Procuring Diversity

Igor Letina and Armin Schmutzler*

February 11, 2015

Abstract

This paper deals with the competitive procurement of complex goods for which sellers have to commit to a design choice before the best design is known. When this uncertainty is sufficiently large, the social optimum requires that sellers offer different designs. An auction that takes place after the qualities of the sellers become common knowledge weakly implements the socially optimal design choices. A buyer who cannot charge participation fees nevertheless prefers a (potentially inefficient) fixed-prize tournament that does not induce design diversity. Auctions with reserve prices induce weakly less diversity than auctions without reserve prices. Ex-post price negotiations (after the realization of qualities) also weakly implement the social optimum, thereby increasing buyer payoffs relative to the optimal contest if her bargaining power is sufficiently large.

Keywords: Procurement, diversity, innovation, auctions, negotiations, tournaments.
JEL: L14, L22, L23.

Conference Draft; preliminary and incomplete

*Igor Letina: Department of Economics, University of Zürich, igor.letina@econ.uzh.ch. Armin Schmutzler: Department of Economics, University of Zürich and CEPR; armin.schmutzler@econ.uzh.ch. We are grateful Dirk Bergemann, Joao Montez, Nick Netzer, Marco Ottaviani, Konrad Stahl, David Wettstein and to seminar participants in Rome (Oligo Workshop) and in Zurich for helpful comments.

1 Introduction

The 1973 Yom Kippur War revealed a fundamental weakness that US-made fighter planes would face in a potential conflict with the Soviet Union. The Israeli Air Force, despite having the most advanced technology, lost 109 aircraft in just 18 days, most of them to radar-guided anti-aircraft systems. Already in 1974 the Defense Advanced Research Projects Agency (DARPA) set out to build an aircraft that would not be as vulnerable to Soviet ground-based defenses as the then-current aircraft. However, DARPA did not know what was the best way to design an aircraft that would suit their needs. The best they could do was to solicit design submissions from several companies with experience and expertise in building aircraft, test the prototypes built on the basis of the most promising designs and then build planes based on the prototype that performed best. That is, DARPA initiated a procurement process that would yield a plane they needed. This procedure eventually led to the Lockheed F-117 Nighthawk, the "invisible" plane.[1]

As the above example suggests, in many procurement situations the buyer does not know ex ante the optimal design of the good or service she is procuring, but once a prototype is built, it is possible to assess the quality of the design. Then the interest of the procurer is not only to obtain a low price, but to obtain sufficient diversity of designs. Similar procurement problems appear in architectural design competitions. When procuring the architectural design for a new building, the buyer does not know what is the best way to design the building, but once she examines the submitted plans, she can choose which one suits her needs best. As a matter of fact, guidelines for architectural design competitions explicitly recognize the need for diversity of designs at a low price. For example, the Royal Institute of British Architects states: "[Competitions] have a reputation for giving clients the best range of design options to choose from and cost a fraction of the total construction cost of a scheme. [...] Competitions enable a wide variety of approaches to be explored simultaneously with a number of designers."[2]

The central questions of this paper are: How should a procurer design the procurement mechanism when the ideal design is not known initially? What are the effects of several common mechanisms on efficiency and distribution? To answer these questions, we develop a model with one buyer and two sellers. The distinguishing feature of our model is that the quality of any design is not known ex ante by either the buyer or the sellers. The sellers choose the design they wish to develop from a continuum of possible designs. Moreover, we assume that the sellers are exogenously heterogeneous, reflecting the idea that they might have access to different technology (as in the stealth fighter example) or different design styles (as in an architectural design). The quality of a design chosen by a particular firm will be high when the design and the identity of the firm are close to an initially unknown state of the world in a suitable metric space.[3]

We first characterize the socially optimal ex-ante design choices. For a large subset of the parameter space, optimal procurement requires that the two firms choose different designs.

[1] See Crickmore (2003).

[2] See Royal Institute of British Architects (RIBA) (2013).

[3] Specifically, we assume a uniform distribution of the state on $[0,1] \times [0,1]$. Each supplier chooses a design in $[0,1]$; his identity corresponds to one of the boundary points in $[0,1]$. Thus, a combination of design and supplier corresponds to point in $[0,1] \times \{0\}$ or $[0,1] \times \{1\}$. Quality is a decreasing function of the (Manhattan) distance between this point an the state of the world.

Intuitively, this provides the buyer with an option value coming from the possibility to react to the information on the state of the world by choosing the more suitable design. The optimal diversity of designs is higher when ex-ante heterogeneity between firms is small and the costs of getting the wrong design is high.

We then turn to the analysis of procurement institutions. We first consider "design contests" for which the buyer specifies a – possibly degenerate – interval of prices that the sellers may ask for. The buyer also decides whether or not to ask sellers to submit these prices before or after the quality of the two designs has become common knowledge ("no information revelation" vs. "full information revelation"). After the buyer has communicated the rules of the game, the sellers choose their designs. They also submit their price bid (before or after the revelation of quality information). Finally the buyer chooses the design that maximizes her net payoff and she makes transfers to the sellers according to the rules of the mechanism. The assumption that buyers always choose the design that maximizes net payoffs reflects non-contractible quality (see Che and Gale 2003).

We show how an auction with full information revelation implements the socially efficient outcome (and, in particular, the socially optimal degree of design diversity). There are several caveats, however. First, implementation is weak in general; in particular, inefficient equilibria without diversity can arise when diversity is optimal. Second, the auction leaves the seller with substantial rents resulting from ex-post monopoly power. Unless the buyer can ask for participation fees, she will therefore prefer not to use such a diversity-inducing auction. For instance, while a fixed-prize tournaments is inefficient, as it does not induce diversity, the buyer can appropriate the entire surplus, which gives her higher payoffs than the full-information auction.

We then go beyond the setting of design contests and ask whether the buyer can gain from refusing to commit to a set of possible prices ex ante, and instead announcing that the price will be determined in negotiations between the buyer and the high-quality supplier once qualities have been revealed. We model these negotiations in a black-box fashion, assuming that the surplus from trade between the two parties (relative to trade with the low-quality supplier) is split in some exogenous way reflecting bargaining power. These negotiations always weakly implement the socially efficient allocation. The buyer receives higher expected payoffs than in the auction with full information revelation that induces the same allocation. If her bargaining power is beyond a threshold value, she even receives higher expected payoffs than in the optimal fixed-prize tournament. The threshold decreases with a parameter reflecting the importance of design diversity relative to the exogenous asymmetry of suppliers.

This paper contributes to the literature on procurement mechanisms. Much of the literature focuses on private information about production costs. The issue is how to incentivize the suppliers to provide the goods at the lowest cost satisfying incentive and participation constraints. A good and extensive overview of this approach to the procurement problem is provided in Tirole and Laffont (1993). However, in many procurement problems, both price and quality matter. This issue is studied in Che (1993) and later in Asker and Cantillon (2008) and Asker and Cantillon (2010). The solution to the problem is a scoring auction, where the winner of the procurement is determined by a score which gives adequate weights to both price and quality.

In the papers above, the buyer and the suppliers know the optimal way to carry out the task under consideration. Bajari and Tadelis (2001) noticed that in construction industry, new information becomes available during the period when the contract is being executed (that is, construction takes place). In their model, the optimal procurement mechanism has to trade off strong incentives through a fixed contract against the ability to adjust to the new information through variable contracts. However, in their model the suppliers know the best way to provide the object ex ante. In Kaplan (2012), the sellers do not know the preferred design of the procurer, but the buyer herself has this information. Kaplan studies what happens when the buyer reveals this information.

In all of the papers cited above, the procurer always knows the optimal way to design the product that is being procured. Thus, there is no need for providing diversity of designs, which is the central issue we study in this paper.

In Section 2, we introduce the set-up and the basic terminology, and we analyze the optimal choice of designs by the two firms. In Section 3, we introduce the notion of a design contest; in Section 4, we analyze their equilibria. Section 5 deals with the optimal choice of contests for the buyer. In Section 6, we derive conditions under which the buyer can do better by not committing to ex-ante price determination in a contest. Section 7 discusses the robustness of our results. Section 8 concludes.

2 Design choices and Quality

A buyer (player B) needs a product that two potential suppliers (players $i \in \{1, 2\}$) can provide. Each seller chooses one product design s_i from some set S_i. Usually, we think of buyers as having access to different designs, so that $S_1 \neq S_2$. However, we allow for the degenerate case of homogeneous buyers ($S_1 = S_2$) as a benchmark. There is a measurable set of states of the world Φ, Neither sellers nor the buyer know the state at the outset. The quality of a design is a function $Q : (S_1 \cup S_2) \times \Phi \to \mathbb{R}^+$. Thus, the design that maximizes quality depends on the state of the world. It may therefore be ex-ante efficient to induce suppliers to choose sufficiently different designs, so as to benefit from the option value of deferring the optimal choice until further information is available.

2.1 Set-Up

We now specify the model further. The specification is chosen with several considerations in mind. First, we want to have a notion of designs that are "central" and designs that are "peripheral". Second, in every other way we want to exclude exogenous reasons for preferring one design option over the other.

We assume that the state of the world is distributed uniformly on $\Phi = [0, 1] \times [0, 1] \subset \mathbb{R}^2$; so that no state is more likely than another one. We also assume that the cost of each design is $F > 0$; in particular, the cost is independent of the design.

We write $\varphi = (\sigma, \theta)$ for a typical state. Moreover, we assume that $S_i = [0, 1] \times \{i - 1\} \subset [0, 1] \times [0, 1]$. We write $s_i = (v_i, i - 1)$ for a typical design of firm i. Hence, we can think of the design set of each firm as embedded into the state space, with the design set of firm 1 corresponding to the lower edge and the design set of firm 2 located on the upper edge (see Figure 1). With this representation, we can identify a firm's design choice with the first (horizontal) coordinate v_i. For $s_i = (v_i, i - 1)$, $i = 1, 2$, $\varphi = (\sigma, \theta)$ and suitable constants Ψ,

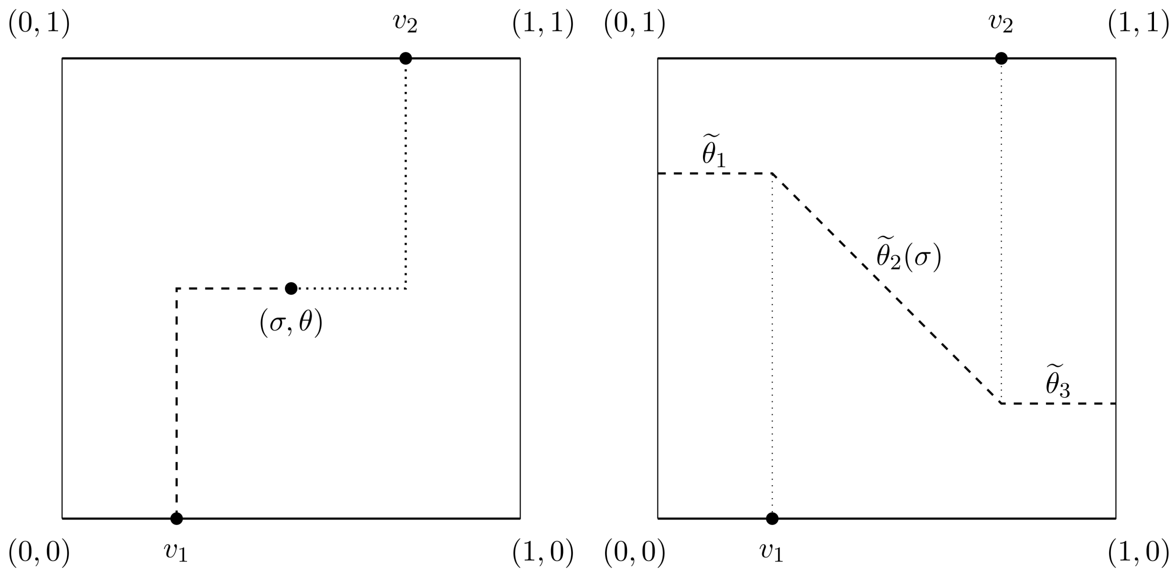

Figure 1: Quality from designs v_1 and v_2.

$a \geq 0$ and $b > 0$, we define $Q(s_i, \varphi) = \Psi - a|i - 1 - \sigma| - b|v_1 - \sigma|$. Thus

$$Q(s_1, \varphi) = \Psi - a\theta - b|v_1 - \sigma| \quad (1)$$

$$Q(s_2, \varphi) = \Psi - a(1 - \theta) - b|v_2 - \sigma| \quad (2)$$

Hence, for each design there is one state of the world under which this design yields maximal quality, and this maximal quality is the same for all designs, given as Ψ. Moreover, a captures the degree of exogenous differentiation between firms: For $v_1 = v_2 = v$, it is the maximum willingness-to-pay that a buyer might have for having design $(v, 0)$ rather than $(v, 1)$ or, conversely, $(v, 1)$ rather than $(v, 0)$. $a = 0$ corresponds to the benchmark case of homogeneous suppliers. The parameter b captures the degree to which different designs choices of a firm within its feasible set affect the final quality of the product. To emphasize the dependence of each firm's quality on the realization of the state, we often write $q_i(\sigma, \theta) \equiv Q(s_i, (\sigma, \theta))$.

Figure 1 (left panel) illustrates the transportation costs for a particular realization of states. The transportation costs correspond to a weighted sum of the length of the vertical and the horizontal dashed (dotted) line for seller 1(2), where the weight is given by a and b in each case.

The following simple result is obvious.

Lemma 1 *(i) $q_1(q_2)$ is decreasing (increasing) in θ.*
(ii) Suppose $v_1 \leq v_2$. If $q_1 < q_2$ for some σ, then $q_1 < q_2$ for any $\sigma' > \sigma$.

Figure 1 (right panel) illustrates the relation between supplier choices, realization of the state and qualities. Suppose that $v_1 \leq v_2$. The dashed line (given by $\tilde{\theta}$) shows the set of states of the world for which the quality supplied by both firms is identical.[4] In line with Lemma 1, the quality of firm 1 (2) is higher if the state is below (above) the dashed line.

For later use, we introduce some notation: For a given realization (σ, θ) of the state, seller 1 is the producer of higher (lower) quality if θ is below (above) some critical value $\widetilde{\theta}(\sigma)$ (see the right panel). We define $q_i^h(\sigma, \theta)$ as the quality of the design offered by firm i when it offers a higher quality than the competitor and $q_i^l(\sigma, \theta)$ as the quality offered by firm i when it offers a lower quality; in this notation, we are suppressing the dependence of q_i^h and q_i^h on v_1 and v_2. Finally, we write $\Delta q(\sigma, \theta) = \Delta q = \max[q_1(\sigma, \theta) - q_2(\sigma, \theta), q_2(\sigma, \theta) - q_1(\sigma, \theta)]$ for the quality differential in state (σ, θ).

2.2 Optimal Design Choices

We now characterize the socially optimal design choices. As the costs of each design are the same, the socially optimal design vector $\left(v_1^{SO}, v_2^{SO}\right)$ must maximize the expectation $E_\varphi[\max\{Q(s_1, \varphi), Q(s_2, \varphi)\}]$. With only one potential seller, the optimal choice would be the central location $v = 1/2$, as this design maximizes the expected quality of the product. With two suppliers, the optimization needs to take into account the option value generated by having different designs to choose from once the state of the world is realized. It will therefore turn out that, if designs have a sufficiently strong effect on quality (that is, if b is large enough), it is optimal to offer at least some diversity of designs. The optimal diversity will depend on the ratio b/a.

Proposition 2 *Suppose without loss of generality that $v_1 \leq v_2$. Then the socially optimal choice of designs is:*

$$\left(v_1^{SO}, v_2^{SO}\right) = \begin{cases} \left(\frac{1}{2}, \frac{1}{2}\right) & \text{if} \quad b < a \\ \left(\frac{a}{2b}, 1 - \frac{a}{2b}\right) & \text{if} \quad a \leq b < 2a \\ \left(\frac{1}{4}, \frac{3}{4}\right) & \text{if} \quad 2a \leq b \end{cases}.$$

Proof. See Appendix. ■

The intuition for the result is simple. Whenever $b < a$, the buyer cares more about getting the product from the right seller than about getting the right design within a seller's design set. In other words, exogenous differences between firms matter more than endogenous differences. The optimal design vector (which minimizes the expected horizontal transportation costs) is $v_1 = v_2 = 1/2$. As b increases, the value of getting the right design increases, and so does the expected value of diversity. Since the set of possible designs is bounded, the expected quality is maximal for $v_1 = 1/4$ and $v_2 = 3/4$. For this choice, the horizontal distance from the optimal design choice is never larger than $1/4$.[5]

[4] In Figure 1, we assume that $\tilde{\theta}[0,1] \subset (0,1)$. Below, we will also deal with the case that $\tilde{\theta}$ attains boundary values.

[5] We mention in passing that there always exists a trivial and uninteresting mechanism that weakly implements the optimal diversity; Suppose the buyer pays each seller a fixed fee that is independent of the realized quality. Then the sellers are indifferent between all available choices. Thus, any design vector is a weak equilibrium.

3 Design Contests

We now suppose the buyer can choose a *design procurement institution* determining the procedure for choosing and remunerating the buyer. For the moment, we consider design contests, which are closely related to the procurement contests analyzed by Che and Gale (2003), with the obvious difference that these authors consider the effort choices of suppliers rather than the design choices. In Section 6, we will consider an alternative class of institutions.

We assume that neither the design choice v_i nor the resulting quality q_i is contractible. For a design procurement contest, we describe the environment $\mathcal{E}^C$ by a tuple (a, b, Ψ, T_1, T_2). Here (a, b, Ψ) are the parameters introduced in the previous section and $T_i\,(i \in \{1, 2\}) \subset \mathbb{R}$ is an allowable set of non-contingent transfers from the seller to buyer i.

We suppose that, for each seller i, the buyer chooses a non-contingent transfer $t_i \in T_i$ and a set P_i of allowable prizes, where $P_i \subset \mathcal{C}(\mathbb{R}^+)$, the set of closed subintervals of $\mathbb{R}^+$. Moreover, she chooses an information regime $\mathcal{I} \in \{\mathcal{N}, \mathcal{F}\}$, which is either no (interim) information revelation ($\mathcal{N}$) or full (interim) information revelation ($\mathcal{F}$). A *design contest* corresponding to a tuple $D^C = (t_1, t_2, P_1, P_2, \mathcal{I}) \in T_1 \times T_2 \times \mathcal{C}(\mathbb{R}^+) \times \mathcal{C}(\mathbb{R}^+) \times \{\mathcal{N}, \mathcal{F}\}$ is the extensive-form game given by the following rules:

1. In period 0, the buyer specifies the tuple D^C.

2. In period 1, the supplier simultaneously select designs $v_i \in [0, 1]$.

3. In period 2, the state of the world is realized and information is distributed to the suppliers according to the information regime. For $\mathcal{I} = \mathcal{N}$, suppliers do not learn anything about the realized qualities, while for $\mathcal{I} = \mathcal{F}$ the suppliers learn both their own and their opponent's quality level.

4. In period 3, suppliers simultaneously choose prices $p_i \in P_i$.

5. In period 4, buyer observes both prices and qualities. The buyer chooses the design i that maximizes $q_i - p_i$ and pays $p_i + t_i$ to the chosen supplier i and t_j to the other supplier.

The following are examples of design contests:

1. $\mathcal{P} = \mathbb{R}^+$: D^C is an auction where suppliers bid their prices, with known qualities ($\mathcal{I} = \mathcal{F}$) or unknown qualities ($\mathcal{I} = \mathcal{N}$).

2. $\mathcal{P} = [0, \overline{P}]$: D^C is an auction where suppliers bid their prices with a reservation price $\overline{P}$, with known qualities ($\mathcal{I} = \mathcal{F}$) or unknown qualities ($\mathcal{I} = \mathcal{N}$).

3. $\mathcal{P} = \{A\}$, where $A > 0$: As $\mathcal{P}$ is a singleton, there is no influence of the supplier on the prize, no matter whether $\mathcal{I} = \mathcal{F}$ or $\mathcal{I} = \mathcal{N}$. In both cases, D^C corresponds to a fixed-prize tournament with prize A set by the supplier.

4 Equilibria of Design Contests

In the following, we calculate the equilibria for design contests. We focus specifically on efficiency properties. For the moment, we ignore the entry decision, assuming that the firms have already sunk the design costs.

4.1 An Efficiency Result

The first result provides a simple but useful sufficient condition for efficiency with full information revelation.

Lemma 3 *Any design contest with full information revelation such that*

$$p_i = \begin{cases} C\Delta q & \text{if} \quad q_i \geq q_j \\ 0 & \text{otherwise} \end{cases}.$$

(weakly) implements the social optimum $\left(v_1^{SO}, v_2^{SO}\right)$ *for any* $C > 0$.

Proof. See Appendix. ■

Thus, the lemma requires the design contest to have the following properties: (a) The winning seller receives a fraction of the difference between the surplus generated by his design and the alternative, and (b) the losing seller receives nothing. Thus, if seller j chooses a socially optimal design, then seller i internalizes the externality that his design choice has for social welfare and maximizes the difference between the surplus generated by his design and the alternative. Since this holds for seller j as well, the choice of designs is socially optimal.

There are several reasons why a design contest with the property described in Lemma 3 only achieves weak implementation, that is, it does not have a unique equilibrium giving rise to the optimal allocation. First, according to Proposition 2, there are two design vectors that are socially optimal whenever $b > a$: $(v_1, v_2) = \left(\frac{a}{2b}, 1 - \frac{a}{2b}\right)$ or $\left(1 - \frac{a}{2b}, \frac{a}{2b}\right)$ when $a \leq b \leq 2a$ and $(v_1, v_2) = \left(\frac{1}{4}, \frac{3}{4}\right)$ and $\left(\frac{3}{4}, \frac{1}{4}\right)$ when $2a \leq b$. In each case, both strategy profiles are equilibria of the proposed mechanism. Second, as the proof of Proposition 2 shows, when $b \in [a, 2a]$, a third equilibrium emerges — the symmetric equilibrium, which is not optimal.

Using Lemma 3, we can show that suitable auctions weakly implement the social optimum.

4.2 Unrestricted Auctions

We now analyze the equilibria for the various subclasses of research contests. The first result states that full-information auctions without reservation prices weakly implement the social optimum.

Proposition 4 *Let* D^C *be such that* $\mathcal{I} = \mathcal{F}$ *and* $P_1 = P_2 = \mathbb{R}^+$. *Then* D^C *weakly implements the social optimum.*

Proof. Observe that, for any realization of q_1 and q_2, the equilibrium of the pricing subgame is $p_i = \max\{0, q_i - q_j\}$ for $i \neq j$, and $i, j \in \{1, 2\}$. Such reward structure belongs to the class for which Lemma 3 holds. Hence, it implements the social optimum. ■

Intuitively, the high-quality firm bids the quality difference Δq in the auction. Anticipating this, it has incentives to choose designs that do not necessarily maximize the probability of winning, but instead yield a high quality differential and thus a high prize in case of success. This involves choosing different designs whenever the optimal allocation involves diversity.

We now show that information revelation is essential for this positive result. To this end, we consider contests for which $P_i = \mathbb{R}^+$ and $\mathcal{I} = \mathcal{N}$. We assume that among the two transportation cost parameters a and b, a is relatively high.

Assumption 1

$$a > \frac{b}{2\sqrt{2}+3}$$

When this assumption is violated, existence problems arise which are similar to those in the standard Hotelling model with linear costs. This is, in particular, true in the special case of homogeneous firms ($a = 0$).

Suppose the suppliers have chosen the design v_i and the price p_i. Let

$$P(p_1, v_1, p_2, v_2) = \text{Prob}\{Q(v_1, 0; \sigma, \theta) - p_1 \geq Q(v_2, 1; \sigma, \theta) - p_2\}$$

Then the expected payoffs of the sellers are

$$\begin{aligned} E\Pi_{s1}(p_1, v_1, p_2, v_2) &= P(p_1, v_1, p_2, v_2)\, p_1 \\ E\Pi_{s2}(p_1, v_1, p_2, v_2) &= (1 - P(p_1, v_1, p_2, v_2))\, p_2 \end{aligned} \tag{3}$$

Proposition 5 *Suppose Assumption 1 holds. Suppose that $\mathcal{I} = \mathcal{N}$ and $P_1 = P_2 = \mathbb{R}^+$. Then the D^C has a unique equilibrium. In this equilibrium,*

$$p_1^{BC} = p_2^{BC} = a \tag{4}$$

$$v_1^{BC} = v_2^{BC} = 1/2. \tag{5}$$

Proof. See Appendix. ■

The degree of exogenous differentiation a fully determines prices. Moreover, the equilibrium involves minimum differentiation. According to Proposition 2, such an equilibrium is not socially optimal whenever $b > a$, reflecting inefficiently high transportation costs.

4.2.1 Auctions with Reservation Prices

Unrestricted auctions result in either no diversity (if $\mathcal{I} = \mathcal{N}$) or in socially optimal diversity (if $\mathcal{I} = \mathcal{F}$). However, the buyer might want to restrict the maximum price that the sellers can ask for. This will result in an auction with reservation price. In this case, the buyer sets the maximum allowable price $\bar{p}$, so that $P_1 = P_2 = [0, \bar{p}]$. Again, no diversity will be induced if $\mathcal{I} = \mathcal{N}$. In the case when $\mathcal{I} = \mathcal{F}$, diversity levels that are lower than in the social optimum are induced and the maximum amount of diversity that can be induced will be decreasing in $\bar{p}$.

Proposition 6 *Let D^C be such that $\mathcal{I} = \mathcal{F}$ and $P_1 = P_2 = [0, \bar{p}]$. Then: (i) the maximum amount of diversity that can be implemented is weakly lower than in the social optimum and (ii) the maximum amount of diversity decreases as $\bar{p}$ decreases.*

Proof. The full characterization of equilibria in auctions with reservation prices is in the appendix. Statement (i) follows from direct comparison of equilibria inducing maximum diversity with socially optimal diversity. The proof of statement (ii) is in the appendix. ■

Figure 2 illustrates a typical outcome of an auction with reservation price. Seller 1 wins in states of the world below $\tilde{\theta}(\sigma)$, while Seller 2 wins above. Now, when the state of the world is particularly favorable to one of the sellers, the maximum price will bind. This means that the seller would like to ask for a higher price, but can only demand $\bar{p}$. This will be the case in

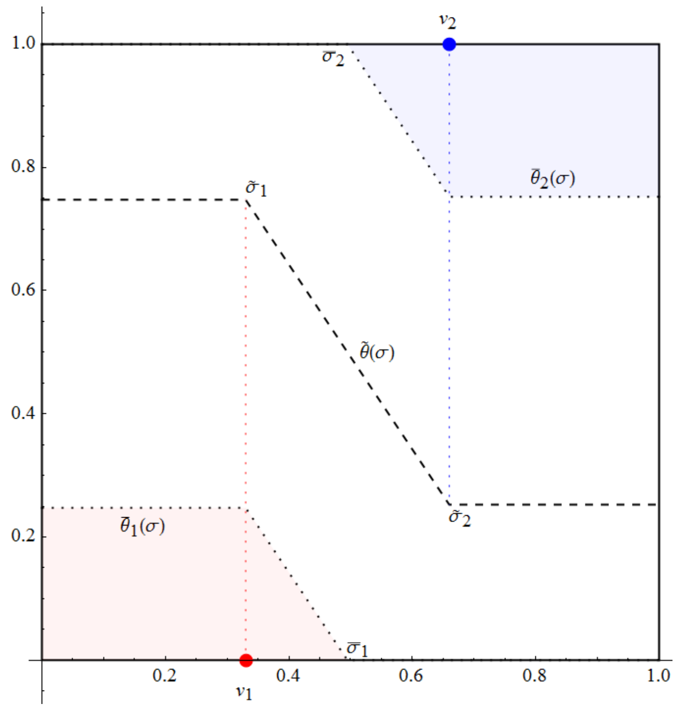

Figure 2: Auction with reservation price.

the lower left shaded region for Seller 1, and in the upper right shaded region for Seller 2. In the unshaded region, the maximum price is not binding, and the sellers demand their quality differential. Since the sellers differentiate in order to be able to ask for a high price when the state of the world is favorable, imposing price ceilings reduces incentives for the sellers to differentiate. Furthermore, lower $\bar{p}$ implies a larger region where the price ceiling will bind, hence the incentives to differentiate will be weaker for lower $\bar{p}$.

Figure 3 illustrates the set of equilibria as a function of reservation price $\bar{p}$. For very low $\bar{p}$, no diversity is induced and both sellers choose $(1/2, 1/2)$. For sufficiently high $\bar{p}$, the ceiling is never binding, so that the outcome is the same as in the unrestricted auction, that is, the socially optimal diversity is implemented. For intermediate levels of $\bar{p}$, equilibria with diversity between socially optimal level and no diversity can be implemented.

Proposition 7 *Suppose Assumption 1 holds. Let D^C be such that $\mathcal{I} = \mathcal{N}$ and $P_1 = P_2 = [0, \bar{p}]$. Then the D^C has a unique equilibrium. In this equilibrium,*

$$\begin{aligned} p_1 &= p_2 = \min\{a, \bar{p}\} \\ v_1 &= v_2 = 1/2. \end{aligned}$$

Proof. Sketch. The proof follows the proof of Proposition 5 closely. From that proof, we know that for any asking price $p > 0$, the unique design choice that maximizes expected profits is $v_1 = v_2 = 1/2$. Given such design choice, the unique price that maximizes expected profits is $p_1 = p_2 = a$. However, if $a > \bar{p}$, this price is not available and in this case the sellers maximize their expected profits by asking for the maximum price $\bar{p}$. ■

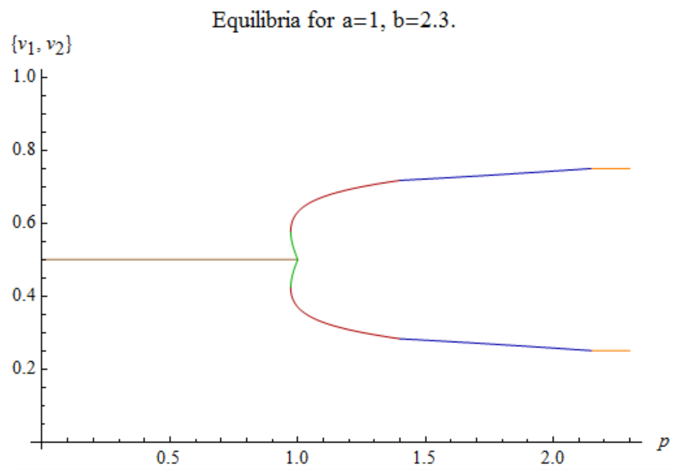

Figure 3: Equilibria as a function of reservation price.

This statement further demonstrates that full information is crucial for inducing diversity. With no information at the price setting stage, the sellers have to choose their designs (for a price that they will choose) in such a way that the combination of (v, p) will maximize the probability of winning and the probability of winning is maximized for $v = 1/2$. When information about the opponent's quality level is available, the sellers can choose to differentiate in order to take advantage of the more favorable states of the world, because in this case they can ask for a higher price.

4.2.2 Fixed Prize Tournaments

Now consider the fixed prize tournament for some arbitrary $A \geq 0$. This corresponds to the contest for which $P_i = \mathbb{R}^+ = \{A\}$ and $I = \mathcal{F}$ or $I = \mathcal{N}$.

Proposition 8 *Suppose that* $\mathcal{I} \in \{\mathcal{F}, \mathcal{N}\}$ *and* $P_1 = P_2 = \{A\}$. *Then there is a unique equilibrium of* D^C. *In this equilibrium,* $v_1 = v_2 = 1/2$.

Proof. The proof follows the proof of Proposition 5 closely. The analysis is considerably simpler, however: Only v_1 and v_2 need to be determined, whereas p_1 and p_2 can be replaced by A. Moreover, the structure of conceivable deviations is much simpler, as only one-dimensional deviations are feasible. ■

As in the beauty contest, minimum differentiation arises in equilibrium for any value of the prize A. Thus, the suppliers choose the same designs in the tournament as in the beauty contest.

4.3 Summary

Under full information revelation, auctions without reservation prices have equilibria which implement the social optimum weakly. In particular, these institutions induce diversity of designs where this is efficient. For auctions without information revelation and for fixed prize tournaments, only a symmetric equilibrium arises where the sellers choose $v_1 = v_2 = 1/2$. The result is intuitive: In these mechanisms, the size of the prize does not depend on the actions of the opponents. Hence, the sellers only care about winning. By contrast, in auctions, the payoff depends on the margin by which one seller outperforms the other. The sellers are therefore willing to differentiate, effectively sacrificing some probability of winning for the larger payoff when they do win. Thus, the sellers internalize some of the positive effects associated with the diversity of designs.

5 Optimal Contests

So far, we have characterized socially optimal allocations, and we have shown that auctions without reservation prices can implement these allocations. However, we also found that buyers have to leave rents on the table to implement the socially optimal outcome with an auction. It is therefore an open question whether auctions are in fact optimal from the perspective of the buyer. As in the previous section, we first deal with the situation where the entry decisions are made, and we also ignore unconditional transfer payments. We then endogenize entry decisions and allow for transfer payments.

When the buyer cannot use unconditional transfer payments, he is better off not inducing diversity.

Proposition 9 *(i) The expected payoff of a buyer in any asymmetric equilibrium of an auction without a reserve price and with full information revelation is lower than in the (symmetric) equilibrium of the optimal tournament.*
(ii) The expected payoff of a buyer in any asymmetric equilibrium of an auction without a reserve price and with full information is lower than in the symmetric equilibrium of the auction.

Proof. (i) The expected payoff of a buyer in the symmetric equilibrium of the optimal tournament corresponds to the expected highest quality in the symmetric equilibrium. The expected payoff of a buyer in the asymmetric equilibrium of the auction corresponds to the expected lowest quality in this equilibrium. The latter is clearly lower than the former. (ii) The expected payoff of a buyer in the symmetric equilibrium of the auction corresponds to the expected lowest quality in the symmetric equilibrium. The expected payoff of a buyer in the asymmetric equilibrium of the auction corresponds to the expected lowest quality in the asymmetric equilibrium. The latter is clearly lower than the former. ■

This discussion suggests that the buyer may sometimes choose design contests that yield lower total surplus than others, because they allow her to appropriate a greater fraction of total surplus. Thus, even though these games might lead to inefficiently low total payoffs, the buyer's surplus may be higher with those institutions than with an efficient alternative. While this argument may sound compelling at first sight, it has limitations. First, one can easily modify any of the remaining games by allowing the buyer to charge an ex-ante participation fee. As long as we continue to assume that the supplier commits to participating in the game if her expected rent (net of fixed costs) is non-negative, then the buyer can extract this rent by asking for an upfront payment corresponding to the rent. She will thus optimally choose the efficient mechanism and use the transfers to appropriate the entire surplus. However, the buyer may not be able to charge substantial entry fees, for instance, because of limited liability constraints (Che and Gale 2003).[6] Second, the buyer needs to make sure that the suppliers break even on expectation, so that they are willing to enter the contest.

6 Negotiations

We have seen that the buyer can induce the socially efficient outcome with an auction with information revelation. However, he has to leave a large surplus to the successful supplier, so that his expected profits are higher with contests that do not induce diversity. In principle, he can solve this problem by charging participation fees from the buyers, but limitations on the set of available transfers may preclude this. In the following, we therefore ask whether alternative procurement institutions might help the buyer to increase her expected payoffs.

In design contests, the buyer commits to paying one of the prizes selected by the suppliers. Instead, we now consider design procurement institutions with *price negotiations*, for which there is no ex-ante commitment of the buyer to a set of prices. The suppliers choose their designs before the state of the world is realized. Then the state is realized, and qualities become common knowledge. We assume that, for any given realization of the quality vector, the negotiation determines a selected supplier and payments from the buyer to the suppliers in a way that is commonly known to all participants.

More formally, the environment $\mathcal{E}^N$ is given by a tuple $(a, b, \Psi, T_1, T_2, \tau)$. Here a, b, Ψ are utility parameters as defined above. T_1, T_2 are sets of allowable uncontingent transfer payments from the buyer to the seller. τ captures the bargaining power of the buyer. The negotiation is characterized by an *allocation mapping* $A^\tau : (q_1, q_2) \mapsto (\{1, 2\}, p_1, p_2)$ assigning to each quality vector a selected supplier and potentially quality-dependent payments from the buyer to the suppliers. We think of this function as mapping the quality vectors on the equilibrium payoffs of an unmodelled negotiation game N.

We make the following assumptions on this negotiation game:

1. In equilibrium, the high-quality design is chosen.

2. The payments are such that the buyer obtains an exogenously determined fraction τ of the additional surplus Δq generated by the high-quality surplus, and this supplier receives the remaining fraction $1 - \tau$. Here τ is a black box parameter capturing the bargaining power of the buyer.

Ignoring fixed costs and transfers, negotiations thus determine payoffs as

$$U^B(q_1, q_2) = \tau \Delta q + \min\{q_1, q_2\}$$

for the buyer and

$$\Pi^i(q_1, q_2) = \begin{cases} (1-\tau)\Delta q & \text{if} \quad q_i > q_j \\ 0 & \text{if} \quad q_i < q_j \end{cases}$$

for the seller.

Corollary 10 *Price negotiations (weakly) implement the social optimum* $\left(v_1^{SO}, v_2^{SO}\right)$.

[6] Risk aversion may also limit the participation fees that buyers can choose, but risk aversion also changes the nature of the design contest itself.

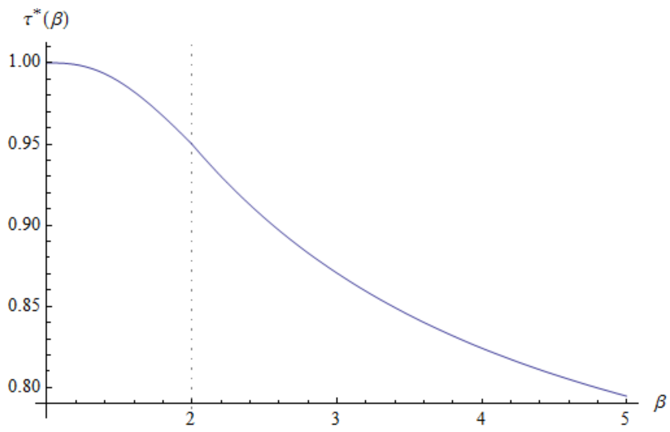

Figure 4: Minimum bargaining power for which buyer prefers negotiations to the optimal tournament.

Proof. See Appendix. ■

In negotiations, the buyer and the higher quality seller bargain over how to split the surplus, that is, how to divide Δq. The successful supplier obtains a share $(1-\tau)$ of the surplus. Thus the transfer to the winning seller is $(1-\tau)\,\Delta q$. With this transfer rule, the mechanism belongs to the class of mechanisms characterized in Proposition 3, with $C = (1-\tau)$. Thus, negotiations weakly implement the socially optimal choice of designs. The distributional properties depend on τ, which is exogenous. No matter what τ is, however, the buyer always prefers negotiations to auctions, because of the outside option of going back to the alternative supplier. Clearly, for sufficiently high bargaining power of the buyer, negotiations are preferable to the optimal tournaments for the buyer. The following results shows how the critical value of bargaining power depends on the other parameters of the problem.

Proposition 11 *Buyer payoffs are higher in the asymmetric equilibrium with price negotiations than in the (symmetric) equilibrium of the optimal tournament if and only if one of the two following conditions hold for* $\beta \equiv \frac{b}{a}$*:*
(i) $1 < \beta < 2$ *and* $\tau > \tau^*(\beta) \equiv \frac{1}{2}\frac{-3\beta+3\beta^2+\beta^3+5}{\beta^3+2}$
(ii) $\beta > 2$ *and* $\tau > \tau^*(\beta) \equiv 2\frac{3\beta+3\beta^2+1}{9\beta^2+4}$

The following figure depicts the critical values $\tau^*(\beta)$ of bargaining power required by the proposition as a function of the relative importance of design fit: When the exogenous asymmetry of firms is sufficiently large (β is not much larger than one, the minimum value of β for which diversity is optimal and sustained by price negotiations), the efficiency gains from inducing diversity are fairly low, and the buyer only prefers negotiations when her bargaining power is very large. As firms become more homogeneous (design adaptation becomes more important), the required bargaining power becomes less important. In the limit (as $\beta \to \infty$), a bargaining power of $\frac{2}{3}$ suffices for buyers to prefer negotiations.

7 Discussion

The preceding analysis suggests how a procurer can efficiently induce diversity of designs: Buyers should use a mechanism where the prize that the successful supplier obtains depends positively on the quality difference to the other supplier. Auctions with full information revelation are a case in point. Institutions without price commitment (where the price is determined in ex-post negotiations) can also implement the socially efficient allocation. Whether auctions or negotiations are preferable for the buyer, depends on her bargaining power in the negotiations. In spite of their potential inefficiency, however, the buyer will often prefer contests that do not induce diversity.

In Section 7.1, we first discuss the robustness of our results. In Section 7.2, we compare our paper with existing work that deals with the relation between procurement mechanisms and effort choices.

7.1 Robustness

7.1.1 Homogeneous suppliers

Though exogenous asymmetry between the suppliers is a very natural assumption, it is instructive to see that most of the analysis goes through with homogeneous buyers. We only use buyer heterogeneity in our analysis of auctions without information revelation. Without Assumption 1 (that the exogenous asymmetry a is sufficiently large relative to the costs b of suboptimal design), the pure-strategy equilibrium would not exist in this case. All other results are still valid when $a = 0$, with the obvious proviso that it is necessary to apply the appropriate parameter restriction in some cases.[7] In particular, therefore, diversity ($v_1 = 1/4$ and $v_2 = 3/4$) is always optimal in this case. Auctions and negotiations with full information revelation weakly implement the socially efficient allocation. In fact, in this case the implementation result is comparatively strong, as the symmetric inefficient equilibria do not exist.

7.1.2 Coordination and mixed strategies

The optimal mechanisms involve multiple asymmetric equilibria for large parameter ranges. While the asymmetry is exactly what is required for social optimality, the multiplicity is a cause for concern. It is unclear how suppliers should coordinate on these equilibria without communication. It might therefore be worth trying to understand whether these mechanisms have mixed-strategy equilibria, and what their properties are. We leave this to future research.

7.1.3 Hidden ex ante information

So far we have emphasized the moral hazard problem of inducing sellers to choose the right action. By contrast, previous literature addressed many aspects of hidden information in the procurement context. These costs are, however, particularly relevant when suppliers can choose between actions that are more or less costly (higher or lower quantity or quality). In the context of the current paper, all actions are equally costly. Of course, one could modify

[7] In Proposition 2, the case $2a < b$ applies, so that $(v_1, v_2) = (1/4, 3/4)$ is optimal. In Proposition 2, the case $3a < b$ applies, so that $(v_1, v_2) = (1/3, 2/3)$ is the equilibrium.

the framework by assuming that different sellers have different fixed costs of design and the buyer does not know these costs. This introduces a rent for low-fixed cost types that the buyer cannot avoid if she wants to induce participation of high-cost types. There are no implications for the relative efficiency of different mechanisms.

Even more fundamentally, one might want to give up the assumption that all designs are equally costly, and sellers might differ with respect to which designs are more or less costly to them. This would clearly necessitate a framework that is much more difficult to analyze than the current one.

7.1.4 Partial Information Revelation

An interesting extension of the current approach is to allow for the case that the quality of each seller is only known to this seller and the buyer. This problem is very difficult. To see this, consider the comparatively simple case of homogeneous suppliers ($a = 0$). A seller who knows his own design choice and quality and assumes a particular design choice of the competitor can draw some inferences about the competitor‘s quality, but he usually does not know exactly what it is. The inferred competitor quality is typically non-monotone in own quality, which makes the problem hard to solve.

7.2 Effort incentives in procurement

Several authors ask how to design procurement mechanisms so as to induce maximal efforts (rather than a variety of approaches). The most comprehensive treatment is Che and Gale (2003). These authors restrict attention to the important case that quality is not verifiable, so that all allowable mechanisms must give the buyer the discretion to select the firm offering the alternative maximizing ex post surplus. The set of allowable mechanisms still includes tournaments and auctions.[8] The authors show that, in a symmetric setting, auctions induce the optimal efforts.

Che and Gale also ask how many suppliers a firm should optimally invite.[9] In their analysis, the optimal number is two.[10] Restricting the number of bidders is useful to induce sufficient investments who need to be sure that they win with a non-negligible probability. While we cannot directly deal with the optimal number of bidders in our setting, it seems clear that there are potential benefits to having more than two players when diversity considerations play a role: At least potentially, the increase in suppliers should add to the diversity of available designs. A precise analysis will be the subject of future work.

8 Conclusions

When buyers procure complex goods, they often do not know the ideal design at the time they ask sellers to invest into providing blueprints. Therefore, it may be optimal to have

[8] Fullerton et al. (2002) also show that first-prize auctions are superior to contests, but they restric attentions to symmetric bidding strategies.

[9] Taylor (1995) and Fullerton and McAfee (1999) discuss the optimal number of bidders , restricting attention to tournaments.

[10] With verifiable quality, the optimal number of firms would be one. A suitable contract would then induce the optimal effort from this firm.

a diversity of designs from which the best one can be chosen ex post. We characterize the optimal ex ante design choice and, in particular, the optimal diversity of designs. We show that the socially optimally design can be obtained with an auction mechanism, provided the bidding takes place after qualities are commonly known. Nevertheless the buyer prefers a fixed-prize tournament that does not induce diversity, because it leaves the sellers with lower rents. We also show that auctions with reserve prizes typically induce less diversity than auctions without reserve prizes. The buyer can potentially benefit from not committing ex ante to a particular mechanism for price determination, but instead leaving the outcome to ex-post price negotiations. In this fashion, she can achieve the socially efficient outcome; if her bargaining power in the negotiations is sufficiently high, she will thereby receive higher payoffs than in a fixed-prize tournament.

Contrary to the existing literature on procurement our paper focusses on two-sided uncertainty about the ideal design for the buyer. It would clearly be interesting to analyze how the insights would differ in a more standard setting where buyers are uncertain about the procurement costs of suppliers. We nevertheless believe that the current analysis provides a helpful ingredient in explaining the occurrence of the wide variety of different approaches to the procurement of complex goods.

References

Asker, John and Estelle Cantillon (2008), "Properties of scoring auctions." *The RAND Journal of Economics*, 39, 69-85.

Asker, John and Estelle Cantillon (2010), "Procurement when price and quality matter." *The RAND Journal of Economics*, 41, 1-34.

Bajari, Patrick and Steven Tadelis (2001), "Incentives versus transaction costs: A theory of procurement contracts." *The RAND Journal of Economics*, 387-407.

Che, Yeon-Koo (1993), "Design competition through multidimensional auctions." *The RAND Journal of Economics*, 24, 668-680.

Crickmore, Paul (2003), *Nighthawk F-117: Stealth Fighter.* Airlife Publishing Ltd.

Kaplan, Todd R. (2012), "Communication of preferences in contests for contracts." *Economic Theory*, 51, 487-503.

Lazear, Edward P. and Sherwin Rosen (1981), "Rank-order tournaments as optimum labor contracts." *The Journal of Political Economy*, 89, 841-864.

Pérez-Castrillo, David and David Wettstein (2001), "Bidding for the surplus: a noncooperative approach to the shapley value." *Journal of Economic Theory*, 100, 274-294.

Royal Institute of British Architects (RIBA) (2013), "Design competitions guidance for clients." URL http://competitions.architecture.com/requestform.aspx.

Tirole, Jean and Jean-Jacques Laffont (1993), *A theory of incentives in procurement and regulation.* MIT Press.