HOW (NOT) TO DESIGN PROCUREMENT MECHANISMS: A LABORATORY EXPERIMENT

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ABSTRACT. In this paper, we examine the relative performance of three commonly used procurement mechanisms: price-only auctions, scoring auctions, and benchmarking. We do so both in theory and in a laboratory experiment. We find that the auctions yield the same level of welfare, and welfare dominate benchmarking. In theory, the "pie" is shared the same in both auctions between buyer and suppliers, and both the buyer and suppliers obtain higher utility than in benchmarking. In contrast, in our experiment, we observe that the price-only auction generates higher supplier utility than the scoring auction, while the scoring auction dominates the price-only auction in terms of expected profit for the buyer. We do find support for the underperformance of benchmarking versus the auctions.

INTRODUCTION

Three commonly used procurement mechanisms are price-only auctions, beauty contests, and benchmarking. In a price-only auction, the buyer rewards the project to the cheapest supplier. Practical examples include school milk tenders (Porter and Zona, 1999, and Pesendorfer, 2000) and infrastructure procurement (Porter and Zona, 1993, and Boone et al., 2007). In a beauty contest, the suppliers submit bids on several dimensions, which may include the payment they wish to receive from

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the buyer, quantity, and quality. The buyer allocates the project to the buyer with the most interesting offer. The US government procures weapon systems using beauty contests (Che, 1993).[1] In a benchmark, each supplier first completes a similar project. The buyer rewards the project to the supplier with the best relative performance in her project. Welfare-to-work projects are allocated this way in Australia (OECD, 2001).

The co-existence of these mechanisms gives rise to the following questions:

- How much do suppliers "bid" in each mechanism?
- Which mechanism generates the highest utility for the buyer?
- Which mechanism generates the highest profit for the suppliers?
- Which mechanism is the most efficient, i.e., generates the highest welfare?

These questions are not only of academic interest. Procurement is big business, both in the public domain (B2G) and in the private one (B2B). In 2002, total expenses on public procurement in the European Union amounted to roughly €1500 billion, i.e., 16% of GDP (European Commission, 2004). Examples of public procurement range from school milk (Porter and Zona, 1999, and Pesendorfer, 2000), to welfare-to-work services (OECD, 2001, and Onderstal, 2006), infrastructure (Porter and Zona, 1993, and Boone et al., 2007), and weapon systems (Che, 1993). Moreover, many firms apply procurement to buy goods, including Convisint, FreeMarkets, General Electric, Mars (Chen-Ritzo et al., 2005), and DaimlerChrysler (Burmeister et al., 2002), the latter having an annual procurement volume of 10 billion Euros.

In this paper, we aim to answer the above questions, both in theory and in a laboratory experiment. We compare prototypes of price-only auctions, beauty contests, and benchmarking. As price-only auction, we study the first-price sealed-bid auction (FP). The highest bidder wins the project and is rewarded for each unit of output she produces in the project. We model a beauty contest as a scoring auction (SA) in which each supplier submits bids on two dimensions: the output she will deliver if she wins the project and the payment she wishes to receive in return. The buyer assigns the project to the supplier whose bid results in the highest non-negative score (a well-defined function of these bids).[2] We model the benchmark as follows. The benchmark (BM) consists of two periods. In period 1, each supplier exerts effort in a project. The supplier expending the highest effort wins a project in period 2. The buyer pays the winner proportional to each unit of output she delivers in the second period.

The structure of our model is as follows: Suppliers compete to win a project, the winning supplier can exert costly effort in the project, which increases the buyer's utility. Suppliers differ in terms of efficiency. We will answer the above questions in two environments: a deterministic one, in which output equals effort, and a stochastic one, in which output equals effort plus a disturbance term. Output is broadly interpreted: cost reduction, delivery time, quality, quantity, and so forth. In the context of welfare-to-work programs, the disturbance term could capture the business cycle, uncertainty about the quality of the unemployed people in the project, and so forth.

Our main theoretical results are the following. FP and SA are outcome equivalent in the sense that both mechanisms generate the same utility for the buyer, the same profit for the suppliers, and the same welfare. In all three mechanisms, the most efficient supplier always wins in equilibrium. FP and SA dominate BM in terms of per project utility for the buyer, profit for the suppliers, and welfare.

Our experiment confirms most, but not all, of these theoretical predictions. FP and SA are equally efficient and both are more efficient than BM. SA yields higher expected utility for the buyer than FP and BM. FP yields weakly higher expected utility for the buyer than BM. FP generates higher expected supplier profit than SA and BM. SA yields weakly higher expected utility for the buyer than BM.

The set-up of the remainder of this paper is as follows. In the next subsection, we discuss the literature that is related to our paper. Section 2 includes the theoretical predictions. In Section 3, we describe our experimental design. In Sections 4 and 5, we discuss the experimental results on an aggregate level and an individual level respectively. Section 6 contains a conclusion. Proofs of propositions and corollaries are relegated to Appendix A.1.

RELATED LITERATURE

Our paper is related to several branches of the literature. First of all, it contributes to the large literature on practical procurement design.[3] Our experiment complements this literature, which is largely theory and case study driven. In order to have a clean comparison between procurement mechanisms, our experimental design abstracts from many issues which are relevant in procurement design, such as attracting and screening bidders, preventing collusion, and post procurement incentives. This literature shows that these issues can all be vital for the success or failure of a procurement mechanism, regardless of the format chosen.

From the theoretical literature, the following results are relevant for our study. First, the mechanism that maximizes the supplier's expected profit has the following properties (McAfee and McMillan, 1986, 1987, and Laffont and Tirole, 1987, 1993): The buyer (1) screens out all suppliers whose efficiency level is below some threshold, (2) gives the winner incentives to provide less effort than in the full-information optimum, and (3) covers more than the winner's costs for the project. A scoring auction can implement a mechanism that maximizes the buyer's expected utility (Che, 1993), in contrast to price-only auctions where the supplier's output is fixed ex ante and beauty contests (Asker and Cantillon, 2008). The reason that price-only auctions with pre-determined output levels are not optimal is that in the optimal contract, output depends on the winner's efficiency level. Beauty contests are not optimal because the buyer cannot credibly commit to screening out bidders or requiring them to deliver less effort then in the full-information optimum.

However, the optimal scoring auction has several practical limitations. For instance, to screen out the least efficient bidders requires the buyer to know the suppliers' cost structure and the distribution function from which they draw their efficiency levels. In practice, such information is not easy if not impossible to acquire. In addition, the optimal mechanism is demanding with regards the buyer's commitment: it (1) requires an ex post suboptimal level of effort from the winning supplier, and (2) the buyer to withhold a welfare enhancing project when the efficiency parameter of all suppliers turns out to be below a certain threshold value. Indeed, for practical mechanism design, Wilson (1987) strongly advocates the implementation of "detail-free" mechanisms, i.e., mechanisms of which the rules do not depend on the above mentioned peculiarities of the environment. In this paper, we compare "detail-free" procurement formats.

We are not the first to study the relative performance of procurement mechanisms in a laboratory experiment. There is a substantial experimental literature on price-only auctions (for an overview, see Kagel, 1995). One important insight from this literature is that mechanisms that are in theory outcome equivalent may yield different outcomes in the lab. In our setting, the first-price sealed-bid auction and the scoring auction are outcome equivalent. So, the earlier experiments on price-only auctions indicate that a priori it may still be the case that one mechanism outperforms the other. Chen-Ritzo et al.'s (2005) experiment is the most closely related to ours. They observe that scoring auctions outperform price-only auctions. In contrast to our experiment, the buyer ex ante fixes the output delivered by the winner. In this sense, our experiment yields a "fairer" comparison between the two mechanisms because in the setting of Chen-Ritzo et al., scoring auctions outperform price-only auctions in theory (Asker and Cantillon, 2008).

THEORY

A risk neutral buyer wishes to procure an indivisible project. We assume that n risk neutral suppliers participate in the procurement. Each supplier i, $i = 1, ..., n$, upon winning the project, is able to expend effort e_i at cost $C_i = C(e_i, t_i)$ where t_i is supplier i's efficiency level.[4] We assume that $C(e,t) = e^2/(2ct)$ where $c > 0$ is a scaling parameter. The suppliers draw the t_i's independently from the uniform distribution on the interval $[a, b]$, $b > a > 0$.

Supplier i has the utility function $U_i = T_i - C_i$ where T_i is the monetary transfer that she receives from the buyer. The output m_i of supplier i if she wins the project equals $m_i = e_i + \varepsilon$, where ε represents "the state of the economy". We assume that ε is a random variable with mean zero and finite variance and that the winner is only informed about ε after she has chosen her effort level. The buyer only observes m_i, i.e., he cannot observe e_i or ε. The buyer's utility equals $U_B = sm_i - T_i$, where $s > 0$ denotes the marginal benefits for the buyer of the supplier's output. Note that $\mathrm{E}\{m_i\} = e_i$, so that a risk neutral buyer aims at maximizing $\mathrm{E}\{U_B\} = e_i - T_i$.

Let S denote net social welfare of the project. Net social welfare is given by $S = U_B + \sum_i U_i$. For the sake of simplicity, we assume that transfers between the buyer and a supplier are welfare neutral. A mechanism is called efficient if S is maximized. A socially optimal mechanism maximizes expected social welfare under the restriction that the suppliers play a Bayesian Nash equilibrium, and under a participation constraint (each participating supplier should at least receive zero expected utility). Because transfers from the buyer to the suppliers are welfare neutral, the optimal mechanism can be readily constructed. First of all, the buyer selects the most efficient supplier, i.e., the supplier with the highest type t_i. Secondly, the buyer induces this supplier to exert effort $e^*(t_i)$ for which

$$e^*(t_i) = cst_i \tag{1}$$

We assume that $\varepsilon > -csa$, so that for the winner's output it holds true that

$$m_i = e^*(t_i) + \varepsilon \geq e^*(a) + \varepsilon = csa + \varepsilon > 0 \tag{2}$$

Finally, the buyer pays a transfer to the suppliers such that all suppliers receive at least zero expected utility in equilibrium. Note that the socially optimal mechanism is efficient.

The buyer can implement the socially optimal mechanism using the first-price sealed-bid auction (FP). FP consists of two periods. In the first period, suppliers independently submit bids. The highest bidder wins the project, and pays her bid. In the second period, the highest bidder exerts effort in the project and receives $T = m\tau_f$ if her output equals m, where $\tau_f > 0$ is the per unit transfer to the winning supplier. The following proposition establishes that FP is efficient if $\tau_f = s$.

Proposition 1. In the unique subgame perfect Nash-equilibrium of FP, a supplier with efficiency parameter t bids.

$$B^{FP}(t) = (1/2)(\tau_f)^2[t - (t - a)/n] \tag{3}$$

If she wins the project, her effort level will be

$$e^{FP}(t) = ct\tau_f \tag{4}$$

The most efficient supplier wins the project. FP implements the socially optimal mechanism if $\tau_f = s$.

Che (1993) shows that also a "scoring auction" (SA) can implement the socially optimal mechanism. In SA, bidders submit bids on several dimensions and the auctioneer assigns the project to the bidder submitting the highest non-negative score (a well-defined function of these bids). In our setting, these dimensions are the supplier's effort e and payment T. The scoring function is $\sigma(e, T) = \tau_s e - T$, where $\tau_s > 0$. The project will be assigned to the supplier with the highest score, unless the score is negative. In the latter case, the project will not be assigned. If the output of the winning supplier is above [below] the effort in her bid, she will get a bonus [malus] equal to τ_s for each unit of output above [below] her effort level. Proposition 2 establishes that the following SA implements the socially optimal mechanism if $\tau_s = s$.

Proposition 2. In the equilibrium of SA, a supplier with efficiency parameter t bids.

$$\{e^{SA}(t), T^{SA}(t)\} = \{ct\tau_s, (1/2)(\tau_s)^2[t + (t - a)/n]\} \qquad (5)$$

The most efficient supplier wins the project. SA implements the socially optimal mechanism if $\tau_s = s$.

The following corollary follows immediately from Propositions 1 and 2. The observation that FP and SA are utility equivalent follows from the facts that both mechanisms are efficient, $e^{FP}(t) = e^{SA}(t)$, and $se^{FP}(t) - B^{FP}(t) = T^{SA}(t)$ if $\tau_s = s$, so that effort and the net payments in both mechanisms coincide.

Corollary 1. If $\tau_f = \tau_s = s$, FP and SA are efficient and generate the same expected utility for the buyer and the suppliers.

Next, we study a benchmark (BM). A benchmark consists of two periods. In period 1, each supplier exerts effort in a project. The supplier expending the highest effort wins a project in period 2. For the sake of simplicity, we assume that period 1 is deterministic, i.e., $P\{\varepsilon = 0\} = 1$, so that it is always the supplier with the highest effort in period 1 who gets the project in period 2. Suppose that a supplier obtains $t_1^{BM}(m_1) = 0$ and $t_1^{BM}(m_2) = m_2\tau_b$ in periods 1 and 2 respectively if her output equals m_1 and m_2 respectively, where $\tau_b > 0$.

Proposition 3 *BM has an equilibrium in which a supplier with efficiency parameter t exerts effort*

$$e_1^{BM}(t) = c\tau_b \sqrt{\frac{n-1}{(b-a)^{n-1}} \int_a^t x^2 (x-a)^{n-2} dx}\text{, and} \tag{6}$$

$$e_2^{BM}(t) = c\tau_b t \text{ in periods 1 and 2 respectively.} \tag{7}$$

The most efficient supplier wins the contract for the second period. BM implements the optimal mechanism in period 2 if $\tau_b = s$.

Corollary 2. If $\tau_b = s$, BM is inefficient in the first period and efficient in the second one.

In order to compare the buyer's and the suppliers' expected utility in BM and the other two mechanisms, it seems natural to evaluate their per project expected utility. BM consists of $n + 1$ projects, n in period 1 and one in period 2. In other words, a "fair" comparison between BM on the one hand and FP and SA on the other requires comparing BM with $n + 1$ projects in FP or SA. We compare the three mechanisms under the condition that $\tau_f = \tau_s = \tau_b = s$, i.e., in situations where the winning supplier delivers the first-best optimal output.

Corollary 3. If $\tau_f = \tau_s = \tau_b = s$, both the buyer's and the suppliers' per project expected utility in BM are lower than in FP and SA.

EXPERIMENTAL DESIGN

In a computerized laboratory experiment, we studied FP, SA, and BM in a setting that is closely related to our theoretical model. We used the following parameters: $n = 2$, $[a, b] = [50,100]$, $c = 1/50$, and $\tau_f = \tau_s = \tau_b = s = 10$. The two main differences between the model and the experimental design are the following. First, the efficiency parameters were drawn according to a uniform distribution on a grid between 50 and 100 with 1 as the smallest step instead of from the entire interval. Second, we approximated the continuous bidding and effort spaces with grids with 1 as the smallest step.

The experiment was conducted at the University of Amsterdam in May 2007. It consisted of three treatments: FP, SA, and BM. We held six sessions, two sessions for each treatment, resulting in a between-subject design. In all sessions, the subjects were separated in groups of four. A session consisted of four parts. In the first two parts, all subjects obtained

TABLE 1
Experimental Design

Treatment	# Groups	# Subjects per group
First-price auction (FP)	6	4
Scoring auction (SA)	9	4
Benchmark (BM)	7	4

a project and were paid ten points for each unit of output. These parts can be seen as practice rounds in which subjects could learn to find the optimal effort in a project and to calculate the profitability of a project. In parts 3 and 4, subjects first competed in an allocation mechanism, and only the winner participated in the project. Parts 1 and 2 [3 and 4] consisted of 5 [10] rounds each. In parts 1 and 3, we confronted subjects with a deterministic environment in which $P\{\varepsilon = 0\} = 1$, while in parts 2 and 4, subjects competed in a stochastic environment in which $P\{\varepsilon = -2\} = P\{\varepsilon = 0\} = P\{\varepsilon = 2\} = 1/3$. Before the start of each round, the subjects were randomly re-matched to another player in their group of four, resulting in 6 (9) [7] independent observations for FP (SA) [BM]. In each period, all subjects drew a new efficiency parameter.[5] Tables 1 and 2 summarize our experimental design.

We paid subjects a lump sum transfer of €5 for showing up and an additional reward equivalent to their earnings during the auctions.[6] In the

TABLE 2
Experimental Design: Organization of the Treatments

Part	Competition?	Environment	Economy	# Rounds
1	No	Deterministic	$P\{\varepsilon = 0\} = 1$	5
2	No	Stochastic	$P\{\varepsilon = -2\} = P\{\varepsilon = 0\} = P\{\varepsilon = 2\} = 1/3$	5
3	Yes	Deterministic	$P\{\varepsilon = 0\} = 1$	10
4	Yes	Stochastic	$P\{\varepsilon = -2\} = P\{\varepsilon = 0\} = P\{\varepsilon = 2\} = 1/3$	10

parts 1 and 2 [3 and 4], we exchange points into cash according to the exchange rate:

200 points = EUR 1

[20 points = EUR 1].

If the subjects had played according to the equilibrium strategies, they would have earned €16.40 [€24.50] on average including show-up fee in FP and SA [BM]. In turned out that in FP (SA) [BM], subjects earned €17.04 (€14.42) [€19.11] on average in approximately 2 (2.5) [2.5] hours including the show-up fee.

In order to help subjects better understand the environment, we programmed calculators that allowed subjects to calculate their profits conditional on winning and effort level. Moreover, we showed them a visual aid that depicted their marginal costs of effort. For more details, see the translation of the instructions in Appendix A.3. After the subjects finished reading the instructions, they had to answer test questions so that we could be sure that they understood the rules of the game.

RESULTS: AGGREGATE DATA

Obviously, parts 3 and 4 are the most relevant parts to study the relative performance of FP, SA, and BM. Table 3 below presents the aggregate outcomes of the mechanisms in terms of welfare, the buyer's utility, and the suppliers' profit. Table 4 includes results of Mann-Whitney U tests to establish whether differences between mechanisms are statistically significant.

The following conclusions emerge if we consider differences statistically significant at the 10%-level. Let us first consider efficiency. FP and SA are equally efficient. Both mechanisms generate a similar level of welfare: 77.71 [77.64] for FP [SA]. The experiment hence confirms the theoretical result from section 2. Both FP and SA are more efficient than BM. BM's per period welfare in the experiment equals 55.64. This is even more inefficient than the theoretical outcome (64.71). These outcomes hold for both the deterministic and stochastic parts of the experiment.

TABLE 3
Aggregate Results

	Environ-ment	**FP**		**SA**		**BM**	
		Theory	Obs.	Theory	Obs.	Theory	Obs.
	Det.	82.5	79.37	82.5	79.63	68.22	59.8
Welfare	Stoch.	78.4	76.05	78.4	75.65	61.2	51.48
	Total	80.45	77.71	80.45	77.64	64.71	55.64
Utility buyer	Det.	66.25	62.98	66.25	69.51	59.35	58.45
	Stoch.	64.2	59.31	64.2	62.92	49.13	38.76
	Total	65.23	60.98	65.23	66.22	54.24	48.69
Utility sellers	Det.	16.25	16.4	16.25	10.12	8.87	1.35
	Stoch.	14.2	17.06	14.2	12.73	12.07	12.71
	Total	15.23	16.73	15.23	11.42	10.47	6.95

Note: "Obs." stands for "observed", "Det." for "deterministic", and "Stoch." for "stochastic".

TABLE 4
Results of Mann-Whitney U Tests

		Deterministic	**Stochastic**	**Total**
	SA ≠ FP	p = 0.953	p = 0.637	p = 0.768
Welfare	SA > BM	p = 0.000	p = 0.000	p = 0.000
	FP > BM	p = 0.001	p = 0.001	p = 0.001
Utility buyer	SA > FP	p = 0.056	p = 0.131	p = 0.070
	SA > BM	p = 0.013	p = 0.000	p = 0.000
	FP > BM	p = 0.117	p = 0.001	p = 0.004
Utility sellers	FP > SA	p = 0.034	p = 0.044	p = 0.014
	SA > BM	p = 0.007	p = 0.416	p = 0.028
	FP > BM	p = 0.001	p = 0.037	p = 0.001

Note: The second column presents the alternative hypothesis. p is the p-value.

Conclusion 1. FP and SA are equally efficient. Both mechanisms are more efficient than BM.

What about the utility of the buyer? SA dominates FP in terms of buyer's utility. This result is not in line with the theoretical outcome of utility equivalence. The level of utility for the buyer in SA in the experiment exceeds the theoretical outcome. This is due to the results in the deterministic part: 69.51 [66.25] in the experiment [theory]. The level of utility for the buyer in FP in the experiment, on the other hand, lies below the theoretical level. SA dominates BM in line with the theory. However, this is entirely due to a low level of buyer utility for BM in the stochastic part of the experiment: 38.76 vs. 58.45 in the deterministic part, with the latter almost equal to theory. FP also dominates BM but not in the deterministic part of the experiment. The difference between FP and BM is not statistically significant. This is due to the fact that FP performs below theory whereas BM equals the theoretical outcome.

Conclusion 2. SA yields higher expected utility for the buyer than FP and BM. FP yields the same [higher] expected utility for the buyer as [than] BM in the deterministic [stochastic] environment.

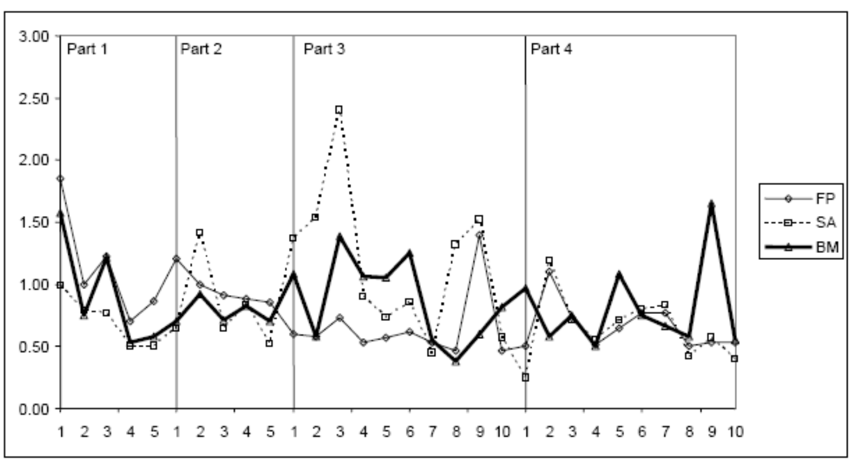
Finally, we consider the suppliers' profits. Since the total pie in FP and SA is equal, the results of the experiment in terms of profits for the suppliers in both mechanisms is the mirror image of the buyers' utility. Hence FP dominates SA and this result is statistically significant both in the deterministic and stochastic environments. Now it applies for FP that the results of the experiment exceed the theoretical results whereas this is not the case for SA. SA dominates BM albeit that this outcome is not statistically significant in the stochastic part. This relates to the high outcome for BM. In fact, BM scores in the stochastic part of the experiment even higher than theory. SA on the other hand, performs less than in theory in both the stochastic and deterministic environments. BM however, has an extremely low suppliers' profit in the deterministic part, corresponding to a high buyers' utility for BM in that part. Hence, in the deterministic environment SA dominates BM. FP dominates BM in terms of profit for the suppliers.

Conclusion 3. FP generates higher expected supplier profit than SA and BM. SA yields higher [the same] expected utility for the buyer than [as] BM in the deterministic [stochastic] environment.

RESULTS: INDIVIDUAL DATA

In this section, we will further explain the above aggregate observations on the basis of individual subjects' behavior. We begin with the subjects' effort choices. For BM, we only focus on effort in the second period for the moment. Figure 1 depicts the absolute difference between observed effort and the optimal effort level in parts 3 and 4. The data reveal that subjects stay close to the dominant strategy in both parts in each mechanism. The average absolute difference between the profit maximizing effort and the actual effort is always less than 2, apart from round 3 in part 3 of SA. There are two reasons why the actual effort levels deviate somewhat from the optimal ones. First, subjects could only enter integers, while the optimal effort levels are typically not an integer. Second, profits were rounded to the nearest integer. Because profit as a function of effort is flat at the optimum, effort levels one or two units above or below the optimal one could still generate (almost) the optimal profit level. So, we can safely conclude that subjects understood very well which effort level maximizes profits. In other words, differences between the three mechanisms are mainly explained by the subjects' bidding behavior.

FIGURE 1
Effort Relative to the Optimal Effort Level in Parts 3 and 4

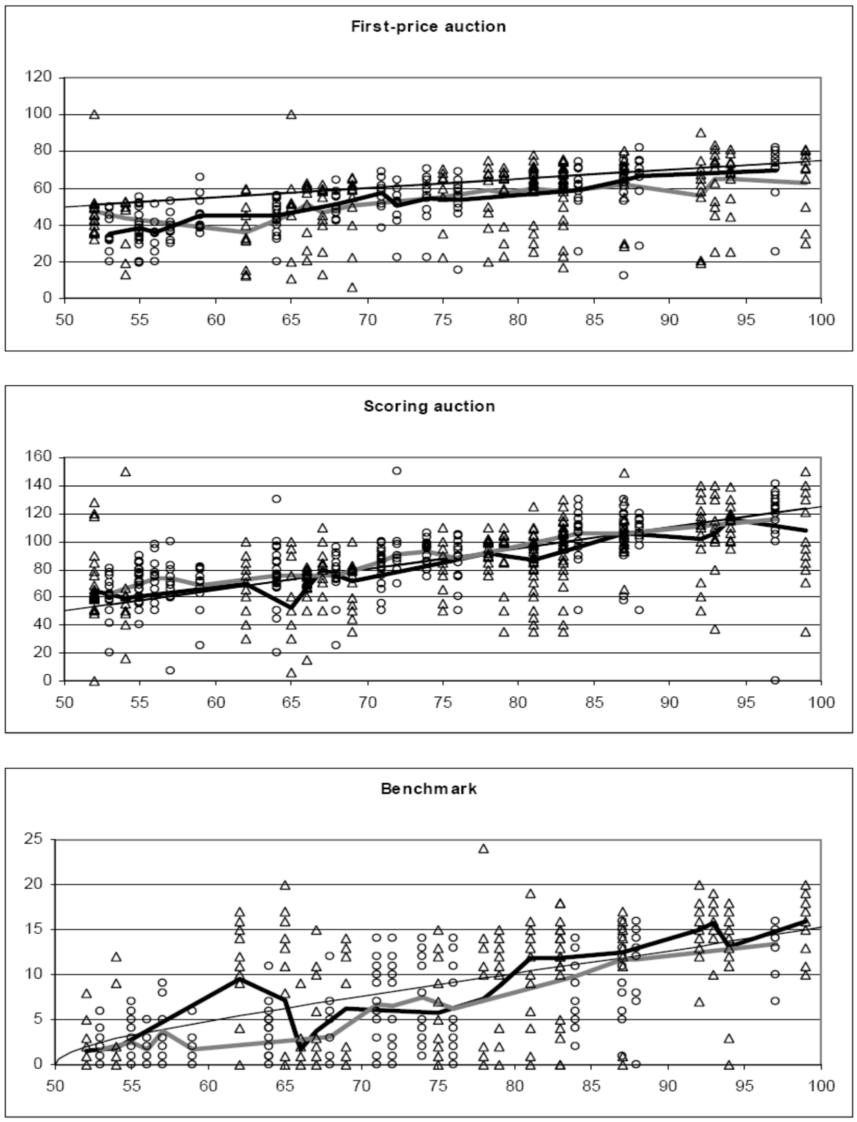


Legend: The figure depicts the average absolute difference between optimal and observed winner's effort.

Figure 2 reveals that average bids in all three mechanisms are close to equilibrium levels. The main deviation holds for FP, where average bids are somewhat lower than what the theory predicts. Note that only in BM, there are noticeable differences between the deterministic and stochastic environments. When players are risk averse we expect to find more cautious bidding in the stochastic environment. In FP and BM lower bids indicates more cautious bidding, whereas in SA the opposite is the case. Observe that in all three mechanisms there is at least some hint of less aggressive bidding, because the grey line lies somewhat below [above] the bold black one in FP and BM [SA]. The effect is most substantial in BM. Figure 2 also shows quite some variation in the bids in the sense that suppliers with the same efficiency level submit different bids. Therefore, it is unlikely that always the more efficient supplier wins, in contrast to what we find in theory. Indeed, Table 5 indicates that this is the case.

The above observations explain most of our findings in the previous section. First of all, we noted that FP and SA are equally efficient, and that they dominated BM in terms of efficiency. Moreover, in both SA and FP, the welfare level is close to the theory, while in BM it is substantially lower (12% and 16% in the deterministic and stochastic environments respectively). In section 2, we established that full efficiency will emerge if the buyer always selects the most efficient supplier, and let her exert effort according to (1). Because the winning supplier's effort is close to optimal, SA and FP are equally efficient if they are equally likely to pick the most efficient supplier. Table 5 shows that this is roughly the case, although FP is somewhat more likely to select the most efficient supplier. Indeed, both mechanisms are very efficient despite the fact that only in about 75% of the cases the most efficient bidder wins. This indicates that the mechanisms are robust in the sense that the welfare losses are relatively small when the buyer does not award the contact to the most efficient supplier. The observation that subjects stayed close to equilibrium bids on average explains why in the experiment, FP and SA dominate BM in terms of welfare: Corollaries 1 and 2 imply that this result holds true. Moreover, Table 3 indicates that the theoretical differences between FP and SA on the one hand and BM on the other are substantial, which is indeed what we observe in the experiment.

FIGURE 2
Bids in FP, SA, and BM



Legend: Open triangles [circles] indicate observed bids in the deterministic [stochastic] environment. The bold black [grey] line connects average bids conditional on efficiency type in the deterministic [stochastic] environment. The thin line depicts the risk neutral Nash equilibrium bids.

TABLE 5
Fraction More Efficient Seller Wins

Mechanism	Deterministic	Stochastic	Total	Theory
FP	74.2%	80.0%	77.1%	100%
SA	81.7%	76.7%	79.2%	100%
BM	67.9%	80.7%	74.3%	100%

While FP and SA are equally efficient in the sense that the pie to be divided among the supplier and the buyers is about the same, the suppliers obtain a larger share in FP than in SA. The main reason is the following. Figure 2 indicates that average bids in SA are at the equilibrium level, while those in FP are somewhat lower than the equilibrium level. Corollary 1 shows that FP and SA would have resulted in the same expected profit for the sellers if they had played according to equilibrium. Because the winning suppliers in FP pay their bids to the buyer, a below equilibrium bid implies that the sellers' utility is higher than in equilibrium. In BM, the pie is divided quite differently between the two environments. BM leaves the supplier with a much lower share of the pie in the deterministic environment than in the stochastic one. The main explanation is that suppliers bid aggressively in the deterministic environment, often above equilibrium levels, while bidding more cautiously in the stochastic environment.

CONCLUSIONS

In this paper, we have examined the relative performance of three procurement mechanisms: price-only auctions, scoring auctions, and benchmarking. We have done so both in theory and in the lab. Our main theoretical results are the following. FP and SA are outcome equivalent in the sense that both mechanisms generate the same utility for the buyer, the same profit for the suppliers, and the same welfare. In all three mechanisms, the most efficient supplier always wins in equilibrium. FP and SA dominate BM in terms of per project utility for the buyer, profit for the suppliers, and welfare.

Our experiment confirms most, but not all, of these theoretical predictions. FP and SA are equally efficient and both are more efficient than BM. SA yields higher expected utility for the buyer than FP and BM.

FP yields weakly higher expected utility for the buyer than BM. FP generates higher expected supplier profit than SA and BM. SA yields weakly higher expected utility for the buyer than BM.

We have to be careful before translating our conclusions into policy recommendations because we tested various mechanisms in an artificial environment. For instance, our experimental results suggest that for the buyer, beauty contests are the preferred mechanism. One important caveat is that we modeled beauty contests as a scoring auction, which do not have the practical feature of beauty contests that, by definition, include subjective award criteria. This renders beauty contests less efficient than scoring auctions because hidden supplier characteristics and perceptions as to how to assess certain aspects in the tender become important in the award process. Another caveat is that in the scoring auction in our experiment, we forced the winner to exert the effort level that she had announced in her bid. Reneging was not an option, while in most beauty contests in practice, this is more an exception than a rule. It is not straightforward that the winning firm will put in as much effort as promised, since the buyer has no means to monitor this. In the face of moral hazard, hence, beauty contests may perform worse than our experiment suggests.

Another dimension in which our experiment may deviate from procurement settings in practice is its one-shot nature. Although subjects compete in several periods, we still have a one-shot design because we rematch students after every round of interaction. In practice, the same suppliers may interact repeatedly in subsequent transactions. As is well known from the game theory literature, repeated interaction may induce collusion among players, and hence change the outcome of the game. (See e.g., Friedman, 1971). Therefore, it could be the case that one procurement mechanisms is more conducive to collusion than another, so that it is not clear whether the conclusions of our experiment still hold. However, also in practice it is often the case that it is not the same sellers who compete, so that our results may still have practical appeal. Moreover, the buyer has several instruments available to prevent collusion, such as using a lowest-price format instead of a second-lowest price format, implementing a serious maximum price, and information disclosure about submitted bids (See, e.g., Albano et al., 2006; Kovacic et al., 2006; and Onderstal and Felsö, 2008).

Indeed, for further research, the following question begs for an answer: To which extent can our theoretical results and observations in the lab be extrapolated to practice? It would be interesting to test the relative performance of the above mechanisms in field experiments. As Levitt and List (2006) argue, laboratory experiments are useful when providing qualitative evidence, and is often the preferred first step when ranking mechanisms. Indeed, we consider our experiment as a point of departure, and by no means the final destination, in a line of research.

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NOTES

1. A price-only auction is sometimes referred to as a request for bids (RFB), and a beauty contest as a request for proposals (RFP). For a further discussion of the differences between the two mechanisms, see Thai (2004).
2. To avoid confusion, we will speak about a scoring auction instead of a beauty contest, because the rules in a beauty contest, by definition, are to some extent subjective, in contrast to the mechanism we have just described.
3. For recent overviews, see the handbooks by Dimitri et al. (2006) and Thai (2008).
4. Note that we assume one dimensional types. Asker and Cantillon (2008) show that this is not necessarily with loss of generality. Many multi-dimensional types problems are essentially one-dimensional. In such models, a vector of types can be substituted by a "pseudo-type."
5. For the sake of comparability of the results, we kept draws constant across treatments. Appendix A.2 contains the parameters drawn for parts 3 and 4.
6. Paying every period as we did induces behavior towards risk neutrality. Paying according to one randomly selected period, instead,

may increase subjects' willingness to take risks (Davis and Holt, 1993).

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APPENDIX
A.1 Proofs of Propositions

Proof of Proposition 1. If a supplier with efficiency level t wins the project, it is easy to check that her optimal effort is $e^{FP}(t) = ct\tau_f$. Her expected profit in the second period equals $ct(\tau_f)^2/2$ so that the profits are distributed according to a uniform distribution on the interval $[ca(\tau_f)^2/2, cb(\tau_f)^2/2]$. Because a supplier's profit represents the value of winning the auction, it is straightforward to check that B^{FP} constitutes an equilibrium strategy. Maskin and Riley (2003) show that this equilibrium is unique. It is readily verified that FP implements the optimal mechanism if $\tau_f = s$.

Proof of Proposition 2. For a given score σ, supplier i chooses effort e and transfer T solving

$$\max_{e,T} T - C(e, t_i) = T - e^2/(2ct_i)$$

$$\text{s.t. } \sigma(e, T) = \tau_s e - T = \sigma.$$

Substituting $T = \tau_s e - s$, the problem becomes

$$\max_e \tau_s e - \sigma - (e^2)/(2t_i).$$

Observe that $e^{SA}(t_i) = c\tau_s t_i$ is a solution. Note that this solution does not depend on σ or T. If supplier i wins, her utility equals

$$T - C(e^{SA}(t_i), t_i) = \tau_s e^{SA}(t_i) - \sigma - C(e^{SA}(t_i), t_i) = ct(\tau_s)^2/2 - \sigma.$$

Suppose that in equilibrium, $\sigma^*(t) \equiv \sigma(e^{SA}(t), T^{SA}(t))$ is increasing in t. If a supplier acts as if having signal t' instead of her true signal t, her expected utility is

$$U^{SA}(t,t') = \left[\frac{t'-a}{b-a}\right]^{n-1}\left[\frac{c(\tau_s)^2 t}{2} - \sigma^*(t')\right],$$

Where the first term in the product on the RHS refers to the winning probability, and the second to the expected utility conditional on winning.

The first-order condition of the equilibrium is

$$\left.\frac{\partial U^{SA}(t,t')}{\partial t'}\right|_{t'=t} = 0$$

which implies

$$(n-1)\left[\frac{c(\tau_s)^2 t}{2} - \sigma^*(t)\right] - \sigma^{*\prime}(t)(t-a) = 0\,.$$

It is readily verified that

$$\sigma^*(t) = \frac{c(\tau_s)^2}{2}\left[t - \frac{t-a}{n}\right]$$

is a solution, which implies that

$$T^{SA}(t) = \tau_s e^{SA}(t) - \sigma^*(t) = \frac{c(\tau_s)^2}{2}\left[t + \frac{t-a}{n}\right].$$

Observe that $\sigma^*(t) \geq 0$ for all t, and that σ is strictly increasing in t, so that the outcome of SA is efficient. It is readily verified that SA implements the optimal mechanism.

Proof of Proposition 3. If a supplier with efficiency level t wins the project, her optimal effort in period 2 is $e^{BM}(t) = ct\tau_b$. Her profit in the second period equals $t(\tau_b)^2/2$. In period 1, if a supplier acts as if she has signal t' instead of t, her expected utility is

$$U^{BM}(t,t') = \frac{c(\tau_s)^2 t}{2}\left[\frac{t'-a}{b-a}\right]^{n-1} - \frac{e_1^{BM}(t')^2}{2ct}\,.$$

The first-order condition is

$$\left.\frac{\partial U^{BM}(t,t')}{\partial t'}\right|_{t'=t} = 0$$

which implies

$$(n-1)(ct\tau_s)^2 \frac{(t'-a)^{n-2}}{(b-a)^{n-1}} = \frac{\partial(e_1^{BM}(t))^2}{\partial t}.$$

It is readily verified that (7) is the unique solution for which the boundary condition

$$e_1^{BM}(a) = 0$$

holds true. Observe that if $\tau_b = s$, social welfare in the second period is maximized because the most efficient supplier is selected, and

$$e_2^{BM}(t) = e^*(t).$$

Proof of Corollary 2. For all $t \in [a, b]$,

$$\begin{aligned} e_1^{BM}(t) &= cs\sqrt{\frac{n-1}{(b-a)^{n-1}}\int_a^t x^2(x-a)^{n-2}dx} \\ &= cs\sqrt{\frac{n-1}{(b-a)^{n-1}}\left[\frac{t^2(t-a)^{n-1}}{n-1} - \int_a^t \frac{2x(x-a)^{n-1}}{n-1}dx\right]}. \\ &< cst = e^*(t). \end{aligned}$$

The second equality in the above chain follows from integration by parts. The inequality follows because $t \le b$ and the integral in the second line is always positive. Therefore, equilibrium effort in the first period is lower than the efficient effort level, so that BM is not efficient in the first period. Proposition 3 implies that BM is efficient in the second period.

Proof of Corollary 3. Let $s = \tau_f = \tau_s = \tau_b$. The buyer's expected utility in FP (U_B^{FP}) and SA (U_B^{SA}) is given by

$$U_B^{FP} = U_B^{SA} = E\{B^{FP}(t^{[1]})\} = \frac{cs^2}{2} E\left\{ t^{[1]} - \frac{t^{[1]} - a}{n} \right\}$$
$$= \frac{cs^2}{2(n+1)}((n-1)b + 2a),$$

where $t^{[1]}$ is the highest out of n types. Let U_B^{BM} denote the buyer's expected utility in BM. Note that the buyer's utility in the second period equals zero because he pays the winner s times her effort. The buyer's expected utility in period 1 from supplier i's project equals sm_i^1. So,

$$U_B^{BM} = nsE\{m_i^1\} = nsE\{e_1^{BM}(t)\}$$
$$= ncs^2 E\left\{ \sqrt{\frac{n-1}{(b-a)^{n-1}} \int_a^t x^2 (x-a)^{n-2} dx} \right\}.$$

Now, let us substitute the integration term x by

$$y \equiv \frac{x-a}{b-a}.$$

The following (in)equalities follow straightforwardly for $n \geq 3$:

$$U_B^{BM} = ncs^2 E\left\{ \sqrt{(n-1)\int_0^u (y(b-a)+a)^2 y^{n-2} dy} \right\}$$
$$= ncs^2 E\left\{ \sqrt{(u(b-a)+a)^2 - 2(b-a)\int_0^u (y(b-a)+a) y^{n-1} dy} \right\}$$
$$< ncs^2 E\{(u(b-a)+a)u^{(n-1)/2}\}$$
$$= \frac{cs^2}{2}\left(\frac{4nb}{n+3} + \frac{8na}{(n+1)(n+3)} \right)$$
$$\leq \frac{cs^2}{2}\left((n-1)b + 2a\right) = (n+1)U_B^{FP} = (n+1)U_B^{SA},$$

Where

$$u \equiv \frac{t_i - a}{b-a}$$

is uniformly distributed on the interval [0,1].

For $n = 2$, the following chain of (in)equalities is readily verified:

$$U_B^{BM} = 2cs^2 E\left\{\sqrt{\int_0^u (y(b-a)+a)^2 dy}\right\}$$

$$= 2cs^2 E\left\{\sqrt{\frac{u^3}{3}(b-a)^2 + u^2(b-a)a + a^2 u}\right\}$$

$$= 2cs^2 E\left\{\sqrt{\frac{u}{3}}\sqrt{u^2(b-a)^2 + 3u(b-a)a + 3a^2}\right\}$$

$$\leq 2cs^2 E\left\{\sqrt{\frac{u}{3}}\sqrt{u^2(b-a)^2 + 2\sqrt{3}u(b-a)a + 3a^2}\right\}$$

$$= 2cs^2 E\left\{\sqrt{\frac{u}{3}}\left(u(b-a)+\sqrt{3}a\right)\right\} = \frac{cs^2}{2}\left(\frac{8}{5\sqrt{3}}b + \left(\frac{8}{3} - \frac{8}{5\sqrt{3}}\right)a\right)$$

$$< \frac{cs^2}{2}(b+2a) = (n+1)U_B^{FP} = (n+1)U_B^{SA}.$$

Now, let us show that the suppliers' per project utility is lower for BM than for FP and SA. From the proof of proposition 3, it follows that over two periods, the expected utility of a supplier with type t is given by

$$U^{BM}(t,t) = \frac{cs^2 t}{2}\left[\frac{t-a}{b-a}\right]^{n-1} - \frac{(e_1^{BM}(t))^2}{2ct}$$

$$= cs^2 \frac{\int_a^t x(x-a)^{n-1} dx}{t(b-a)^{n-1}}$$

$$= \frac{cs^2}{n}\frac{(t-a)^n}{(b-a)^{n-1}}\left[\frac{nt+a}{(n+1)t}\right]$$

$$\leq \frac{cs^2}{n}\frac{(t-a)^n}{(b-a)^{n-1}}.$$

The last inequality in the above chain follows from integration by parts. The inequality holds true because $a \leq t$.

For FP and SA,

$$U^{FP}(t,t) = U^{SA}(t,t) = \frac{cs^2}{2n}\frac{(t-a)^n}{(b-a)^{n-1}} .$$

Now, it is immediate that

$$U^{FP}(t,t) = U^{SA}(t,t) \geq \frac{U^{BM}(t,t)}{n+1}.$$

for all $n \geq 2$ and $t \geq a$, where a strict inequality holds if $n > 2$ or $t > a$. Consequently, the ex ante expected utility in FP and SA is higher than in BM.

A.2 Parameter Draws

TABLE 6
Parameter Draws for each Round

	Deterministic		**Stochastic**		
Round	t_1	t_2	t_1	t_2	ε
1	65	62	64	59	0
2	99	92	59	87	-2
3	67	81	76	53	0
4	93	83	72	71	-2
5	78	69	84	68	2
6	94	54	74	64	0
7	75	87	87	71	2
8	52	66	55	55	0
9	52	79	57	97	2
10	83	81	55	88	-2

A.3 English Translation of Instructions

Welcome to this experiment on decision-making! You can make money in this experiment. Your choices and the choices of the other participants will determine how much money you will make. Read the instructions carefully. There is paper and a pen on your table. You can use these during the experiment. Before the experiment starts, we will hand out a summary of the instructions.

The Experiment

The experiment consists of four parts. In each part, you will earn points. At the end of the experiment, your points will be exchanged in euros. You will start with a starting capital of 5 euros.

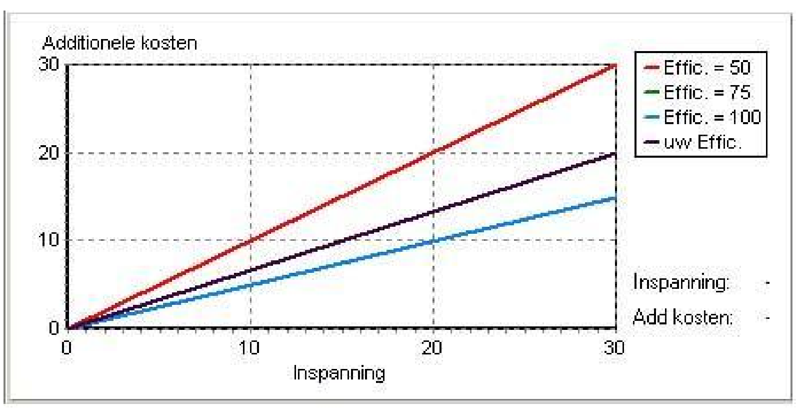
During the experiment, you will compete with another participant to win a project. If you win the project, you will decide how much effort you will exert. The more effort you exert, the more points you will earn. However, effort is also costly.

The Costs of Effort

The costs of effort depend on how efficient you are. Your efficiency level is an integer between 50 and 100, where each number between 50 and 100 is equally likely. The higher your efficiency level, the lower your effort costs.

Figure 3 presents the additional costs of effect if your efficiency level equals 75. This figure indicates how much extra costs you will make if you provide one additional unit of effort. Observe that your costs are lower than at an efficiency level of 50, but higher than if your efficiency level had been 100.

FIGURE 3
Screenshot



Legend: “Inspanning” is Dutch for “effort”, “Additionale kosten” for “additional costs”, and “uw” for “your”. “Effic.” stands for “efficiency level” and “Add” for “additional”.

An example illustrates the above. Suppose your efficiency level equals 50, and you deliver 3 units of effort. Your total costs are than 1 + 2 + 3 = 6. The reason is that for the first unit of effort, the costs are 1, for the second unit 2, and for the third unit 3. If your efficiency level is 100 then your costs at the same level of effort are lower: 0.5 + 1 + 1.5 = 3. Your costs at efficiency level 75 are somewhere in between.

To help you make these calculations, during the experiment, at the bottom-right corner of your screen, a calculator will appear.

The Benefits from Effort

Every unit of effort produces one unit of output, for which you get points. Suppose, for instance, that you receive 10 points per unit of output, and that you deliver 12 units of output. In that case you earn 10*12 = 120 points.

Instructions Part 1

The first part of the experiment consists of 5 rounds. For every 200 points that you earn in this part, you will receive € 1 at the end of the experiment.

In part 1, you won't yet compete with another participant for the project. In other words: you are guaranteed to execute the project. In each round, you must decide how much effort to expend in the project.

In part 1, you obtain 10 points for each unit of effort. Your profit from a project is the number of points you get for your effort minus your effort costs. As said, your costs depend on your efficiency level. At the bottom-right corner of your screen, a calculator will appear which calculates revenue, costs, and your profit if you type in specific effort levels. You can run as many calculations as you like.

Your efficiency level varies from one round to the next. Each round, the computer draws your new efficiency level, i.e., an integer between 50 and 100. Each number between 50 and 100 is equally likely.

Before we start part 1, let us return to Figure 3. This figure allows you to derive which effort level maximizes your profit.

Suppose your efficiency level equals 50, and that you obtain 10 points for each unit of effort. Your profit is maximized if you choose an effort level of 10. Why? Let us start at effort level 0. It is more interesting to exert 1 unit of effort, because the costs for doing so are 1, while your gains from this unit of effort equal 10. The same holds true for the second unit of effort. This costs you 2 points, but its revenue is, once again, equal to 10. The same reasoning holds true for the third up to the tenth unit of effort: each unit yields 10, but costs less than that. Is it interesting to deliver an 11th unit? No: this will cost you 11 points, but generates only 10. The same holds true for any effort level above 10. Summarizing: it is optimal to expend 10 units of effort.

Instructions part 2

The second part of the experiment is almost identical to the first. Also this part consists of 5 rounds. For every 200 points that you earn in this part, you will receive € 1 at the end of the experiment. The points that you obtained in the first part will be added to your starting capital. The sum will be your starting capital for part 2.

Like in part 1, you exert effort in a project. This effort generates output. The main difference with part 1 is that in part 2, your output depends on the state of the economy, on which you have no influence. If the state of the economy is “neutral”, then each unit of effort yields one unit of output. If the state of the economy is “good”, then your output equals your effort plus two additional units of output. However, if the state of the economy is “bad”, you lose two units of output compared to the neutral state. In short: you can determine your effort level, but you only know afterwards how much output it generates.

Let us give an example for clarification. Suppose you obtain 10 points per unit of output, and that you deliver 12 units of effort. In a neutral state of the economy, your output is 12 as well. In that case, you earn 10*12 = 120 points. If the economy is good, your output equals 12+2 = 14, so that you score 10*14 = 140 points. In the case of a bad economy, your output equals 12-2 = 10, which gives you 10*10 = 100 points.

Your efficiency level varies from one round to the next. Each round, the computer draws your new efficiency level, i.e., an integer between 50 and 100. Each number between 50 and 100 is equally likely.

Instructions part 3

The third part of the experiment lasts for 10 rounds. For every 200 points that you earn in this part, you will receive € 10 at the end of the experiment (so 10 times as much as in the previous parts). Your earnings of the first two parts will be transferred to your starting capital of part 3. In this part, you compete with another participant for a project. Each round consists of two periods.

[FP: In the first period, you submit a bid. The same holds true for the other participant. The highest bidder will execute the project. He of she has to pas his or her bid, that will be subtracted from his or her current capital. If bids are identical, you both have 50% probability of winning the project.]

[BM: In the first period, you exert effort in a project. The same holds true for the other participant. You and the other participant do not receive any payment for your effort, but its costs will be subtracted from your capital. The player delivering the highest effort in period 1, completes another project in period 2. If effort levels are identical, you both have 50% probability of winning the project.]

[FP and BM: In the second period, the winner chooses how much effort to expend in the project. For each unit of effort, he or she obtains 10 points. In this part, the state of the economy is always neutral. The output of the project is therefore equal to the winner’s effort. The loser does not do anything in the second period.

[SA: In the first period, you bid both an amount of money and an effort level. The same holds true for the other participant. These bids result in a score, which is equal to ten times the effort level minus the amount of money. The bidder with the highest score wins, unless the score is negative. If scores are identical, you both have 50% probability of winning the project. If you both offer a negative score, none of you will complete the project. The one who executes the project, exerts the effort promised in his or her bid. He or she receives the amount of money that he or she bid. The player with the lower score obtains zero points.]

In every round, you obtain a new efficiency level, in a same manner as in part 1. The same holds true for your competitor. Therefore, it is very likely that your competitor has a different efficiency level than you.

Finally, in each round, the computer selects at random the person with whom you will compete.

Instructions part 4

Also the fourth part of the experiment lasts for 10 rounds. For every 200 points that you earn in this part, you will receive € 10 at the end of the experiment (the same as in the previous part). The points that you obtained in the previous parts will be added to your starting capital. The sum will be your starting capital for part 4.

The part is similar to the previous one, the main difference being that the state of the economy can be good, neutral or bad. Each state is equally likely.

[SA: If you have the higher score, and if the state of the economy is good, you obtain an additional reward of 20, because your output is higher than promised. In the case of a bad economy, you get a fine equal to 20 points if you win the project.]

[BM and FP: If the state of the economy is "neutral", then each unit of effort yields on unit of output. If the state of the economy is "good", then your output equals your effort plus two additional units of output. However, if the state of the economy is "bad", you lose two units of output compared to the neutral state.]

[BM: In the first period, the state of the economy is always "neutral", so that the player with the higher effort in period 1 completes the project in period 2.]