Innovative procurement design for facility management services

Alessandro Avenali, Claudio Leporelli, Giorgio Matteucci, Alberto Nastasi, Fabio Nonino, Pierfrancesco Reverberi

Abstract— We introduce a multi-attribute auction-based mechanism with an endogenous scoring rule as a mean to innovate procurement design related to outsourcing of facility management (FM) activities in private and public sectors. The mechanism allows the procurer to request bids on several measurable technical and economic attributes of the supply of FM services, detailed in the procurement contract. The procurer also assigns weights to such features to signal their relevance to the sellers, while the score obtained with respect to any attribute is endogenously determined on the basis of the submitted offers. The proposed mechanism allows the procurer to mitigate the most relevant drawbacks due to the lack of skills and crucial information on the outsourced non-core activities. In fact, on one hand, it can extract from suppliers valuable private technical knowledge as well as information on the supply cost, and, on the other hand, it save the procurer from supporting the effort to specify ex ante both the exact required value for any technical feature of the supply, and the way a specific offer is scored.

Keywords— Facility management activities, outsourcing, incomplete contracts, multi-attribute auctions, endogenous score

I. Introduction

Facility management (FM) is a multidisciplinary approach for designing, planning and managing the non-core services in an integrated and coordinated way; these services support the strategic core activities and are essential for the effective and efficient functioning of an organization ([1]; [2]). In particular, FM concerns the management of employee-related services, building, spaces, utilities, property, portfolio, asset management, ICTs management, administration and legal advice. The premise of outsourcing is that the contractors own superior competencies on the processes outsourced, and can reduce costs due to its capacity to reach economies of scale leading to better quality of the services. In the last years, the FM discipline has been mainly developed by large private companies and central public administrations, with the purpose of integrating and coordinating many activities, and at the same time achieving efficiency, effectiveness and reduction of services cost. For instance, the problem of outsourcing FM activities in the Italian public sector is relevant. The yearly value of the awarded contracts signed by the Italian public administration for FM activities outsourcing in the year 2009 has been about 14 billion of euro, while the value of the potential market is about 27 billion ([3]).

Alessandro Avenali, Giorgio Matteucci, Claudio Leporelli, Alberto Nastasi, Fabio Nonino, Pierfrancesco Reverberi

Department of Computer, Control, and Management Engineering Antonio Ruberti, Sapienza University of Rome
Italy

Since 2002, CONSIP (CONcessionaria Servizi Informativi Pubblici), a company of the Ministry of Economy and Finance, carried out FM tenders on behalf of central and local administration. In 2008 the value of the CONSIP awarded contracts has been 12 billions; therefore, CONSIP gained a prominent position in the allocation of FM activities of the Italian public sector (Ferri, Pala 2009). Moreover, 50% of total orders (87050 orders) has been contracted out through online negotiations ([4]).

Nevertheless, switching costs incurred by the transition to an external provider, such as those associated with supplier selection, negotiations, reorganization and control, are high. The externalization of FM activities is certainly the right solutions, but only if the organization clearly identifies its own needs, coherently to its own strategy, defines the proper service conditions, and subsequently identifies the possible best contractors and reduces the costs of purchasing process.

Moreover, following recent trends in FM, private sector and public administration is trying to adopt the global service (GS), namely, a contract where the regular maintenance activities are substituted by a plurality of services and the contractor is fully responsible on the results. This type of contract moves the service objective from a specific activity implementation process to the effective achievement of satisfying results (target service levels) and aims at identifying a single contractor for a multiplicity of services. As a matter of fact, this solution gives more responsibility to the supplier but also more power. Both in the private and public sector, the procedures applied to announce a FM global service call for tenders are typically based on auctions, as transparent and efficient mechanisms if well designed. More in detail, a public administration can apply the open procedure, the restricted procedure, the competitive dialogue and, exceptionally, the negotiated procedure ([5]).

Two crucial steps in a FM outsourcing contract are (i) the understanding, the prioritization and the communication to potential suppliers of what the organization requires, and (ii) the development of a contracting mechanism that reflects the areas of concern and encourages the supplier to fulfill the organization expectations ([6]). Both these two critical aspects originate from the five main risks of outsourcing, as identified by [7]: dependence on the suppliers, hidden costs, service provider's lack of necessary capabilities, social risk and the loss of know-how. However, the latter plays a crucial role. As a matter of this fact, there are evidences that outsourcing involves high risks in terms of loss of competencies on the non-core processes ([8], [9], [10]), and also on related technology-based competencies ([11]). This fact makes the definition of proper service conditions (service levels) and the subsequent identification of the best contractors by the

procurer extremely difficult, and, in the average-long run, shifts the power asymmetry in favor of service providers.

Outsourcing FM services usually requires an high degree of interaction and service customization. Thus, FM companies offer field-based services, based on a high interaction with the client, at a high customization and specialization level; to do this, they have to work inside the client structure and thus they highly impact on the client performances. However, the expectations in service outsourcing are often imprecise and the objective is subjective (because not so easily measurable as in manufacturing outsourcing). Thus, the failure in satisfying the clients' expectations, scarcely clarified in the contract due to a clients' lack of knowledge on the outsourced activities, is ground of conflicts, contract cancellations and penalties.

In recent past, many scholars and practitioners partnering arrangements have become popular in FM ([12]), in order to transform the adversarial relationships into cooperative ones. Even if the relationship among procurer and supplier cannot be based only on the contract (due to its incompleteness Williamson [13] highlights that all real contracts are incomplete because of negotiation costs, bounded rationality and information asymmetry. It follows that various pre- and post-contractual opportunistic behaviors of contractors may arise.), the contract is still the keystone on which all the relationships are based and cannot be easily modified. So, before creating a partnership, a careful contractual definition of requirements, service levels and of supplier's commitments is necessary and crucial.

Moreover, on the procurer side there is also growing necessity to change some services characteristics during the contract period. In fact, after the bargaining and the contract signature, the flexibility of adding new features or enhancing/decreasing services is usually highly reduced ([14]). In synthesis, the real challenge in the outsourcing of facility management activities is writing a contract that is specific enough to protect the procurer (by defining the proper requirements and service levels) and flexible enough to accommodate unplanned events ([15]), by reducing, at the same time, the cost of negotiations and the power asymmetry in favor of service providers.

To this purpose, [16] suggest to introduce flexible options in the outsourcing contract clauses, such as, for example, clauses which associate the supplier payment to the performance of the client organization, clauses which permit early termination of the contract.

A different form of flexibility in FM contract is represented by the Service Level Agreement (SLA), an appendix of outsourcing contract in which the target service levels are clarified and, in some cases, can be periodically changed according to specific rules and restrictions. But a first challenge and benefit of using SLA is that the organization must establish exactly what the core business is, while a second one is the definition of what level of service should be provided. As highlighted by [17], the level at which services are pitched should reflect and be linked to best practices. However, benchmarking best practices is quite impossible in the realty, above all during the phase of call for tender definition.

Another possible solution comes from the European public sector, where the European Directive 18/2004 approved the collaborative relationship between client and potential contractors before the call for tenders in the so-called technical dialogue. This activity allows the public administration to collaborate with the private companies, the knowledge owner, with the objective to identify the best management model and particularly to prepare the contract terms. But this practice cannot significantly mitigate the criticality due to information asymmetry and does enhance the cost of negotiations.

In this work, we propose a multi-attribute auction-based mechanism that allows private companies and public administrations to outsource FM services by mitigating the most relevant drawbacks due to the client's lack of skills and crucial information on the purchased non-core activities. The proposed mechanism does not require a high effort to the procurer in terms of providing detailed expectations; in fact, it aims at extracting crucial technical and economic information directly from the suppliers, by inducing them to compete both in terms of prices and knowledge revealed (e.g. plausible service levels, suppliers' commitments, the right duration of the contract). In this sense, the proposed mechanism is also quite practice for the client organization. Moreover, the mechanism saves the procurer from signaling ex ante to the suppliers the score that every possible specific offer on any attribute will obtain.

In particular, the mechanism allows the procurer to request bids on several measurable technical and economic attributes of the supply of FM services, according to the procurement contract. Moreover, the procurer can assign weights to such features to signal their relevance to the sellers. Furthermore, the score obtained by every bid with respect to any attribute cannot be known by the players before bidding (i.e. ex ante) as it is endogenously determined on the basis of the submitted offers (i.e. ex post).

The paper is organized as follows. Section 2 introduces the framework, the issues to be addressed and the main features of the proposed solution, while Section 3 presents the endogenous multi-attribute auctioned-based mechanism designed for the procurement of facility management activities. Section 4 delineates some concluding remarks.

II. Information asymmetry and the attribute model

Let us consider a scenario where a company or a local/central public administration, the procurer [1], needs to outsource a bundle of facility management services aimed at supporting his core activities. In order to buy the necessary FM services, a common practice [2] consists of designing a transparent contest which single providers and alliance of

---

[1] To prevent confusion, from now on we refer to the procurer as "he" and any seller as "she".

[2] This approach is often applied by many big organizations, such as, for instance, central public administrations, multinationals, utilities (electric power, water and transportation companies), large-scale distribution companies.

suppliers [3] can take part in; usually, either participation is completely open or it is restricted to companies/coalitions which have been previously selected as skillful through a qualification process (which, in its turn, can be required by any company/coalition or only after being invited by the procurer himself).

Therefore, the procurer defines a formal proposal where detailed supply rules are provided. For instance, the procurer might specify the quantity demanded with the required quality, the payment conditions, the set of penalties in the case that the described undertakings are not fulfilled ex post, the terms of delivery and warranty. Moreover, when participation is open, in order to select a reliable provider/coalition both in terms of owned know-how and economic performances, the formal proposal could provide for a set of characteristics that the supplier/coalition must have (specific certifications, targets for key financial ratios, etc.). However, this formal proposal, usually composed by a main body and by several technical annexes, is not wholly specified, in the sense that some quantitative characteristics have to be decided within the contest (e.g. the overall required price) by calling for bids on these features from the suppliers. Once the contest is over, the formal proposal gets completely specified and thus it represents the procurement contract, which is binding with respect to the provider/coalition which is selected as the winner of the competition. In this sense, we will refer to the quantitative features which are specified through the competition process as contract attributes. Moreover, in the following, a single organization or a coalition of organizations which share the responsibility of being compliant with the procurement contract will be indistinctly referred to as supplier (or seller or provider).

In this work we consider the case where every competition allows for one single provider. In other words, we consider the majority case where either a global contract view is adopted (only a single formal proposal for all the FM services is implemented such that a single winner is allowed), or multiple separate contests are carried out, each one related to a specific set of FM services but each one allowing for exactly one winning supplier. [4]

---

[3] Often, a seller can value the supply of a particular FM service more if she can also supply another specific FM service (for instance, because of cost savings due to scale and scope economies). In such a case, the seller is provided with high incentives in formulating a single economic proposal in order to supply all these FM services to the procurer. However, even in this case the single supplier can be not able (because of any technical or economic reason) to provide all the required FM services, and thus she could find convenient to be the leader or a simple member of a coalition of enterprises which jointly take the responsibility of fulfilling the FM services procurement contract. Therefore, in general, a single supplier or an alliance of providers can be awarded the required supply of FM services.

[4] In principle, the procurer could define separate and distinct formal procurement proposals and simultaneously acquire all the needed FM services though the same allocation procedure. In so doing, the procurer would allow for multiple winning providers/coalitions without know ex ante how the FM services will be partitioned among the winning suppliers. This combinatorial auction based approach would likely rice the competition level among the suppliers as they could offer by tuning better the exploitation of possible production synergies among FM services ([18], [19]). However, such an approach is largely minority in the practice and identifying the winning bids requires a high computational effort (see [20], [21]).

Whatever the mechanism to select the supplier, the procurer foremost has to completely specify the characteristics of the supply of every FM service (the desired quality, delivery terms, prices, penalties, etc.). However, providing all these contract features for every demanded FM service could require a big effort for the procurer, both in terms of own dedicated human resources and of money (e.g. in the case that he decides to pay some professional consultants to perform specific analysis and writing parts of the technical annexes). Moreover, when suppliers have crucial private information (above all on the technical issues), the procurer could be wrongly driven to define contract features which could be unfitting or even damaging to the procurer himself. Therefore, in presence of high level of information asymmetry, how could the procurer cheaply acquire the necessary knowledge to effectively formulate all contract features? Obviously, in the case whereby the procurer could have full access to the suppliers' private know-how, he could set effective contract futures. Thus, the procurer would need a mechanism to extract (at least partially) the necessary knowledge directly from the sellers.

A recent work ([22]) have dealt with a similar problem and the approach they propose could be taken as inspiration to design an effective mechanism to acquire FM services. In particular, under the collective innovation environment a multi-attribute combinatorial auction-based mechanism has been proposed with the aim of allowing a seeker to acquire the skills and the technical knowledge to generate innovation. Putting apart the combinatorial framework (see note 7), the mechanism proposed in [22] presents an interesting feature, namely, the fully endogenous scoring rule. In particular, any submitted bid obtains a score which depends on the bid itself, but also on the opponents' bids [5]. In fact, a bid is scored very high if it is sufficiently better than the average bid, while it is scored very low when it is sufficiently worse that the average bid. In a sense, although this approach belongs to the literature strand of multi-attribute auctions ([23]; [24]; [25]; [26]; [27]), it follows the principle underlying the yardstick competition paradigm ([28]), where the benefits which any player can get do not exclusively depend on the player's efficiency but mainly on the efficiency of the player's opponents. More in detail, a partial score and a weight are associated with any contract parameter; such partial scores are evaluated on the basis of the distance from the average value which has been offered for the parameter, and the average distance from the average offered value for the parameter. Then, the overall score assigned to the submitted bid is equal to the weighted summation of the computed partial scores.

Indeed, the idea underlying this scoring rule could be very useful also in our context, where the loss of knowledge which affect the procurer generates a high level of information asymmetry which could be reduced by inducing the potential FM service providers to reveal as private technical and economic information as possible. In fact, being the obtained score partially depending on the distance of the offered effort of the supplier from the opponents' offered efforts, any player might be provided with high incentives to balance the level of

---

[5] This rule is defined under a combinatorial framework where bids on bundles are stored and can be dominated.

the revealed information associated with any attribute in such a way that, on average, the offered effort results ex post sufficiently larger than the average effort signaled by all the participants in the contest.

However, the scoring rule proposed in [22] cannot be entirely applied in out context mainly as this rule does not fix any upper or lower bound on the partial scores; in fact, any partial score associated with parameter i can be evaluated more than 1 (or less than -1) and, in so doing, it is not possible to know ex ante the maximum and the minimum number of points which a bid can obtain with respect to a specific attribute. This aspect would likely provide high incentive to the providers to reveal as much private information as possible for every contract attribute. However, it cannot be viable in our context. In fact, under a multi-attribute auction procedure applied to allocate the supply of FM services, to set ex ante, for any parameter, a maximum number of points which can be assigned to any attribute (and thus to the overall bid) is mandatory in the practice, due to issues related to transparency and fairness.[6]

Therefore, although we preserve the idea of endogenously computing the score of a bid by analyzing all the submitted bids with respect to any considered attribute, we propose a different way to determine any single partial score. In the next section, while illustrating the whole mechanism, we detail the new scoring rule.

III. The multi-attribute mechanism

We now introduce a few notation and definitions to model the multi-attribute procurement contract and to describe the proposed mechanism. By following [22], any contract can be characterized by some parameters (or attributes), that is, quantitative data which can be specified by selecting exactly one value among those the procurer has defined as feasible for such parameters. In particular, any attribute is defined by the procurer as ascendant (descendent) in the case that the higher (the lower) the attribute, the better the resulting contract for the procurer. Let positive integer r be the overall number of (ascendant/descendent) contract attributes, and nonnegative reals $w_1, \ldots, w_r$ be the weights associated by the procurer to the parameters in order to signal to the suppliers which attributes are the most crucial (with $\sum_{a=1,\ldots,r} w_a = 100$). Moreover, let $[l_1, u_1], \ldots, [l_r, u_r]$ be the real intervals which identify for any attribute the feasible values (with $l_a < u_a$ for any $a = 1, \ldots, r$). Any parameter a has to be set in every suppliers' bid equal to a value of the feasible set $[l_a, u_a]$.[7]

Let us denote by $\bar{v} = (v_1, \ldots, v_r) \in [l_1, u_1] \times \ldots \times [l_r, u_r]$ a version of the multi-attribute procurement contract, that is, the contract obtained by setting contract attribute a equal to $v_a \in [l_a, u_a]$ for any $a = 1, \ldots, r$. Given two distinct contract versions $\bar{v}_1 = (v_{1,1}, \ldots, v_{r,1})$ and $\bar{v}_2 = (v_{1,2}, \ldots, v_{r,2})$ of a contract, version $\bar{v}_1$ is equal to $\bar{v}_2$ when $v_{a,1} = v_{a,2}$ for any ascendant/descendant parameter a. Moreover, version $\bar{v}_1$ is dominated by $\bar{v}_2$ when (i) $v_{a,1} \leq v_{a,2}$ for any ascendant parameter a and $v_{a,1} \geq v_{a,2}$ for any descendant parameter a, and (ii) for at least one attribute $\bar{a} \in \{1, \ldots, r\}$ inequality $v_{\bar{a},1} < v_{\bar{a},2}$ holds if $\bar{a}$ is ascendant or $v_{\bar{a},1} > v_{\bar{a},2}$ holds if attribute $\bar{a}$ is descendant.

We now describe the proposed multi-attribute auction-based mechanism and its endogenous scoring rule.[8] Essentially, it is a multi-attribute one-shot auction-based mechanism, where suppliers are called to submit contract versions, that is, the bids. Only valid bids are allowed, namely, bids where the value offered for any parameter is feasible. In particular, it works as follows:

At the beginning of the mechanism, the procurer decides the attributes and the related data (directions, intervals and their rounding rules, weights), and the score rounding rule. Such information is then communicated to any participant.

Let B the set of any (valid) bid submitted by the sellers. Each bid in B that results dominated by another bid in B is removed from B and thrown away, as only a non-dominated bid represents an instance of revealed private information, and thus it can contributes to affect the score assigned to any other bid. Moreover, considering only non-dominated bids will discourage shill bidding, that is, deliberate placing fake bids by some provider, who take part in the auction through multiple identities, to artificially drive down the level of the average bid.

At the end of the mechanism, a score for each bid in B is computed and the highest-score one is selected as winning (ties are broken randomly).[9] Then the mechanism discloses to the participants all bids in B and indicates the winning one. Then, the auction ends and the contract underlying the winning bid becomes binding with respect to the supplier who have placed it.

Let us now detail how computing the score of each submitted bid. As said, the scoring rule must have the property of assigning very high score to those bid which are sufficiently better than the average effort provided by all the bids. For instance, if the attribute is ascendant then a function with an endogenously determined "S" shape could be applied (e.g. based on the average and the deviation of the submitted offers for the attribute). In any case, to be viable in practice, the

---

[6] In practice, to any attribute is associated a positive weight which represents the maximum number of points which can be obtained by any bid with respect to this attribute. Commonly, all these weights sum to 100, and thus any bid can obtain an overall score that ranges between 0 and 100; such score is the summation of the partial scores, each one between 0 and the related weight.

[7] Actually, in a real implementation of the mechanism only a limited number of real values of any interval could be chosen according to some rounding rule. For instance, any submitted value $v_a \in [l_a = 2.5, u_a = 15]$ for an ascendant (descendant) parameter a could be rounded down (up) to two

decimal places.

[8] In practice, the score too is subject to a rounding rule which has to be defined ex ante the bids submission.

[9] Obviously, the score of any bid which has been discarded as dominated is, by construction, strictly lower than the score of the bid which dominates it.

selected rule must comply with the following requirements due to transparency and fairness issues:

For any attribute a, the function which maps any offer $v_{a,j}$ into a partial score a_j must be continue in any point of the corresponding interval (score jumps are not compliant with fairness requirement). Moreover, if the attribute is ascendant (descendant) then it has to be increasing (decreasing) monotone.

For any attribute a, the function which maps any offer $v_{a,j}$ for a into a partial score a_j must return a value between 0 and the maximum weight w_a. For an ascendant (descendant) attribute, the function has to return $a_j = 0$ ($a_j = w_a$) when $v_{a,j} = l_a$ ($v_{a,j} = u_a$), and return $a_j = w_a$ ($a_j = 0$) when $v_{a,j} = u_a$ ($v_{a,j} = l_a$).

For any attribute a, the function which maps any offer $v_{a,j}$ for a into a partial score a_j must be defined over the whole interval, whatever the set of offers for parameter a be. The function has to be defined even in the particular case whereby each provider submits exactly the same offer for attribute a, namely, any provider offers the average offer.

For any attribute a, the function which maps any offer $v_{a,j}$ for a into a partial score must return a value for the average offer which is consistent with its position within the interval (i.e. the returned value has to tend as towards 0 as the average offer tends to l_a, while it has to tend as towards w_a as the average offer tends to u_a). This returned value has to be consistent with the position of the average offer within the interval even when all providers offer exactly the same value for attribute a, namely, the average.[10]

The scoring rule must be not discriminatory, namely, any two identical bids must be equally scored.

Given supplier p's bid $\bar{v}_j$, score b_j depends on the weight associated by the procurer to any parameter and on the values offered by provider p and by p's opponents for any attribute characterizing the contract. In particular, the way of computing the scores is based on the relative efforts supported by p's opponents with respect to supplier p's effort; in fact, given the average of the feasible values offered so far through bids in B for an ascendant (descendant) parameter of the contract, then the larger (the lower) than this average is the feasible value offered for the same parameter by provider p through bid $\bar{v}_j$, the higher is the score associated with bid $\bar{v}_j$. In such a way, for instance, if provider p is bidding high quality while p's best opponents are offering low quality, then

p will get a score much higher than in the case whereby all p's opponents also offered high quality. This approach of determining the score could provide the suppliers with high incentives to increase their efforts with respect to any attribute defined by the procurer (in such a way, it allows the procurer to partially extract from suppliers their private information). Furthermore, it saves the procurer the burden of designing ex ante a specific function for each parameter which signals to the suppliers the score that every possible specific offer on any attribute will obtain.

In particular, given any contract version $\bar{v}_j = (v_{1,j}, \dots, v_{r,j}) \in B$, score b_j of bid $\bar{v}_j$ is computed as follows. First, for $i = 1, \dots, r$ the mechanism computes both average m_a and standard deviation σ_a of the values offered for parameter a by all suppliers:

$$m_a = \frac{\sum_{j \in B} v_{a,j}}{|B|} \qquad \sigma_a = \sqrt{\frac{\sum_{j \in B} (v_{a,j} - m_a)^2}{|B|}}$$

Such quantities are then applied to provide an endogenous partial score a_j of attribute a, subject to requirements from 1 to 5. In particular, if a is ascendant then $a_j = w_a f_+(v_{a,j})$, where $f_+(v_{a,j})$ is an increasing monotone function which assigns a value between 0 and 1 to the submitted offer $v_{a,j}$ as follows:

$$f_+(v_{a,j}) =$$
$$\begin{cases} \frac{(v_{a,j} - l_a)}{(u_a - l_a)} * \left(\frac{(v_{a,j} - l_a)}{(m_a - l_a)} \right)^{\ln(1 + \sigma_a)} & v_{a,j} \in [l_a, m_a] \\ 1 - \frac{(u_a - v_{a,j})}{(u_a - l_a)} * \left(\frac{(u_a - v_{a,j})}{(u_a - m_a)} \right)^{\ln(1 + \sigma_a)} & v_{a,j} \in [m_a, u_a] \end{cases}$$

Note that the higher the deviation σ_a, the greater the partial score for those players who offer larger than the average, and the smaller the score for those sellers who offer lower than the average. For instance, let us consider an ascendant attribute a whose feasible values are in $[10\,000, 20\,000]$. In Figure 1 function $f_+(v_{a,j})$ is exemplified in the case that $m_a = 16\,500$ and $\sigma_a \in \{0, 9, 90, 900\}$, while in Figure 2 it is illustrated in the case that that $m_a = 12\,500$ and $\sigma_a \in \{0, 9, 90, 900\}$.

---
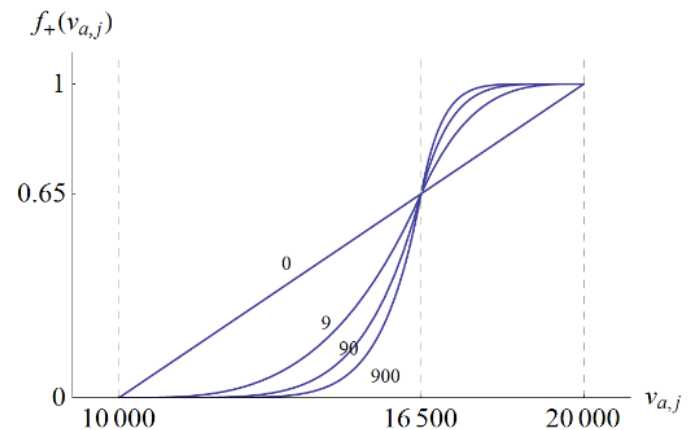
[10] In [22], when all players submit the same offer for a parameter under the collective innovation environment, such an offer is essentially erased from the computation as considered non differential. On the contrary, under the FM framework, it is crucial to make transparent the points globally assigned to any player; thus, when all players submit the same offer for an attribute, the implemented tool has to automatically assign a partial score to the bid. In addition, such a partial score must reflect the actual effort provided by the supplier, namely, it must be higher (lower) if it is similar to the upper (lower) bound associated with the attribute. In other words, it has not to be a constant.

Figure 1.   Function f_+ (v_(a,j)) provided that m_a=16 500 and σ_a∈ {0,9,90,900}.
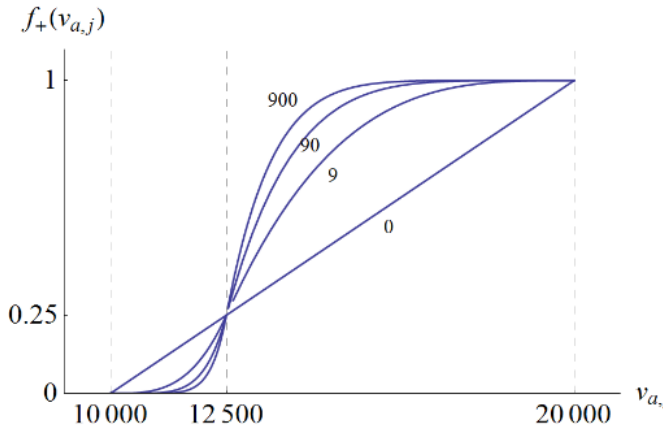

Figure 2.   Function $f_+(v_{a,j})$ provided that $m_a = 12\,500$ and $\sigma_a \in$ {0,9,90,900}.

Similarly, in the case that attribute a is descendent, the related partial score is $a_j = w_a f_-(v_{a,j})$, where $f_-(v_{a,j}) = 1 - f_+(v_{a,j})$ is a decreasing monotone function which assigns a value between 0 and 1 to the submitted offer $v_{a,j}$ as follows:

$$f_-(v_{a,j}) =$$
$$\begin{cases} 1 - \frac{(v_{a,j}-l_a)}{(u_a-l_a)} * \left(\frac{(v_{a,j}-l_a)}{(m_a-l_a)}\right)^{\ln(1+\sigma_a)} & v_{a,j} \in [l_a, m_a] \\ \frac{(u_a-v_{a,j})}{(u_a-l_a)} * \left(\frac{(u_a-v_{a,j})}{(u_a-m_a)}\right)^{\ln(1+\sigma_a)} & v_{a,j} \in [m_a, u_a] \end{cases}$$

Finally, the overall score of bid $\bar{v}_j$ is equal to:

$$b_j = \sum_{a=1}^{r} a_j = \sum_{\substack{a=1:\, a \text{ is} \\ \text{ascendant}}}^{r} w_a f_+(v_{a,j}) + \sum_{\substack{a=1:\, a \text{ is} \\ \text{descendant}}}^{r} w_a f_-(v_{a,j})$$

It is easy to verify that the scoring rule is compliant with requirements from 1 to 4. In particular, let us observe what follows:

Function $f_+(\cdot)$ is continuous also at m_a. Thus, who offers at the average for an ascendant (descendant) attribute a obtains a partial score for the attribute equal to $w_a \frac{(m_a-l_a)}{(u_a-l_a)}$ ($w_a \frac{(u_a-m_a)}{(u_a-l_a)}$).

Function $f_+(\cdot)$ returns 0 at l_a, even when the average is exactly equal to l_a, that is, $f_+(l_a)|_{m_a=l_a} = f_+(m_a) = \frac{(m_a-l_a)}{(u_a-l_a)} = \frac{(l_a-l_a)}{(u_a-l_a)} = 0$. Therefore, the provider who offers l_a for an ascendant (descendant) attribute a obtains a partial score equal to $w_a \cdot 0 = 0$ ($w_a \cdot 1 = w_a$).

Function $f_+(\cdot)$ returns 1 at u_a, even when the average is exactly equal to u_a, that is, $f_+(u_a)|_{m_a=u_a} = f_+(m_a) = \frac{(m_a-l_a)}{(u_a-l_a)} = \frac{(u_a-l_a)}{(u_a-l_a)} = 1$. Therefore, the supplier who offers u_a

for an ascendant (descendant) attribute a obtains a partial score equal to $w_a \cdot 1 = w_a$ ($w_a \cdot 0 = 0$).

Moreover, by construction, the scores assigned with any two identical bids are equal, and thus the scoring rule is not discriminatory.

Finally, let us remark how common "S" shape functions cannot be applied in our case as they do not fulfill with one or more requirements from 1 to 4. For example, given an ascendant attribute, the partial score based on the (endogenously determined) logistic function $w_a \dfrac{1}{1+e^{-\frac{v_{a,j}-m_a}{\sigma_a}}}$ cannot satisfy requirement 2, 3 and 4 (e.g. let us consider the case that each provider exactly offers the average offer).

Let us now describe an example with four players and a contract with three attributes related to just one FM service. The first attribute represents a measure of the capacity level of the FM service at issue; let us assume it is ascendant and its range is [8,14] (only integer values can be accepted). The second attribute represents a measure of the minimum quantity of FM service per year that the procurer will have to acquire for four years [0,200] (only integer values can be accepted). The third attribute indicates a measure of the price per unit of service [2,7] (only real values rounded up to one decimal place can be accepted). The attributes weights are $w_1 = 35$, $w_2 = 20$ $w_3 = 45$. Moreover, let us assume that the procurer decides that partial scores are rounded to two decimal places.

Supplier $S1$ submits the contract version $\bar{v}_1 = (8,130,3)$, $S2$ submits $\bar{v}_2 = (12,160,4)$, $S3$ submits $\bar{v}_3 = (8,140,3)$ and $S4$ submits $\bar{v}_4 = (13,120,5)$. Since $\bar{v}_3$ is dominated by $\bar{v}_1$ then $B = \{\bar{v}_1, \bar{v}_2, \bar{v}_4\}$. Thus, it results that:

$$m_1 = \frac{8+12+13}{3} = 11$$

$$\sigma_1 = \sqrt{\frac{(8-m_1)^2+(12-m_1)^2+(13-m_1)^2}{3}} = 2.16$$

$$m_2 = \frac{130+160+120}{3} = 136.67$$

$$\sigma_2 = \sqrt{\frac{(130-m_2)^2+(160-m_2)^2+(120-m_2)^2}{3}} = 17$$

$$m_3 = \frac{3+4+5}{3} = 4$$

$$\sigma_3 = \sqrt{\frac{(3-m_3)^2+(4-m_3)^2+(5-m_3)^2}{3}} = 0.82$$

Therefore, the scores assigned with the contract versions in set B are:

$$b_1 = w_1 f_+(8) + w_2 f_-(130) + w_3 f_-(3) = 0 + 8.75 + 39.05 = 47.8$$

$$b_2 = w_1 f_+(12) + w_2 f_-(160) + w_3 f_-(4) = 27.68 + 1.06 + 27 = 55.74$$

$$b_4 = w_1 f_+(13) + w_2 f_-(120) + w_3 f_-(5) = 33.35 + 11.76 + 14.13 = 59.24$$

At the end of the mechanism, the winning contract version is $\bar{v}_4$ with a score equal to 59.24. The auction ends and the contract version $\bar{v}_4 = (13,120,5)$ gets binding with respect to bidder $S4$.

IV. **Concluding remarks**

When suppliers have (economic and technical) crucial private information, client organizations may incur into very high risk when outsourcing FM services, both in terms of purchasing the wrong thing and at the wrong price. The proposed multi-attribute auction-based mechanism allows the procurer to mitigate these risks by requiring a low effort to the procurer in terms of providing detailed terms and conditions related to the characteristics of the supply of every FM service. In fact, the mechanism aims at extracting significant technical and economic information directly from the providers, by inducing them to compete both in terms of prices and knowledge revealed. In fact, it takes inspiration from the principle underlying the yardstick competition approach while scoring the submitted bids.

In particular, the auction-based mechanism allows the procurer to request bids on measurable attributes of the procurement contract, which are then endogenously scored by taking into account the features of all the submitted bids which satisfy a specific dominance requirement.

Therefore, the proposed mechanism could find practical implication through the implementation of a web-based application inside e-procurement platforms of the private operators and public administrations.

References

[1] De Toni A.F., Fornasier A., Montagner M., Nonino F. (2007). A Performance Measurement System for Facility Management. The Case Study of a Medical Service Authority. International Journal of Productivity and Performance Management, 56(5/6): 417-435.

[2] De Toni A.F., Nonino F. (2009). The facility management: non core services definitions and taxonomy. In A.F. De Toni, A. Ferri, and M. Montagner (Eds.), Open Facility Management. A successful implementation in a public administration (pp. 3-28). Italy, Milan: International Facility Management Association.

[3] Osservatorio Nazionale FM (2010). The Italian Market of Facility Management in Italy. Available at: http://www.osservatoriofm.it [retrieved January 10, 2010].

[4] CONSIP (2009). Rapporto annuale 2008 CONSIP. Available at: http://www.pubblicaamministrazione.net/file/whitepaper/000114.pdf [retrieved January 10, 2010].

[5] Brugnoletti M., Fogli S. (2009). Law concerning facility management contract award in Europe and Italy. In De Toni A.F., Ferri A., Montagner M. (Eds.), Open Facility Management. A successful implementation in a public administration (pp. 3-28). Italy, Milan: International Facility Management Association.

[6] Jones O.J. (1995). Corporate Partnering in Facilities Management. Facilities, 13(13): 21-26.

[7] Bertrand Q., Franc O. (2003). Bringing Together Strategic Outsourcing and Corporate Strategy: Outsourcing Motives and Risks. European Management Journal, 21(5): 647-661.

[8] Alexander M., Young D. (1996). Outsourcing: where's the value? Long Range Planning 29: 728-730.

[9] Bettis R., Bradley S., Hamel G. (1992). Outsourcing and industrial decline. Academy of Management Executive 6(1), pp. 7-22.

[10] Doig S.J., Ritter R.C., Speckhals K., Woolson D. (2001). Has outsourcing gone too far? McKinsey Quarterly, 4: 24-37.

[11] Hoecht A., Trott P. (2006). Outsourcing, information leakage and the risk of losing technology-based competencies. European Business Review, 18(5): 395-412.

[12] Roberts P. (2001). Corporate Competence in FM: Current Problems and Issues. Facilities, 19(7/8): 269-275.

[13] Williamson O.E. (1979). Transaction-Cost Economics: The Governance of Contractual Relations. Journal of Law and Economics, 22 (October): 3-61.

[14] Belcourt M. (2006). Outsourcing - The benefits and the risks. Human Resource Management Review, 16: 269-279.

[15] Johnson B. (1999). Counterintuitive Management of Information Technology. Business Horizons, March- April, 1999.

[16] Harris A., Giunipero L.C., Tomas G., Hult M. (1998). Impact of Organizational and Contract Flexibility on Outsourcing Contracts. Industrial Marketing Management, 27: 373-384.

[17] Pratt T. (2003). Introducing a Service Level Culture. Facilities, 21(11/12): 253-259.

[18] Avenali A., Bassanini A. (2007). Simulating combinatorial auctions with dominance requirement and loll bids through automated agents. Decision Support Systems, vol. 43, n. 1, pp. 211-228.

[19] Avenali A. (2009). Exploring the VCG mechanism in combinatorial auctions: The threshold revenue and the threshold-price rule. European Journal of Operational Research, vol. 199, pp. 262-275.

[20] De Vries S., Vohra R.V. (2003). Combinatorial Auctions: a Survey. Informs Journal on Computing, vol. 15 (3), pp. 284-309.

[21] Avenali A. (2007). Resolution Branch and Bound and an Application: the Maximum Weighted Stable Set Problem. Operations Research, vol. 55, n. 5, pp. 932-948.

[22] Avenali A., Battistella C., Matteucci G., Nonino F. (2013). A mechanism for supporting collective innovation: the open contract-based challenge. Information Systems and e-Business Management, vol. 11 (4), pp. 541-568.

[23] Che Y.-K. (1993). Design Competition Through Multidimensional Auctions. Rand Journal of Economics 24, 668-679.

[24] Branco F. (1997). The Design of Multidimensional Auctions. Rand Journal of Economics 28, 63-81.

[25] Teich J.E., Wallenius H., Wallenius J., Koppius O.R. (2004). Emerging Multiple Issue e-Auctions. European Journal of Operational Research, vol. 159 (1), pp. 1-16.

[26] Chen J., Huang H. (2005). On-line Multi-attributes Procurement Combinatorial Auctions Bidding Strategies. Lecture Notes in Computer Science, 3516, 578-585.

[27] Schnizler B., Neumann D., Veit D., Weinhardt C. (2008). Trading grid services – a multi-attribute combinatorial approach. European Journal of Operational Research, vol. 187 (3), pp. 943-961.

[28] Shleifer A. (1985). A theory of yardstick competition. The RAND Journal of Economics, vol. 16 (3), pp. 319-327.