{1-\delta}\underbrace{[(1-\beta)\rho k - g + (\beta-\hat{\beta})k + T(\hat{\beta}) - T(\beta) - (E(c) - c_N^N)]}_{u^{AN}-u^{auc}} \geq r_S^{AN} \tag{A15}$$

where

$$r_S^{AN} = \frac{g}{(1-\beta)\rho}$$

The buyer chooses a non-negative value of β to maximise this programme. Let λ be the Karush-Kuhn-Tucker multiplier of ($A13$). The Lagrangian can be written as follows:

$$\begin{aligned} L(\beta;\lambda) &= v - (1-\beta)(1-\rho)k - E(c) - g - T(\beta) \\ &+ \lambda\{\frac{\delta}{1-\delta}[(1-\beta)\rho k - g + (\beta-\hat{\beta})k + T(\hat{\beta}) - T(\beta) \\ &- (E(c) - c_N^N)] - \frac{g}{(1-\beta)\rho}\} \end{aligned} \tag{A16}$$

First, suppose that at the optimum $\lambda^{AN} = 0$, that is the buyer's dynamic enforcement constraint is slack. Then the derivative of the Lagrangian with respect to β yields:

$$\frac{\partial L}{\partial \beta}(\beta^{AN};\lambda^{AN}) = (1-\rho)k - T'(\beta^{AN}) \leq 0$$

As β^{AN} takes a nonnegative value, the optimal investment in augmented auctions when the BDE constraint is slack is:

$$T'(\beta^{AN}) = (1-\rho)k \tag{A17}$$

which is socially efficient.

Then, consider the case in which the BDE constraint binds. The value of β^{AN} can be retrieved from the BDE:

$$T(\beta^{AN}) = (1-\beta^{AN})\rho k - g + (\beta^{AN}-\hat{\beta})k + T(\hat{\beta}) - (E(c) - c_N^N) - \frac{1-\delta}{\delta}\frac{g}{(1-\beta^{AN})\rho} \tag{A18}$$

Taking the derivative with respect to β I obtain:

$$T'(\beta^{AN}) = (1-\rho)k - \frac{(1-\delta)}{\delta}\frac{g}{(1-\beta^{AN})^2\rho}. \tag{A19}$$

Again, when the right-hand side of the above expression is negative, $\beta^{AN} = 0$.

Note that the objective function is concave and the constraint is convex so that the necessary conditions are also sufficient for optimality.

□

Appendix B

Observable Investment - Proof of Remark 2

With the employment contract the buyer can promise a transfer r_i to each supplier contingent on e. Consider the following reward schedule: a supplier receives $r(e_1) = g$, if he has invested, $r(e_0) = 0$ if he has remained idle. This induces the suppliers to invest. The buyer will then set $f = \frac{1}{n}I(n)$ to extract the expected information rent from each supplier. The buyer's dynamic enforcement constraint is:[44]

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] \geq ng.$$

If the buyer cannot exchange transfers with each suppliers after the investment is observed, she can reimburse the suppliers with a one-period delay through the participation fee. Therefore $f_{i,t} = \frac{1}{n}I(n) - \frac{g}{\delta}$ if i invested at time $t-1$ and $f_{i,t} = \frac{1}{n}I(n)$ otherwise. The condition to ensure $e = 1$ becomes:

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_N^N)] \geq \frac{ng}{\delta}.$$

□

Different Informational Assumptions

Assume that $\xi_t \in \{S, F\}$ is observed by the buyer and by supplier i only if $q_{i,t} = 1$, i.e., only if supplier i has been selected for production in period t. Likewise, assume that only the buyer and the selected supplier in period t observes $r_{i,t}$. Below, I show how to amend the relational contracts described in Section 4 for both augmented auctions and augmented negotiations to deal with these different informational assumptions. Both relational contracts have an element of loyalty, as they also specify a favourite pool of suppliers (a favourite supplier in the case of augmented negotiations).

Augmented auctions. Consider the following multilateral relational contract in augmented auctions with a favourite pool of suppliers, that specifies:

(i) *the identity of the favourite suppliers*, $\mathcal{N}_{fav} \in \{1, ..., N\}$, namely the suppliers that will be invited to the auction in every period;
(ii) the other features of the procurement mode $(f_t, \bar{b}_t)$;
(iii) the invited suppliers' acceptance and investment decisions, d_t and e_t, as well as the bids b_t as function of their own realised cost;
(iv) the supplier's choice, $q_{i,t}$, as function of the bids;
(v) the discretionary bonuses $r_{i,t}$ contingent on the realisation of ξ_t.

Off-the-equilibrium path, the relational contract prescribes that a selected supplier reacts to a buyer's refusal to pay the promised bonus by ceasing to trade with her in future periods. Any buyer's deviation which is detected by the other players leads the suppliers to cease to trust her promised rewards. However, they will still trade with her.[45] As for the punishment following the selected supplier's refusal to accept the discretionary bonus, this triggers a *different* PPE of the continuation game, that is, one that can be distinguished by the other players. Given that there are a plethora of equilibria of the repeated game and a profit-maximising buyer always leaves zero rents to a supplier (i.e., his mini-max payoff), it is not problematic to move to a PPE of the continuation game that gives zero profit to the supplier after his deviation and that it is different from the PPE of the continuation game that follows a buyer's deviation. The two

[44] To determine the buyer's fall-back position after a deviation, I assume that the suppliers converge to the equilibrium in which $e_i = 0$ for all i.

[45] This is just an illustrative example that leads to a solution not very dissimilar from that presented in Section 4. Obviously, one could contemplate different punishments, e.g., all suppliers stop trading with the buyer if they directly observe a deviation or they infer that she reneged on the relational contract in the past.

equilibria of the continuation game must enable the other suppliers to perfectly identify when the buyer deviated so that they can also carry out the punishment. In light of the above, a suitable candidate is the infinite repetition of the buyer-preferred equilibrium of the one-shot game, wherein an open auction is held and all N suppliers participate and choose $e = 0$.

Lemma 5. *In augmented auctions with a pool of favourite suppliers $\mathcal{N}_{fav}$, a relational contract specifying $f^{favA} = \frac{1}{n}I(n) - g$, $\bar{b}^{favA} = \bar{c} - R(1)$, $d_i^{favA} = 1$, $e_i^{favA} = 1$, and $b_i^{favA} = c_i - R(1)$ for all $i \in \mathcal{N}_{fav}$, $r_F^{favA} = 0$, $r_S^{favA} = \frac{B(n,g)}{(1-\beta)\rho}$ in every period is self-enforcing if:*

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - ng - (c_n^n - c_{N-1}^{N-1})] \geq \frac{B(n,g)}{(1-\beta)\rho}. \tag{B1}$$

Proof. This relational contract satisfies the favourite suppliers' participation, incentive-compatibility, and dynamic-enforcement constraints. Also note that each favourite supplier's expected profit is zero, as his information rent is extracted in each period through f^{favA}.[46] Consider now the buyer's dynamic-enforcement constraint. If the buyer pays the discretionary reward after $\xi = S$, she loses r_S^{favA} in this period but she will enjoy the per-period payoff u^{favA} in future periods, with

$$u^{favA} = v - (1-\beta)(1-\rho)k - ng - c_n^n.$$

If the buyer reneges on the bonus in period t, that selected supplier will not trade with the buyer anymore. If the buyer invites the same pool of favourite suppliers in period $t+1$, that is, $\mathcal{N}_{t+1} = \mathcal{N}_{fav}$ the suppliers will infer from the previous selected supplier's refusal to trade that the buyer reneged on the bonus and they will all choose $e = 0$. If the buyer selects a different pool of suppliers in period $t+1$, i.e., $\mathcal{N}_{t+1} \neq \mathcal{N}_{fav}$, the invited suppliers will react by choosing $e = 0$ because this itself represents a deviation from the relational contract. Hence, the best per-period payoff the buyer can achieve in the subsequent periods is $v - (1-\beta)k - c_{N-1}^{N-1}$, which is obtained when all suppliers are invited, the supplier selected in period t declines to participate, the other suppliers participate and choose $e = 0$.[47] Hence, condition (B1) is retrieved.[48] □

Augmented negotiations. Consider the following multilateral relational contracts in augmented negotiations with a favourite supplier, that specifies:

(i) *the identity of the favourite supplier*, $i_{fav} \in \{1, ..., N\}$, namely the supplier that will produce the good in every period;
(ii) the other features of the procurement mode $(f_t, \bar{b}_t)$;
(iii) the favourite supplier's acceptance d_t, investment e_t, and price b_t decisions;
(iv) the contingent reward $r_t(\xi_t)$.

Off-the-equilibrium path, the relational contract prescribes that the favourite supplier reacts to a buyer's refusal to pay the promised reward by refusing to trade in following periods. Any buyer's deviation which is detected by the other players leads the suppliers to cease to trust her promised rewards. Following a supplier's deviation, an auction with N suppliers and $e_i = 0$ for all suppliers is played (this is the buyer's preferred equilibrium of the stage game).

[46] Note that the lack of a proper punishment following a supplier deviation (i.e., after the supplier's refusal to accept a non-negative payment) is justified by the fact that this supplier cannot be forced to receive less than his mini-max payoff.

[47] Note that this is an equilibrium of the continuation game as each supplier is indifferent between accepting or declining to participate given that they obtain zero profits.

[48] Note that, if a selected supplier refuses a discretionary bonus in period t, the relational contract prescribes that the buyer hold an open auction with N suppliers in period $t+1$. All N suppliers will participate, including the one that turned down the bonus in the previous period (and, as a result, every supplier will learn the identity of the breacher), and choose $e = 0$.

Lemma 6. *In augmented negotiations with a favourite supplier, i_{fav}, a relational contract specifying $f^{favAN} = \frac{\beta g}{(1-\beta)\rho} + \bar{b}^{favAN} - E(c)$, $\bar{b}^{favAN} = b^{favAN} = \bar{c} - R(1)$, $d^{favAN} = 1$, $e^{favAN} = 1$, $r_F^{favAN} = 0$, $r_S^{favAN} = \frac{g}{(1-\beta)\rho}$ in every period is self-enforcing if*

$$\frac{\delta}{1-\delta}[(1-\beta)\rho k - g - (E(c) - c_{N-1}^{N-1})] \geq \frac{g}{(1-\beta)\rho}. \tag{B2}$$

Proof. This relational contract satisfies the favourite supplier's participation, incentive-compatibility, and dynamic-enforcement constraints. Also note that the favourite supplier's expected profit is zero on-the-equilibrium path, as his information rent is extracted ex-ante through f^{favAN}. Hence, a favourite supplier's deviation (i.e., his refusal to accept a bonus) is not punished because a supplier cannot be forced to receive less than his mini-max payoff. Consider now the buyer's dynamic-enforcement constraint. If the buyer pays the discretionary reward after $\xi = S$, she loses r_S^{favAN} in this period but she will enjoy the per-period payoff u^{favAN} in future periods, with

$$u^{favAN} = v - (1-\beta)(1-\rho)k - g - E(c).$$

If the buyer reneges in period t, the favourite supplier will not trade with her thereafter. Then, the best the buyer can do is to hold open auctions: The favourite supplier will refuse to trade, whereas the other suppliers will participate, will learn about the buyer's deviation, and will choose $e = 0$. If the buyer chooses $\mathcal{N}_{t+1} \neq i_{fav}$, the invited suppliers different from i_{fav} participate but do not choose high investment, as prescribed by the relational contract. Thus, condition (B2) is retrieved. □

Competition and Quality

First, I show that it may be better to have some non-investing suppliers when Assumption 2 (ii) does not hold. To this end, I compare the surplus that can be obtained when all the suppliers invited by the buyer invest with the surplus that can be obtained when only a subset of the invited suppliers invest. Consider first the surplus of augmented auctions in which n^* suppliers are invited and they all invest (recall that n^* is the surplus maximising number of solicited suppliers in augmented auctions where $e_i = 1$ for all invited suppliers):[49]

$$SW^A(n^*) = v - (1-\beta)(1-\rho)k - c_{n^*}^{n^*} - n^* g.$$

Now, consider the surplus of augmented auctions with M solicited suppliers, with $2 \leq M \leq N$, of whom m invest, with $0 \leq m \leq M$:

$$\begin{aligned} SW^A(m, M) =& v - \alpha\left(\frac{m}{M}\right)(1-\beta)(1-\rho)k - \left(1 - \alpha\left(\frac{m}{M}\right)\right)(1-\beta)k \\ & - mg - \alpha\left(\frac{m}{M}\right)c_m^m - \left(1-\alpha\left(\frac{m}{M}\right)\right)c_{M-m}^{M-m}, \end{aligned}$$

where $\alpha\left(\frac{m}{M}\right)$ is the probability that an investing supplier is selected with $\alpha(0) = 0$, $\alpha(1) = 1$, and that is increasing in m and decreasing in M.

Compare the two welfare expressions where, for ease of notation I do not report the arguments of function α:[50]

$$\begin{aligned} SW^A(n^*) \geq & \quad SW^A(m, M) \\ \Leftrightarrow v - (1-\beta)(1-\rho)k - c_{n^*}^{n^*} - n^* g \geq & \quad v - \alpha(1-\beta)(1-\rho)k \\ & - (1-\alpha)(1-\beta)k - mg - \alpha c_m^m - (1-\alpha)c_{M-m}^{M-m}. \end{aligned}$$

[49] Note that augmented negotiations would be optimal if $n^* = 1$.

[50] I carry out the comparison abstracting away from implementation issues.

This can be rewritten as:

$$\alpha\big(v-(1-\beta)(1-\rho)k-c_{n^*}^{n^*}-n^*g\big)+(1-\alpha)\big(v-(1-\beta)(1-\rho)k-c_{n^*}^{n^*}-n^*g\big)$$
$$\geq \alpha\big(v-(1-\beta)(1-\rho)k-c_m^m-mg\big)+(1-\alpha)\big(v-(1-\beta)k-c_{M-m}^{M-m}-mg\big).$$

Split the problem up and note that the inequality between the first two terms of each side requires that:

$$\alpha\big(v-(1-\beta)(1-\rho)k-c_{n^*}^{n^*}-n^*g\big)\geq \alpha\big(v-(1-\beta)(1-\rho)k-c_m^m-mg\big).$$

This is equivalent to:

$$-c_{n^*}^{n^*}-n^*g\geq -c_m^m-mg,$$

which is always satisfied by the definition of n^*. This inequality can be conveniently rewritten as:

$$c_m^m-c_{n^*}^{n^*}\geq (n^*-m)g.$$

Consider the inequality between the other two terms:

$$(1-\alpha)\big(v-(1-\beta)(1-\rho)k-c_{n^*}^{n^*}-n^*g\big)\geq (1-\alpha)\big(v-(1-\beta)k-c_{M-m}^{M-m}-mg\big).$$

The above inequality boils down to

$$(1-\beta)\rho k+\big(c_{M-m}^{M-m}-c_{n^*}^{n^*}\big)\geq (n^*-m)g,$$

which, in light of the previous condition, is always satisfied if

$$(1-\beta)\rho k+\big(c_{M-m}^{M-m}-c_{n^*}^{n^*}\big)\geq c_m^m-c_{n^*}^{n^*},$$

or

$$(1-\beta)\rho k\geq c_m^m-c_{M-m}^{M-m}.$$

Note that this sufficient condition is always satisfied if Assumption 2 (ii) holds. Conversely, for k sufficiently low, it may be the case that augmented auctions where not all invited suppliers invest yields a higher surplus.

Consider now the relationship between the importance of quality for the buyer and the number of invited suppliers as well as the number of investing suppliers:

Proof of Remark 3

Denote by m^* and M^* the surplus maximising number of investing suppliers and solicited suppliers, respectively. By using the tools of monotone comparative statics (e.g., see Milgrom and Shannon, 1994), I now show that SW^A exhibits nondecreasing differences in (m,k) and in $(M,-k)$. Note that if $m'>m$ and $k'>k$, then

$$SW^A(m',k')-SW^A(m,k')\geq SW^A(m',k)-SW^A(m,k)$$
$$\alpha\left(\frac{m'}{M}\right)(1-\beta)\rho(k'-k)\geq \alpha\left(\frac{m}{M}\right)(1-\beta)\rho(k'-k),$$

which is always satisfied given that $\alpha(\cdot)$ is increasing in m. This implies that m^* is monotone non-decreasing in k.

Let $M'>M$ and $k'>k$, then

$$SW^A(M',k)-SW^A(M,k)\geq SW^A(M',k')-SW^A(M',k')$$
$$\alpha\left(\frac{m}{M}\right)(1-\beta)\rho(k'-k)\geq \alpha\left(\frac{m}{M'}\right)(1-\beta)\rho(k'-k),$$

which is always satisfied given that $\alpha(\cdot)$ is decreasing in M. Thus, M^* is monotone nonincreasing in k. □

Proof of Proposition 4.

Consider first augmented negotiations. These are self-enforcing only if the same (BDE^{AN}) reported in Lemma 4 holds. Note that, to be self-enforcing, $(1-\beta)\rho k > (E(c) - c_N^N) + g$. Thus, a decrease in k makes open auction with $e_i = 0$ for all $i \in \mathcal{N}$ more likely.

Next, determine the conditions under which augmented auctions with $M \leq N$ invited suppliers, of whom $1 \leq m \leq M$ invest, are self-enforcing. I start by describing the selection process. The buyer adopts a modified version of the second price reverse auction, wherein the bidder who promises to deliver the highest value to the buyer wins the auction and receives as a payment the second highest differential value. In particular, to see why (11) is the buyer's favourite choice rule in augmented auctions, note that a high-investment supplier $i \in \{1, ..., m\}$ is preferred to a low-investment supplier $j \in \{m+1, ..., M\}$ if and only if:

$$v - b_i - (1-\beta)(1-\rho)k - R(1) \geq v - b_j - (1-\beta)k,$$

which holds whenever $b_i \leq b_j + (1-\beta)\rho k - R(1)$. Here, I am implicitly assuming that the buyer selects a high-investment supplier when her expected utility is the same. Consider now the bidding behaviour of a high-investment supplier, for instance, bidder 1 in a given period (time subscript is dropped), given supplier-selection rule (11):

$$[EP(b) + R(e_1) - c_1]Pr\left[b_1 \leq \min\left\{\min_{i\in\{2,...,m\}} b_i, \min_{j\in\{m+1,...,M\}} b_j + (1-\beta)\rho k - R(1)\right\}\right].$$

It is a weakly dominant strategy for bidder 1 to bid his true cost of production, minus the expected discretionary payment $R(e_1)$, if

$$P(b) = \min\left\{\min_{i\in\{2,...,m\}} b_i, \min_{j\in\{m+1,...,M\}} b_j + (1-\beta)\rho k - R(1)\right\}.$$

To see this, note that by bidding more than $c_1 - R(e_1)$, supplier 1 reduces the probability of winning without affecting his payoff conditional on winning. In contrast, by bidding less, supplier 1 increases the probability of winning but just because he would win also in states where his payoff conditional on winning would be negative.[51] The bidding behaviour of a low-investment supplier can be similarly described and is omitted.

Consider now the incentives of a supplier in the group of high-investment suppliers to choose $e = 1$ instead of $e = 0$. First of all, for his incentive compatibility constraint to be satisfied, $R(1) - R(0)$ must be sufficiently large. The minimum difference which guarantees $e = 1$ will now be a function of g, m, and M, and will be denoted by $B(m, M, g)$ which has features similar to $B(n, g)$ characterised in the proof of Lemma 3. Among other things, $B(m, M, g) > g$. To help satisfy the buyer's dynamic enforcement constraint, $r_S = \frac{B(m,M,g)}{(1-\beta)\rho}$ and $r_F = 0$. The buyer's dynamic enforcement constraint in modified augmented auctions, $BDE^A(m, M)$ can be thus written as:

$$\frac{\delta}{1-\delta}\left[\alpha\left(\frac{m}{M}\right)(1-\beta)\rho k - mg - \left(\alpha\left(\frac{m}{M}\right)c_m^m + \left(1-\alpha\left(\frac{m}{M}\right)\right)c_{M-m}^{M-m} - c_N^N\right)\right] \geq \frac{B(m, M, g)}{(1-\beta)\rho}.$$

Given that high-investment suppliers compete away the expected reward at the bidding stage, an additional condition that must be verified for them to invest is that the expected information rent is large enough. A modified bidding competition constraint, since $M - m$ suppliers are asked to choose $e_j = 0$,

[51] For instance, suppose 1 chose $e_1 = 1$ and bids $b_1 = c_1 - R(1) - \epsilon$ with $\epsilon \geq 0$ and suppose that his strongest rival is a low-investment supplier. 1's expected payoff would be:

$$[\min_{j\in\{m+1,...,M\}} c_j + (1-\beta)\rho k - c_1]Pr[c_1 - \epsilon \leq \min_{j=m+1,...,M} c_j + (1-\beta)\rho k].$$

If $\epsilon > 0$, 1 would win even when $c_1 > \min_{j=m+1,...,M} c_j + (1-\beta)\rho k$, leading to a negative payoff.

must hold. Focusing on high-investment supplier 1, we define the expected information rent in these modified augmented auctions as:

$$\begin{aligned} IR(m,M) \equiv & \int_{\underline{c}}^{\bar{c}} \left(\int_{c_L \leq c_{NI}+(1-\beta)\rho k} \left(\int_{\underline{c}}^{c_L} (c_L - c_1) d\Phi(c_1) \right) d\Phi_{NI}(c_{NI}) \right) d\Phi_L(c_L) \\ & + \int_{\underline{c}}^{\bar{c}} \left(\int_{c_{NI}+(1-\beta)\rho k < c_L} \left(\int_{\underline{c}}^{c_L} (c_{NI} + (1-\beta)\rho k - c_1) d\Phi(c_1) \right) d\Phi_L(c_L) \right) d\Phi_{NI}(c_{NI}), \end{aligned} \tag{B3}$$

where Φ_L (respectively, Φ_{NI}) is the distribution of the strongest rival 1 faces among the high-investment (low-investment) suppliers. To see how (B3) is obtained, note that if $c_L \leq c_{NI} + (1-\beta)\rho k$, supplier 1 gets $(c_L - c_1)$ if $c_1 \leq c_L$ because the strongest rival 1 faces is a high-investment supplier. Thus, if $c_L \leq c_{NI} + (1-\beta)\rho k$, 1's expected information rent in stage 1 is:

$$(c_L - c_1)Pr[c_1 \leq c_L] = \int_{\underline{c}}^{\bar{c}} \left(\int_{\underline{c}}^{c_L} (c_L - c_1) d\Phi(c_1) \right) d\Phi_L(c_L).$$

Conversely, if $c_L > c_{NI} + (1-\beta)\rho k$, supplier 1 gets $(c_{NI} + (1-\beta)\rho k - c_1)$ if $c_1 \leq c_{NI} + (1-\beta)\rho k$ because the strongest rival 1 faces is a low-investment supplier. Thus, if $c_L > c_{NI} + (1-\beta)\rho k$, 1's expected information rent in stage 1 is:

$$\begin{aligned} & Pr[c_1 \leq c_{NI} + (1-\beta)\rho k] = \\ & \int_{\underline{c}}^{\bar{c}} \left(\int_{\underline{c}}^{c_{NI}+(1-\beta)\rho k} (c_{NI} + (1-\beta)\rho k - c_1) d\Phi(c_1) \right) d\Phi_{NI}(c_{NI}). \end{aligned}$$

Putting them together, (B3) is retrieved. Note that the information rent $IR(m,M)$ depends on the number of high-investment and low-investment suppliers. If at (m,M), $IR(m,M) < g$, a high-investment supplier will be unwilling to choose $e = 1$.

Intuitively, $IR(m,M)$ is decreasing in m and M, as the fewer the number of high and low investment competitors, the greater the chances of winning the auction and the higher the expected reward. The suppliers' expected information rents are optimally extracted in every period by the buyer through the participation fees. Suppose now that $IR(m,M)$ holds up to some $(\tilde{m},\tilde{M})$. It follows that there exists some level of the discount factor above with augmented auctions that induce $e_{i,t} = 1$ for all $i \in \{1,...\tilde{m}\}$ in every period t can be implemented on-the-equilibrium path. To determine the minimum level of the threshold δ, I take the number of bidders and high-investment suppliers that have greater chances of satisfying $BDE^A(m,M)$. This pair is given by any $(\hat{m},\hat{M})$ that satisfy $IR(m,M) > g$ and maximises

$$\frac{\delta}{1-\delta}\left[\alpha\left(\frac{m}{M}\right)(1-\beta)\rho k - mg - \alpha\left(\frac{m}{M}\right)c_m^m + \left(1-\alpha\left(\frac{m}{M}\right)\right)c_{M-m}^{M-m} - c_N^N\right] - \frac{B(m,M,g)}{(1-\beta)\rho}.$$

If $\delta > \min\{\delta^{AN}, \delta^A(\hat{m},\hat{M})\}$ both some modified augmented auctions and augmented negotiations that induce investments are self-enforcing. Being self-enforcing necessarily implies that they are preferred to open auctions with $e_i = 0$ for all $i \in \mathcal{N}$. If $\delta < \min\{\delta^{AN}, \delta^A(\hat{m},\hat{M})\}$, the buyer will adopt open auctions where no supplier chooses $e = 1$.

Lastly, note that a decrease in k makes an open auction with $e_i = 0$ for all $i \in \mathcal{N}$ more likely. The reason is twofold. Firstly, $IR(m,M)$ decreases as a high-investment supplier is less likely to win the auction and his expected payment decreases. As a result, the bidding competition constraint is less likely to be satisfied. Secondly, the surplus of modified augmented auction declines which means that $BDE^A(m,M)$ is less likely to be satisfied for any (m,M). □

Acknowledgements. I am particularly grateful to Robert Gibbons and Patrick Legros for their insightful comments and suggestions. I also thank the editor Robert M. Sauer, the anonymous referees, Tommaso Aquilante, Daniel Barron, Antonio Estache, Mate Fodor, Mark Hou, Elisabetta Iossa, Georg Kirchsteiger, Luca Livio, Ester Manna, David Martimort, Martin Peitz, Tom Potoms, Konrad Stahl, André Stenzel, and

Adam Szeidl for their valuable comments. Thanks to audiences at the XXXIX Simposio of the Spanish Economic Association in Palma de Mallorca, 3rd Ph.D. Students Workshop in Industrial and Public Economics held at Universitat Rovira i Virgili (Spain), XXX Jornadas de Economia Industrial held at the University of Alicante (Spain), University of Cologne, Central European University, Diego Portales University, Universitat de Barcelona, University of Mannheim, ECARES, and MIT Organisational Economics lunch, where I presented an early version of this manuscript. Usual disclaimer applies.

References

Abreu, D. (1988). On the theory of infinitely repeated games with discounting. *Econometrica*, 56(2):383–96.

Albano, G. L., Cesi, B., and Iozzi, A. (2017). Public procurement with unverifiable quality: The case for discriminatory competitive procedures. *Journal of Public Economics*, 145:14 – 26.

Andrews, I. and Barron, D. (2016). The allocation of future business: Dynamic relational contracts with multiple agents. *American Economic Review*, 106(9):2742–59.

Asanuma, B. (1989). Manufacturer-supplier relationships in Japan and the concept of relation-specific skill. *Journal of the Japanese and international economies*, 3(1):1–30.

Bajari, P., McMillan, R., and Tadelis, S. (2009). Auctions Versus Negotiations in Procurement:An Empirical Analysis. *Journal of Law, Economics and Organization*, 325:372.399.

Bajari, P. and Tadelis, S. (2001). Incentives versus Transaction Costs: A Theory of Procurement Contracts. *The RAND Journal of Economics*, 32:387–407.

Baker, G., Gibbons, R., and Murphy, K. J. (1994). Subjective performance measures in optimal incentive contracts. *The Quarterly Journal of Economics*, 109(4):1125–56.

Baker, G., Gibbons, R., and Murphy, K. J. (2002). Relational contracts and the theory of the firm. *The Quarterly Journal of Economics*, 117(1):39–84.

Baker, G., Gibbons, R., and Murphy, K. J. (2011). Relational adaptation. *Unpublished manuscript, USC Marshall School*.

Barron, D. and Guo, Y. (2019). The use and misuse of coordinated punishments. Technical report, Working Paper, Northwestern University, November 2019.

Barron, D. and Powell, M. (2019). Policies in relational contracts. *American Economic Journal: Microeconomics*, 11(2):228–49.

Bernstein, L. (2015). Beyond relational contracts: Social capital and network governance in procurement contracts. *Journal of Legal Analysis*, 7(2):561–621.

Board, S. (2011). Relational contracts and the value of loyalty. *American Economic Review*, 101(7):3349–67.

Bull, C. (1987). The existence of self-enforcing implicit contracts. *The Quarterly Journal of Economics*, 102(1):147–159.

Burt, D. N. (1989). Managing suppliers up to speed. *Harvard Business Review*, 67(4):127–135.

Calzolari, G., Felli, L., Koenen, J., Spagnolo, G., Stahl, K. O., et al. (2019). Trust, investment and competition: Theory and evidence from german car manufacturers. *CRC TR 224 Discussion Paper*, (No 081).

Calzolari, G. and Spagnolo, G. (2009). Relational contracts and competitive screening. *CEPR Discussion Papers 7434*.

Chakravarty, S. and MacLeod, W. B. (2009). Contracting in the shadow of the law. *The RAND Journal of Economics*, 40(3):533–557.

Che, Y.-K. and Chung, T.-Y. (1999). Contract damages and cooperative investments. *The Rand Journal of Economics*, pages 84–105.

Che, Y.-K. and Gale, I. (2003). Optimal design of research contests. *The American Economic Review*, 93(3):646–671.

Che, Y.-K. and Hausch, D. B. (1999). Cooperative investments and the value of contracting. *American Economic Review*, pages 125–147.

Che, Y.-K. and Yoo, S.-W. (2001). Optimal incentives for teams. *American Economic Review*, pages 525–541.

Clark, K. B. (1989). Project scope and project performance: the effect of parts strategy and supplier involvement on product development. *Management science*, 35(10):1247–1263.

Corts, K. S. (2012). The interaction of implicit and explicit contracts in construction and procurement contracting. *Journal of Law, Economics, and Organization*, 28(3):550–568.

Dyer, J. H. (1996). How Chrysler created an American keiretsu. *Harvard Business Review*.

Fudenberg, D., Levine, D. I., and Maskin, E. (1994). The folk theorem with imperfect public information. *Econometrica*, 62(5):997–1039.

Ganuza, J.-J. (2007). Competition and cost overruns in procurement. *The Journal of Industrial Economics*, 55(4):633–660.

Grey, W., Olavson, T., and Shi, D. (2005). The role of e-marketplaces in relationship-based supply chains: A survey. *IBM systems Journal*, 44(1):109–123.

Herweg, F. and Schmidt, K. M. (2017). Auctions versus negotiations: the effects of inefficient renegotiation. *The RAND Journal of Economics*, 48(3):647–672.

Herweg, F. and Schmidt, K. M. (2019). Procurement with unforeseen contingencies. *Management Science*.

Klein, B., Crawford, R. G., and Alchian, A. A. (1978). Vertical integration, appropriable rents, and the competitive contracting process. *Journal of Law and Economics*, 21:297.

Laffont, J.-J. and Tirole, J. (1993). *A theory of incentives in procurement and regulation*. MIT press.

Legros, P. and Newman, A. F. (2008). Competing for ownership. *Journal of the European Economic Association*, 6(6):1279–1308.

Levin, J. (2002). Multilateral contracting and the employment relationship. *The Quarterly Journal of Economics*, 117(3):1075–1103.

Levin, J. (2003). Relational incentive contracts. *American Economic Review*, 93(3):835–857.

Lippert, S. and Spagnolo, G. (2011). Networks of relations and word-of-mouth communication. *Games and Economic Behavior*, 72(1):202–217.

Loertscher, S. and Riordan, M. H. (2018). Outsourcing, vertical integration, and cost reduction. *American Economic Journal: Microeconomics*, page forthcoming.

MacLeod, W. B. and Malcomson, J. M. (1989). Implicit contracts, incentive compatibility, and involuntary unemployment. *Econometrica: Journal of the Econometric Society*, pages 447–480.

Malcomson, J. M. (2012). Relational incentive contracts. *Handbook of Organizational Economics eds. Robert Gibbons and John Roberts*, pages 1014–1065.

McMillan, J. (1990). Managing Suppliers: Incentive Systems in Japanese and US Industry. *California Management Review*, 32(4).

McMillan, J. (1994). Reorganizing Vertical Supply Relationships. *Trends in business organization: Do participation and cooperation increase competitiveness?*, pages 203–222.

Milgrom, P. and Roberts, J. (1990). The economics of modern manufacturing: Technology, strategy, and organization. *The American Economic Review*, pages 511–528.

Milgrom, P. and Shannon, C. (1994). Monotone comparative statics. *Econometrica*, 62:157–157.
Myerson, R. B. (1981). Optimal auction design. *Mathematics of operations research*, 6(1):58–73.
Roberts, J. (2004). *The Modern Firm: Organizational Design for Performance and Growth*. Oxford University Press.
Tan, G. (1992). Entry and r & d in procurement contracting. *Journal of Economic Theory*, 58(1):41–60.
Taylor, C. R. and Wiggins, S. N. (1997). Competition or compensation: Supplier incentives under the american and japanese subcontracting systems. *The American Economic Review*, pages 598–618.
Taylor, T. A. and Plambeck, E. L. (2007a). Simple relational contracts to motivate capacity investment: Price only vs. price and quantity. *Manufacturing & Service Operations Management*, 9(1):94–113.
Taylor, T. A. and Plambeck, E. L. (2007b). Supply chain relationships and contracts: The impact of repeated interaction on capacity investment and procurement. *Management science*, 53(10):1577–1593.
Tirole, J. (2009). Cognition and incomplete contracts. *The American Economic Review*, 99(1):265–294.
Tunca, T. I. and Zenios, S. A. (2006). Supply auctions and relational contracts for procurement. *Manufacturing & Service Operations Management*, 8(1):43–67.
Van Biesebroeck, J. (2007). Complementarities in automobile production. *Journal of Applied Econometrics*, 22(7):1315–1345.
Williamson, O. E. (1975). Markets and hierarchies. *New York*, pages 26–30.
Womack, J. P., Jones, D. T., and Roos, D. (2007). *The Machine that changed the world: The story of lean production*. Simon and Schuster.