How to allocate R&D (and other) subsidies: An experimentally tested policy recommendation

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Abstract

This paper evaluates the typically applied rules for awarding R&D subsidies. We identify two sources of inefficiency: the selection based on a ranking of individual projects, rather than complete allocations, and the failure to induce competition among applicants in order to extract and use information about the necessary funding. In order to correct these inefficiencies we propose mechanisms that include some form of an auction in which applicants bid for subsidies. Our proposals are tested in a simulation and in controlled lab experiments. The results suggest that adopting our proposals may considerably improve the allocation.

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“Public money is like holy water; everyone helps himself to it.”—Italian Proverb

1. Introduction

R&D subsidies to industry are an important part of research policy. For example, the federal government of Germany roughly spends €2 billion per year for supporting industry R&D. In 2002, this accounted for approximately 20% of its total R&D spending.1 Typically, R&D subsidy programs are geared to a particular purpose such as job creation in particular regions or research intensity in particular industries. Some of these programs offer grants, others provide loans at subsidized interest rates or funding in return for a profit share. Most programs support small and medium sized businesses (SMEs).

In the present paper we analyze programs that offer nonrefundable grants. This is a common form of subsidization. In most of these programs the allocation of funds is organized in competitions, as follows.2 Applicants submit written project proposals to a program manager at some due date. These proposals are pre-screened and short-listed, and then evaluated by a team of experts on the basis of their scientific and economic merit. Based on the expert advice, a committee grades projects, using a small set of grades such as A, B, and C. And the committee selects projects in the order of the assigned grades,

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1 See e.g., Czarnitzki and Fier (2001) or Federal Ministry of Education and Research (2004) for more details.

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2 A detailed description and analysis of some of the programs applied in Germany can be found in Federal Ministry of Education and Research (2004), Blum et al. (2001), Becker et al. (2004), and Eickelpasch and Fritsch (2005).
down from A to C, until the available budget is exhausted. Thereby, each funded project receives a subsidy equal to a predetermined percentage of the scheduled refundable project cost.\footnote{Typically, only part of the project cost, such as personnel cost, is eligible for subsidies. A frequently employed rule is the “matching grant” where 50\% of the refundable project cost are reimbursed.}

We mention that similar R&D subsidy programs are employed in many other countries. For example, an account of programs employed in the UK and the US can be found in Binks et al. (2003).

In the present paper we will not debate the merit of directly subsidizing firms’ R&D activities.\footnote{Some researchers, such as Martin and Scott (2000), have suggested that one should subsidize venture capitalists rather than firms. Other researchers investigate into the overall effectiveness of R&D subsidies in promoting research in private enterprises. See, e.g., García-Quevedo (2005) for an international survey and Czarnitzki and Licht (2006) for a survey on the effects of R&D subsidies in Germany.} However, we object to the way in which firms’ projects are selected and subsidies are determined.

Specifically, we see two main deficiencies and propose to modify the currently used attribution procedure in two ways:

1. Funding the best projects until the budget is exhausted is inefficient. Instead, the selection should be based on a ranking of complete allocations of funds.
2. Funding the selected projects at a predetermined percentage of project cost is inefficient. Instead, one should induce applicants to compete by lowering their requests for funding.

In order to achieve these objectives, we propose to base the selection of projects on a ranking of allocations, and to embed that selection rule in a simple auction mechanism. The development of an auction-like mechanism for awarding subsidies has been suggested by Blum et al. (2001) and Blum and Kalus (2003). They propose that firms should compete with their requests for funding in order to economize on the amount of subsidies. Specifically, they propose to allocate a given budget of subsidies to those who request the lowest subsidy rates, as a share of their total project cost. However, this allocation rule can only give meaningful results if all projects that compete in one auction yield the same benefit per currency unit, which is rather restrictive.

In this paper, we develop the idea of auctioning subsidies with the goal to make it applicable to a larger class of applications, allowing for arbitrary quality and cost differences across projects. For this purpose we develop a slightly complicated selection rule that is based on a ranking of all possible allocations of subsidies and awards in such a way that the highest ranking feasible allocation is reached. Our proposed mechanisms match this allocation rule with either an open, descending-bid or a sealed-bid bidding procedure. We use Monte Carlo simulations and controlled lab experiments to test the proposed mechanisms.

The plan of the paper is as follows. In Section 2, we discuss selection rules and show why one should select on the basis of a ranking of complete allocations. In Section 3, we explain two specifications of an auction mechanism and explain how our auction problem relates to the existing auction theory literature. Section 4 evaluates the proposed selection rule by a Monte Carlo simulation. Section 5 describes the design of a lab experiment to test the two auction mechanisms and Section 6 reviews its results. The paper closes in Section 7 with a summary and discussion.

2. Ranking projects versus ranking allocations

Before we design mechanisms that induce competition for funding, we explain how one should select who shall be subsidized, taking the subsidies to be paid to those who are selected as given.

Suppose applicants have submitted project proposals and the selection committee has evaluated them and has short-listed a set of projects \( P := \{1, \ldots, n\} \) which are judged as eligible for funding. Project \( i \) shall receive a subsidy of \( s_i \) if selected. The selection committee has to choose a subset of projects that shall be funded within the limits of the given budget \( B \).

The standard selection rule is based on a ranking of individual projects, from the set of short-listed projects, as follows: (1) each project is assigned a grade from a given set of grades (for the moment one may assume that each project has a distinct grade); (2) projects are selected, moving from highest to lower grades, until the given budget is exhausted. As a result, no lower-grade project ever crowds out a higher grade. This may seem to be a desirable property; however, it is generally not optimal.

As an illustration consider the example of four projects, \( P = \{P_1, \ldots, P_4\} \), which require the following subsidies if selected: \( s = \{100, 50, 50, 50\} \) and a budget of 150. Suppose the selection committee has the preference order \( P_1 \succeq P_2 \succeq P_3 \succeq P_4 \). Then the selection based on the ranking of individual projects leads to the selection of projects \( \{P_1, P_2\} \). However, if \( \{P_2, P_3, P_4\} \) is preferred to \( \{P_1, P_2\} \), it would be better to select \( \{P_2, P_3, P_4\} \) since that allocation is also feasible at the
given budget. This indicates that the selection based on the ranking of individual projects leads astray, because it does not take into account that a high-grade project may crowd out several lower-grade projects which are inferior in pairwise comparisons, but lead to a superior allocation. Indeed, that selection is equivalent to preferring every single higher-grade to any number of lower-grade projects.

Therefore, as a first step towards achieving a better selection process, the selection committee should think in terms of complete allocations, and apply the following selection rule.\footnote{To an economist, this proposal may seem fairly obvious. However, in our experience, program managers are not aware of the flaws of the current selection procedure.}

**Proposal 1.** Select projects based on a ranking of allocations, rather than based on a ranking of projects, as follows: (1) determine all allocations that are feasible (can be funded with the given budget); (2) rank all feasible allocations and select the projects that are part of the highest ranking feasible allocation.

In practical application this procedure may be fairly complex, since the number of allocations increases exponentially with the number of projects. Therefore, we recommend sticking to a fixed grading system, as it is typically used in the current system, consisting of at most three grades, such as \{A, B, C\}. Such a grading system treats projects of the same grade as perfect substitutes. We were also told by program managers that employing a fixed grading system, as it is rather than based on a ranking of projects, in our experience, program managers are not aware of the flaws of the current selection procedure.

For example, for the grade set \{A, B, C\} the equivalence rules \{e(b), e(c)\} state the number of grade-A projects that are equivalent to one grade-B, resp. grade-C, project. We also employ this practical device in our lab experiments which are described in Section 5.

The proposal requires neither the use of grades nor constant equivalence rules. Using such constant equivalence rules corresponds to assuming linear indifference curves in the commodity resp. grade space. For example, for the grade set \{A, B, C\} the indifference curves in the commodity resp. grade space.

Therefore, we were also told by program managers that employing this practical device in our lab experiments (follows:)

## 2.1. Formal statement of the allocation ranking problem

We conclude this section with a precise statement of the allocation ranking problem. The notation introduced here will also be used to describe our auction mechanisms.

For this purpose, let \(P := \{1, \ldots, n\}\) be the finite set of short-listed projects and \(A\) the set of subsets (i.e., the power set) of \(P\). Therefore, \(A\) is the set of all conceivable allocations from which the committee has to select one, under some feasibility constraint.

Ideally, the selection committee has a complete preference ranking, “\(\succeq\)”, of all allocations, such that for all \(a, a' \in A\) one has \(a \succeq a'\) or \(a' \succeq a\) that is reflexive and transitive. Such a preference ranking defined on a set of finite alternatives can be represented by an (ordinal) utility function, \(U: A \to \mathbb{R}\), such that \(\forall a, a' \in A: U(a) \geq U(a')\) \iff \(a \succeq a'\). The promised subsidy for project \(i\), if it is part of the allocation, is denoted by \(s_i\).

The choice of allocation based on a ranking of individual projects (as in the status quo procedure) is denoted by \(a^d\) and the choice of allocation according to Proposal 1 is denoted by \(a^p\). Thus, \(a^p\) is the maximizer of \(U(a)\) over all feasible allocations that can be funded with the given budget \(B\):

\[
a^p \in \arg\max_{a \in A} \left\{ U(a) \sum_{i \in a} s_i \leq B \right\}. \tag{1}
\]

As mentioned before, committees often employ a grading scheme as a simplifying device. Together with an equivalence rule of grades this may lead to a pragmatic construction of a utility function, as follows.

Let \(G := \{g_1, \ldots, g_m\}\) be a set of grades, such as \(G = \{A, B, C\}\) where \(g_1 > g_2 > \ldots > g_m\). Then, the first step is to grade all projects, which is summarized by \(\Gamma: P \to G\). Using \(\Gamma\), one then computes, for each allocation its frequency distribution of grades, denoted by \(\gamma: A \to \mathbb{N}^m\).

Next, the committee chooses an equivalence rule \(e: G \to \mathbb{R}^m\), where \(e(g_j)\) states the number of grade-\(g_1\) projects that are equivalent to one grade-\(g_j\) project. Of course, \(1 = e(g_1) > e(g_2) > \ldots > e(g_m)\).

Combining the grading scheme and the equivalence rule, one finds the utility function:

\[
U(a):= \sum_{j=1}^{m} \gamma_j(a)e(g_j). \tag{2}
\]
Also notice that the selection based on ranking individual projects can be viewed as a special case of a ranking based on allocations if and only if the project manager has lexicographic preferences, which give first priority to grade $g_1$ projects, second priority to grade $g_2$ projects, etc.

3. Two auction mechanisms

We now turn to the second deficiency of the current subsidization policy: the funding of projects at a predetermined percentage of the refundable project cost. Generally this leads to excessive funding of those who are selected, and thus tends to exclude other valuable projects.

Typically, the selection committee cannot know the amount of funding needed to induce the applicant to carry out its project. They only know that this unknown amount is not greater than $s_i$, the amount of subsidy that would be granted according to the current rules. This suggests that one can reduce funding without losing valuable projects. It requires the design of a mechanism that induces applicants to compete by lowering their request for funding.

We propose two such mechanisms: one sealed-bid and one open, descending-bid mechanism. Both mechanisms are auction-like in the sense that applicants compete with their requests for funding which can be considered as their bids and the mechanism selects the best allocation that can be funded with the given budget.

To carry out their project as stated in the application, the applicant requires a certain amount of subsidization, which is denoted by $z_i$. The fact that $z_i$ is private information motivates the use of the auction mechanisms. An auctioneer knowing $z_i$ could directly implement the optimal allocation, namely:

$$a^o \in \arg \max_{a \in A} \left\{ U(a) | \sum_{i \in a} z_i \leq B \right\},$$

by funding each applicant in the allocation exactly at the required level to implement its project.

Each applicant now submits a bid $b_i$ according to one of the following two mechanisms.

3.1. Sealed-bid mechanism

The sealed-bid mechanism is characterized by the following allocation and pricing rules:

1. Each applicant $i \in P$ makes a sealed bid $b_i \in [0, s_i]$, without knowing the bids made by others. Bids are requests for funding.
2. On the basis of the given bids $b = (b_1, \ldots, b_n)$, the mechanism
   (a) selects the allocation, $a^*$, that solves the maximization problem:
   $$a^* \in \arg \max_{a \in A} \left\{ U(a) | \sum_{i \in a} b_i \leq B \right\}. \tag{4}$$
   (b) pays a subsidy equal to $b_i$ if $i \in a^*$ and equal to 0 otherwise.

3.2. Open, descending-bid mechanism

The second mechanism is an open, descending-bid auction which consists of several “rounds”:

1. Each applicant $i$ faces his own price clock that starts at $s_i$. Subsequently, the reading of the price clock declines at rate $\Delta$ in each round.
2. The final bid $b_i$ of applicant $i$ is the price where he stops his price clock. After stopping the price clock, applicants are not allowed to lower their bid any further. Applicants can see others’ price clocks at any time and can always observe if other applicants have stopped in an earlier round.
3. On the basis of the given bids $b = (b_1, \ldots, b_n)$, the mechanism selects the allocation as in the sealed-bid mechanism.

Proposal 2. Use either the sealed-bid or the open, descending-bid mechanism. This induces competition for funding.

3.3. Maximum bid restriction

It is advisable to structure the auction in such a way that its outcome can never be inferior to the outcome that would be reached if one would apply Proposal 1 only, without an auction.

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6 An applicant who requires more than $s_i$ would not apply because he would not be able to carry out the project as stated in the application. In most programs there is close monitoring by program managers such that applicants are not able to change the nature of their project significantly once the application is accepted.

7 Notice that the maximum bid is set to $s_i$. This maximum bid restriction is discussed in Section 3.3.

8 If $a^*$ is not unique, it selects the allocation that minimizes $\sum b_i$; if the result is still not unique, it selects at random.
Table 1
Example of an open, descending-bid auction

<table>
<thead>
<tr>
<th>Applicant</th>
<th>Utility</th>
<th>$z_i$</th>
<th>$s_i$</th>
<th>Round 1</th>
<th>Round 2</th>
<th>Round 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53</td>
<td>20</td>
<td>40</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>47</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>37</td>
<td>10</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>15</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>$a$</td>
<td>${1, 2}$</td>
<td></td>
<td></td>
<td>${2, 3, 4}$</td>
<td>${2, 3, 4, 5}$</td>
<td>${1, 2, 4, 5}$</td>
</tr>
<tr>
<td>$U(a)$</td>
<td>100</td>
<td></td>
<td></td>
<td>122</td>
<td>157</td>
<td>172</td>
</tr>
</tbody>
</table>

This can be achieved by setting individual maximum bids equal to the subsidy rates $s_i$ that would be granted according to the current subsidy rules. Therefore, we propose:

**Proposal 3.** If one uses one of the auction mechanisms, set each applicant’s maximum bid equal to the subsidy rate that would be granted according to the current subsidy rules (which was denoted by $s_i$).

In policy advice one should always try to make proposals that cannot yield an outcome inferior to that achieved by the status quo practice. To achieve this is the only purpose of Proposal 3.

Notice that we already incorporated this proposal in the two auction mechanisms described before.

### 3.4. An example of an open, descending-bid auction

The following example illustrates the working of the open, descending-bid mechanism (see Table 1). It assumes a budget of 70, a bidding decrement of 5, and five applicants (1–5). Projects are substitutes and have the utilities stated in column 2. The associated minimum subsidies ($z_i$) are stated in column 3, and the subsidies $s_i$ that would be granted if no auction were used in column 4. Italic numbers indicate which applicants would be part of the allocation if the auction would stop at the current round. If no auction were used, the allocation would be $\{1, 2\}$, with total utility 100.

This example assumes that all applicants stop their price clocks at round 3. The auction ends with allocation $a^* = \{1, 2, 4, 5\}$. The example illustrates how an applicant, in the course of an auction, can be crowded out at some round and return to the allocation in a later round. The last row of the table states the total utility of the respective allocations. The optimal allocation is $\{1, 2, 3, 4\}$ and the maximum feasible utility is 175.

### 3.5. The nature of the auction problem

The present auction problem can be viewed as that of a multi-object procurer (auctioneer) facing several single-unit suppliers (bidders), where both the auctioneer and bidders are budget-constrained. To the best of our knowledge such a problem has not been studied before, neither in the theoretical nor in the experimental auctions literature.

There is a literature on standard single- and multi-unit auctions with budget constrained bidders (see Che and Gale, 1998; Laffont and Robert, 1996 for the single-unit case, and Benoît and Krishna, 2001 for the multi-unit case). However, a budget constrained auctioneer, which is of crucial importance in the present framework, has never been considered. Its game theoretic analysis raises a number of technical complications. The problem shares some features with package auctions (see Cramton et al., 2006). The common denominator is that the auctioneer faces a complex selection problem because he must have a ranking of all feasible allocations in order to select the best.

### 4. Monte Carlo simulation

The simulation is designed to assess the benefit of switching from a selection based on a ranking of individual projects to a global decision procedure that is based on a ranking of allocations, as recommended in Proposal 1. Notice that adding an auction mechanism, as proposed in Proposal 2, gives rise to further improvements.

The simulation is designed as follows: we consider a pool of 250 projects and a given budget of $B = 1000$. Each project has two characteristics: its grade (either $A$ or $B$), which is drawn independently with equal probability, and the status quo subsidy, $s_i$, which is drawn independently from a uniform distribution with support $(0, B)$. The program manager’s preferences are characterized by a fixed equivalence rule $e_B$ which indicates that grade-$A$ projects are equivalent to one grade-$B$ project.
We wrote a VBA program for Microsoft Excel that draws the grade of each project and its parameter \( s_i \) at random and then computes the two allocations, the status quo allocation and the allocation based on Proposal 1. This procedure is repeated 1000 times to obtain an empirical distribution of selected allocations for different equivalence rules \( e_B \in \{0.3, 0.5, 0.7, 0.9, 0.99\} \).

The results of these simulations are presented in Fig. 1 in the form of cumulative distribution functions, \( F(x) \). There, \( F(x) \) denotes the probability that Proposal 1 gives rise to a relative gain in the value of the selected allocation of \( x \) or less. The value of an allocation is computed as \( n_A + e_B n_B \), where \((n_A, n_B)\) denotes the number of \( A \) and \( B \) projects in the respective allocation. And the relative gain in value is computed by dividing the increment in value due to switching from status quo allocation, \( a^p \), to the allocation based on Proposal 1, \( a^p \), by the value of the status quo allocation, \( a^f \).

Evidently, the relative value gains increase, in the sense of first-order stochastic dominance, if grade-\( B \) projects become more valuable relative to grade-\( A \) projects. This is plausible, because giving absolute priority to grade-\( A \) projects, as the status quo preference rule does, becomes more costly as projects become closer substitutes.

5. Experiments

In order to test the two auction mechanisms we set up a series of computerized lab experiments. There, subjects were assigned to play the role of a firm that applies for a R&D subsidy. They either participated in the sealed-bid or in the open, descending-bid mechanism. In the experiment, we used a simple grading scheme for projects as proposed above, with only two grades.

5.1. Experimental design

In the experiment, we formed groups of six subjects participating in one of the two mechanisms. Prior to the auction, each subject \( i \) was given the following private information \((z_i, \pi_i, s_i, g(i))\):

1. the minimum subsidy needed to execute one’s project, \( z_i \);
2. the private profit earned in addition to the subsidy if one’s project is executed, \( \pi_i \);
3. the maximum (resp. starting) bid, \( s_i \);
4. the grade of one’s project, \( g(i) \), either \( A \) or \( B \).

The smallest monetary unit was 1 ECU (experimental currency unit).

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The program code is available upon request from the authors.

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For instructions and screenshots see Giebe et al. (2005).
Each subject was informed that \((z_i, \pi_i, s_i)\) were independently drawn from uniform distributions with supports \(z_i \in \{0, 1, \ldots, 5\}\), \(\pi_i \in \{0, 1, \ldots, 10\}\), \(s_i \in \{5, 6, \ldots, 10\}\), and that there would be three grade-A and three grade-B projects, assigned to subjects with equal probability.

The following information was given to all subjects:

1. the budget \(B = 20\),
2. the preference ranking over possible allocations:

\[
\{A, A, A, B, B, B\} \succ \{A, A, A, B, B\} \\
\succ \{A, A, B, B, B\} \succ \{A, A, A, B\} \succ \{A, A, B, B\} \\
\succ \{A, B, B, B\} \succ \{A, A, A\} \succ \{A, A, B\} \\
\succ \{B, B\} \succ \{A, A\} \succ \{A, B\} \\
\succ \{B\} \succ \{A\} \succ \{B\}. \tag{5}
\]

In the sealed-bid mechanism subjects were asked to enter their requested subsidy, \(b_i\), referred to as “bid” in a computer screen window. After all bids were submitted, the software computed the best feasible allocation, based on the above preference ranking, according to the rules described in Section 4. Those subjects who were part of the allocation received a credit equal to \(b_i + \pi_i\) ECU; all others received no credit.

The open, descending-bid mechanism was set up as a clock auction. There, each subject had its own price clock, starting at the maximum bid \(s_i\) and decreasing at the fixed rate of one ECU per round. In each round, we first asked the grade-A subjects to make simultaneous bids; then, all grade-B subjects observed the bids of all grade-A subjects, and made their own simultaneous bids. There, a bid means that one either freezes the current reading of one’s price clock or accepts a reduction by one ECU. This procedure continued until all subjects had stopped their price clock.

A subject who stopped its price clock in one round was not able to “unfreeze” it later. In each round, the active grade-A subjects could see the current reading of the price clocks of all subjects and who had already stopped its price clock in which previous round and at which price. Similarly, the active grade-B subjects could see the current reading of the price clocks of all subjects, which subjects had stopped in previous rounds, and, in addition, which grade-A subjects stopped in the current round.

When all subjects had stopped their price clock, the final bids \(b\) were the levels at which the individual price clocks had been stopped; the auction ended, and the software computed the best feasible allocation by the same rule as in the sealed-bid mechanism. Those subjects who were part of the allocation earned a credit of \(b_i + \pi_i\) ECU; all others received no credit.

5.2. Experimental procedure

The experiments were conducted in November 2003 at the Department of Economics, Humboldt University at Berlin. The subjects were 96 student volunteers. They were recruited by advertisements in lectures and by mail shots. Most of them were undergraduate economics or business students.

The treatments were computerized using the experimental software “z-Tree” developed by Fischbacher (1999).

We conducted eight sessions. Four sessions were dedicated to the sealed-bid mechanism, and another four sessions to the open, descending-bid mechanism. In each session there were twelve distinct subjects.

5.2.1. Instructions and trial auction

After being seated at a computer terminal, subjects were given written instructions including a detailed example.

In the instructions we referred to an allocation as a “combination,” to a subsidy as a “grant,” and to an applicant as a “bidder” in order to keep the terminology as neutral as possible without making it unduly difficult to understand the mechanism. We made clear that all decisions would be taken anonymously and that identities would not be revealed. Two control questions checked whether the instructions were understood by all subjects. These control questions were computerized, with feedback for incorrect answers. Then, a “trial auction” was played which did not count for earnings.

5.2.2. Assignment of subjects to payoff-relevant auctions

A session consisted of two parallel sequences of five auctions, each played by six subjects. After each auction subjects were randomly and anonymously reassigned to one of the two groups playing the next auction. After each auction subjects were privately informed about their earnings. In order to reduce path dependencies, subjects were not told which allocation was selected. At the end of the session subjects got a summary account of their earnings, and earnings were paid, including a show-up fee.

5.2.3. Payoffs

A typical sealed-bid session took 40 and an open, descending-bid session 90 min. Each subject’s earnings
Table 2

Frequency distribution of implemented allocations

<table>
<thead>
<tr>
<th>Allocations (ordered by rank r)</th>
<th>Sealed-bid Frequency</th>
<th>Open, descending-bid Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: {A, A, A, B, B, B}</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>2: {A, A, A, B}</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>3: {A, A, B, B}</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>4: {A, A, A}</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>5: {A, A, B, B}</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

in ECU were converted into € at the rate 9 ECU = €1; in addition, subjects earned a show-up fee of €4 in a sealed-bid and €10 in an open, descending-bid session.

In sealed-bid sessions earnings were between €5.90 and €11, with an average of €8.40, and in the open, descending-bid sessions between €11.70 and €17.40, with an average of €14.40.

6. Results

Altogether, 96 subjects participated in eight sessions with a total of 78 payoff-relevant auctions. The trial auctions are not considered in our analysis. As groups were rematched in every auction, subjects were able to learn from each other’s behavior. Because of this, the results within a session are not independent. Hence, each treatment consists of four independent observations, one per session.

Since the set of independent observations is relatively small, we perform a mainly descriptive data analysis. Of course, each auction resulted in one of the allocations stated in Eq. (5). These allocations are ranked by assigning a number \( r \in \{1, \ldots, 15\} \), where \( r = 1 \) stands for \( \{A, A, A, B, B, B\} \), \( r = 2 \) for \( \{A, A, A, B, B, B\} \), etc. For convenience of notation we refer to the rank of the implemented allocation as \( r^* \), that of the optimal allocation as \( r^0 \), and that of the allocation that would be implemented if all bids were equal to the maximum bids as \( r^p \).

As it happened, the optimal allocation was \( \{A, A, A, B, B, B\} \) in 70 of the 78 auctions and \( \{A, A, A, B, B\} \) in the remaining eight auctions.

Table 2 indicates which allocations were implemented in the experiments.

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11 Actually, 80 auctions took place. However, due to a network problem, the data of 2 of the open, descending-bid auctions were lost. Subjects were only informed after the experiment. They received a lump-sum payment of €2 for the third auction where the problem occurred. We therefore think that the data from the remaining auctions can be analyzed.

12 Wilcoxon Rank–Sum tests using the difference in average bids in the two mechanisms \((n = 8)\) confirm our result on the 10%-significance level.
Before, both mechanisms induce a remarkable intensity of competition.

We measure the improvement due to the auction by computing the average difference between the rank \( r^p \) and that of the implemented allocation, \( r^* \), i.e., \( |r^* - r^p| \). In the sealed-bid mechanism that measure is equal to 5.78 and in the open, descending-bid mechanism it is 5.89. \(^{13}\) On average the auction increases the number of subsidized projects, relative to the allocation \( a^p \), by 2.04. This indicates that adding the auction brings about a remarkable improvement.

6.2. Efficiency

We call the outcome first-best if an auction implements the allocation \( a^o \), i.e., if \( r^o = r^p \). Similarly, we call it second-best or higher if \( r^* = r^o + 1 \) resp. \( r^* > r^o + 1 \). We measure the deviation from the first-best by computing the average difference between the ranks of the optimal and the implemented allocations, \( r^* - r^o \). In the sealed-bid mechanism that measure is equal to 1.45 and in the open, descending-bid mechanism it is 1.31. This indicates that the auctions implement allocations that are close to the efficient ones.

Fig. 3 summarizes the efficiency properties of both mechanisms. Without the auction, the implemented allocation would have been, on average, eighth-best. Thus, the deviation from efficiency is considerably smaller than the deviation from the allocations that would be reached without the auction.

6.3. Handicapped bidders

Figs. 4 and 5 show that grade-A bidders bid higher on average. This applies to all eight sessions. Specifically, in the sealed-bid mechanism, grade-A bidders bid 27% higher on average and in the open, descending-bid mechanism 12% higher. \(^{14}\)

6.4. Private profits

Intuitively, higher private profits should induce lower bids because those bidders should care more about getting the minimum funding needed to get their project off the ground, rather than about collecting unnecessarily high subsidies.

The Pearson coefficients for the correlation between private profit and the bid are \( \rho_{p,b} = -0.1 \) for the sealed-bid mechanism and \( \rho_{p,b} = -0.15 \) for the open, descending-bid mechanism. The negative sign does indeed confirm this conjecture. However, the observed correlation is rather weak.

\(^{13}\) The average difference between \( r^* \) and the rank of the status quo allocation, i.e., the allocation that would be reached without using any of our proposals, is 6.1 on average.

\(^{14}\) Wilcoxon Signed–Rank tests \((n = 4)\) confirm these results for both mechanisms on a 5%-significance level.
6.5. Experienced bidders

In the sealed-bid mechanism, average bids remain fairly stable during a session. However, in the open, descending-bid mechanism the average bid in the first auction of each sequence is 15.7% higher than in the final one.

Fig. 6 states the outcomes of the fourth and fifth auction of each sequence, i.e., after bidders have acquired some experience. It indicates that experience induces more competitive bidding, resulting in a higher degree of efficiency. However, this improvement due to experience is more pronounced in the open, descending-bid mechanism.\(^{15}\)

Not surprisingly, players lower their bids after they lose an auction. This learning effect is particularly strong in the sealed-bid auction. In fact, after losing an auction bids are on average reduced by 33.7% in the sealed-bid auction and by 16.7% in the open auction. And 73.7% of all losers respond in this way in the sealed-bid and 62.5% in the open auction.

We mention that the open mechanism reveals all individual maximum bids which remain hidden in the sealed-bid mechanism. Therefore, when we attribute differences between bidding behavior to the different auction mechanisms, one may object that we ignore the potential impact of the different information structure. Of course, we could have revealed all maximum bids also in the sealed-bid mechanism. Instead we checked whether there was any significant correlation between bids and observed maximum bids of competing bidders in the open, descending-bid mechanism. We found no significant correlation and therefore feel confident that this difference in information structure does not bias our findings.

7. Policy recommendations and discussion

The present paper analyzes the allocation of subsidies to fund socially valuable projects that are not feasible without subsidy. We focus on R&D subsidies, but possible applications of our mechanisms range from the funding of charitable projects to academic fellowships. Currently, these allocation decisions are based on a ranking of individual projects, and subsidies are awarded successively to the best projects until the budget is exhausted, which is not a good policy.

We identify two sources of inefficiency and propose better mechanisms. Specifically, we make two recommendations, the first of which can be implemented without the second:

- Select projects on the basis of a ranking of complete allocations rather than on a ranking of individual projects.
- Induce applicants to reveal information about their true need for funding and use that information. We advise to employ either an open, descending-bid or a sealed-bid auction-like mechanism in which applicants bid for subsidies.

Ideally, the first proposal calls for a ranking of all allocations. But this is generally too complex. Therefore, we recommend to use simple grading schemes, combined with fixed equivalence rules. This will improve the allocation relative to the currently used selection procedure (which implicitly assumes lexicographic preferences), without raising the level of complexity.

We test the first proposal by means of a Monte Carlo simulation. We show that the efficiency gain from using a ranking of allocations is larger if projects are closer substitutes.

We test the second proposal in controlled lab experiments. We find that both proposed mechanisms induce a high level of competition among applicants and improve efficiency. The highest efficiency gains are realized by the open, descending-bid mechanism.

Of course, the proposals will only be implemented if they are favorably assessed by the representatives of the firms who apply for R&D subsidies and by the policymaker and his administrators.

\(^{15}\) A Wilcoxon Signed–Rank test on the 5%-significance level (\(n = 4\)) confirms our result: For the open, descending-bid mechanism, bids during the first two auctions of each sequence are significantly higher than in the final two. For the sealed-bid mechanism, the hypothesis of significantly higher bids in the first two auctions of each sequence is rejected. Our observations are based on only 32 “late” auctions, 16 per treatment. A more extensive series of experiments would be required to check the robustness of these results.
As part of our study for the Germany Ministry of Economics and Labor (Becker et al., 2004) our coauthors from GIB and Fraunhofer ISI conducted an extensive opinion survey among German firms who had before applied for R&D subsidies in order to find out to what extent they would accept the implementation of the proposals. The results of this survey indicate that the majority of firms approves of the competitive selection procedure. Remarkably, acceptance among small and low equity firms, and those who complained about the current low success rate, is strongest. Altogether, the sealed-bid format has a higher acceptance rate than the open, descending-bid format.

With some exceptions, the program managers of the various R&D subsidy programs were less favorably disposed towards the proposed selection mechanisms. They objected that the proposals are not practicable, ranking allocations would be too complex, project quality would suffer if price counts in the selection, and that price competition would increase post-contractual opportunism.

Recently we learned about a project funded by the German Ministry of Education and Science in which a somewhat similar auction-like procedure has been tested for awarding public funds to farmers providing “ecological goods” such as grasslands with high ecological diversity. Although the allocation problem and the auction mechanism differ, some features are similar, e.g., the presence of budget constraints, quality classes for the provided goods, and a price discriminating award procedure. The results of the first field experiments reported in Groth (2005) suggest that these auction mechanisms are indeed practicable and can be implemented at reasonable cost.

The complexity of ranking allocations is certainly an issue. In this regard there is a need to simplify (for example, as proposed above, by using a simple grading scheme combined with an equivalence rule) and for supporting software tools that facilitate the comparison of complex alternatives. A similar complexity issue comes up in package auctions when a number of heterogeneous goods are auctioned. However, this has not deterred users such as the Federal Communications Commission in the US to choose this highly complex auction format.

In our analysis we have evaluated the impact of our proposed mechanisms assuming a given set of projects. This ignores that the proposed change in selection and allocation rules may affect the proposed projects. If applicants anticipate that they compete not only in terms of project quality but also in terms of the requested amount of funding, they may propose different projects. However, this may very well be a change for the better.

The currently used selection rules favor “large” projects with high quality and high cost, which has been criticized by some applicants and program managers.16 The proposed new rules allow “small” projects, with low cost and lower quality, to compete with the large ones because a combination of small projects may be preferred. This will surely induce participation of more small projects, probably to such an extent that the average quality of applications goes down. Nevertheless, as long as large projects are not discouraged from participation, the new selection rule will improve the quality of allocation.

Of course, if more “small” projects participate, and the success rate of “large” projects goes down, it is to be expected that less “large” projects participate. Therefore, it may be the case that the adoption of the proposed rules will adversely affect the quality mix of applications. If the selection rule accurately reflects the preferences, this change in the composition of submitted projects only indicates that proposals are better matched with these preferences. However, this puts a heavy burden on identifying preferences and translating them into the grading scheme.

We also mention that when more (on average smaller) projects are subsidized, the administrative costs will probably increase. Also, the adoption of auction mechanisms may raise transaction costs both to the administration and to proposers, especially if an open, descending-bid mechanism is employed. Of course, these issues have to be properly weighted in selecting one of the proposed bidding mechanisms.

Another concern was that switching to the proposed rules may exacerbate the problem of post-contractual opportunism, on the ground that the money saved on subsidies is compensated by a reduction of firms’ R&D activities. However, if firms can benefit from delivering less than the promised R&D activities, and get away without being sanctioned, one should expect that they do so regardless of the amount of the subsidy. We do not deny that there is a problem of post-contractual opportunism; but it is not clear why it should increase if one adopts the proposed selection and payment rules.

Finally, we mention that administrators are probably reluctant to change the current selection procedure also because the current practice gives them considerably more leeway. No one can be expected to give up such power on his own initiative. Therefore, the policymaker should exercise his power to make rules, and not delegate it to those who execute them. Unfortunately,

16 Eickelpasch and Fritsch (2005).
this obvious principle is frequently violated in the public sector.

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