A Multiattribute Sealed-Bid Procurement Auction with Multiple Budgets for Governments' Vendor Selection

Jay Simon
jrsimon@nps.edu

Francois Melese
fmelese@nps.edu

Defense Resources Management Institute
Naval Postgraduate School
699 Dyer Rd
Monterey, CA 93943

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Abstract

This paper offers a new approach to government's vendor selection decisions in major public procurements. A key challenge is for government purchasing agents to select vendors that deliver the best combination of desired non-price attributes at realistic funding levels. The mechanism proposed in this paper is a multiattribute first price, sealed bid procurement auction. It extends traditional price-only auctions to one in which competition takes place exclusively over attribute bundles. The model is a multiattribute auction in which a set of possible budget levels is specified. This model reveals the benefits of defining a procurement alternative in terms of its value to the buyer over a range of possible expenditures, rather than as a single point in budget-value space. This new approach leads to some interesting results. In particular, it suggests that in a fiscally constrained environment, the traditional approach of eliminating dominated alternatives could lead to sub-optimal decisions. Finally, an extension of the model explicitly examines the buyer's decision problem under budget uncertainty by applying a utility function assessed over the value measure.

Keywords: Public procurement; defense acquisition; affordability; vendor selection; multiattribute auctions

1. Introduction

Over the next five years, the US Department of Defense (DoD) plans to spend more than $357 billion on the development and procurement of major defense systems. Recent congressional testimony urges the DoD to "achieve a balanced mix of weapon systems that are affordable" (Sullivan (GAO) 2009). In the absence of profits to guide public procurement decisions, the challenge is to select vendors that deliver the best possible combination of desired non-price attributes at realistic funding levels. The public procurement mechanism proposed in this paper is a multiattribute first price, sealed bid procurement auction.

The US Federal Acquisition Regulations (2005) provided guidance in subpart 14.5 on a two-step procurement process for government agencies:

> Step one consists of the request for, submission, evaluation, and (if necessary) discussion of a technical proposal. No pricing is involved. Step two involves the submission of sealed price bids by those who submitted acceptable technical proposals in step one. Invitations for bids shall be issued only to those offerors submitting acceptable technical proposals in step one. An objective is to permit the development of a sufficiently descriptive and not unduly restrictive statement of the Government's requirements especially useful for complex items. (https://www.acquisition.gov/far/html/Subpart 14_5.html)

Blondal (2006) discusses a similar two-stage[1] bidding process, in which the procuring agency issues a general request, and then later issues a detailed request based on the responses received.

Much of the multiattribute auction literature, including Che (1993), Beil and Wein (2003), and Parkes and Kalagnanam (2005), either implicitly or explicitly includes price alongside non-price attributes in the buyer's value/utility function[2]. While this standard approach is appropriate in many private-sector contexts, it generates complications in public procurements such as major defense acquisitions. Unlike the private sector where the incentive to maximize profits provides a clear objective, the best government decision makers can do is to maximize value to the public given budget constraints.

Due to the existence of budget constraints, Michael and Becker (1973) make the argument that costs be excluded from measures of value. Their focus is on performance and affordability. This concept is known as “cost as an independent variable” (CAIV). Vendors compete for a government contract based on their relative costs of producing different quality levels of components and their unique (sunk) technology investments that define their ability to offer different tradeoffs among these components. Larsen (2007) offers the following explanation of CAIV:

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[1]Blondal defined "stage" differently than we do in this paper. We use the term to refer to a decision or set of decisions that depends only on exogenously given parameters and previous decisions. For example, Blondal considers a government agency's offer and the vendor responses to be a single stage, whereas we treat these as two distinct stages. Using our interpretation, Blondal's model is in fact a five-stage process.

[2]Value functions are often referred to in defense procurement as *measures of effectiveness* (MOEs). The term “MOE” is used in a few different ways. It may describe an attribute itself, a single-attribute value function, or a multiattribute value function, which might incorporate the whole objectives hierarchy, or only a portion of it. For a detailed discussion of MOEs, see Sproles (2000). Regardless, this paper emphasizes using an MOE that includes exclusively non-price attributes.

> All acquisition programs/issues consist of three fundamental elements: cost, performance and schedule. Under CAIV, performance and schedule are considered a function of cost. Cost and affordability should be a driving force not an output after potential solutions are established. (p. 15)

Loerch, Koury, and Maxwell (1999) discuss a *Value Added Analysis* approach for applying multiattribute preferences to optimize the United States Army's force structure under a budget constraint, in accordance with the CAIV concept. The scope of our model differs from theirs, in that we focus on a single acquisition program. This allows us to incorporate vendors' decision making into the model, along with issues of asymmetric information. In our model, as in theirs, prices/costs do not appear in the buyer's value function. Instead, the buyer provides information about possible budget levels, allowing prices to appear in affordability constraints in the spirit of CAIV.

Budget constraints may not be known when the vendor selection decision is made. Buede and Bresnick (1999) describe the acquisition process as having four major phases, and point out that vendor selection occurs in the first phase, while the budget may change throughout the entire process. Two pioneers in defense economics, Hitch and McKean (1967), advocate determining the maximum effectiveness for a given budget, and then examining how each alternative fares under several different budget scenarios. Quade (1989) also advocates evaluating vendor proposals based on a range of possible budgets. This leads to the generation of what we call an "expansion path" for each vendor, showing how the vendor's proposals change as the budget increases/decreases, and thus providing a more complete view of the vendor's ability to provide performance. Our model allows the buyer to offer a set of possible budget levels and solicit vendor proposals for each one, leading to the generation of expansion paths.

Expansion paths are invaluable, because the buyer has otherwise very limited knowledge of the vendors' costs of producing a particular attribute, as well as the technologies (production functions) that combine those attributes into the products under consideration. Parkes and Kalagnanam (2005) describe the vendors' private information: "Seller costs can be expected to depend on [the] local manufacturing base and sellers can be expected to be well informed about the cost of (upstream) raw materials" (p. 437). The general motivation for constructing the expansion paths is expressed succinctly by Keeney (2004): “If you do not have the right problem, objectives, alternatives, list of uncertainties, and measures to indicate the degree to which the objectives are achieved, almost any analysis will be worthless” (p. 200). It is imperative in public procurement for alternatives to be adequately described, and for any budget uncertainty to be explicitly acknowledged. We emphasize that this can be carried out using a *value-focused thinking* approach, as discussed by Keeney (1992) and by Parnell (2007) in the context of national defense. That is, it is important for the buyer's evaluation process to be carried out independently of the particular alternatives offered. Two examples of this approach to public decision making with multiple objectives are presented by Merrick et al. (2005) and Mild and Salo (2009).

In Section 2, we introduce our proposed three-stage procurement model, emphasizing the use of a value function with exclusively non-price attributes, and the specification of a set of possible budget levels. We formulate the decision problems faced by the buyer and the vendors, and discuss some of the insights which can be gained from the use of the model.

We also provide two historical examples of government procurement decisions that likely could have benefited from a more complete formulation of alternatives and uncertainties.

After vendor bids have been solicited for a spectrum of possible budget levels, Section 3 expands the formulation of the buyer's problem to explicitly include the buyer's beliefs about the probability associated with various budget levels. We follow a decision under uncertainty approach as introduced by Pratt, Raiffa, and Schlaifer (1964). In addition to expressing their beliefs about various budget levels as probabilities, the government buyer specifies a utility function over the value of attribute bundles that incorporates his/her risk attitude, as discussed by Dyer and Sarin (1982) and Matheson and Abbas (2005). This results in a new metric proposed to evaluate vendors: an expected utility measure of performance.

2. Model

Our model consists of three stages, illustrated in Figure 1.

*****INSERT FIGURE 1 HERE*****

The procurement agency (buyer) begins by specifying a multiattribute value function over a set of desired attributes $A = \{a_1, \ldots, a_n\}$, as well as a set of (increasing) possible budget levels $B = \{b_1, \ldots, b_k\}$. There are m vendors, each of whom will respond in the second stage with a bid. A bid consists of a set of attribute levels that can be produced by a vendor for each of the k possible budget levels. Vendor j's bid can be expressed as k vectors of the form $A_j = \left(a_{1j}, \ldots, a_{nj}\right)$ for $j = 1, \ldots, m$, where a_{ij} is the level of attribute i offered by vendor j.

Note that unlike bids in most multiattribute auctions, A_j does not include any information about price. Instead, the price is implicitly captured by the possible budget constraints. The buyer's ultimate decision (the third stage) is to select a vendor $j \in \{1,\ldots,m\}$. The buyer's preferences over the attributes are represented by a value function $V\left(A_j\right)$. The same value function is used for all possible realized budget levels.

For ease of exposition, we assume $V\left(A_j\right)$ is an additive multiattribute value function similar to that discussed by Keeney and Raiffa (1976) and Kirkwood (1997), although it is later demonstrated the conclusions of the paper do not require $V\left(A_j\right)$ to be additive. The use of additive multiattribute value functions requires the assumption of mutual preferential independence (Dyer and Sarin 1979, Kirkwood and Sarin 1980). This implies that alternatives can be compared based exclusively on the set of attributes over which they differ, ignoring common levels of other attributes.

For any given budget level, the buyer's objective is:

$$\max_j \; V\left(A_j\right) = \sum_{i=1}^{n} w_i v_i\left(a_{ij}\right), \qquad (1)$$

where w_i is the weight the buyer places on attribute i: $0 \le w_i \le 1$, and $\sum w_i = 1$, and $v_i\left(a_{ij}\right)$ is the buyer's single-attribute value function for attribute i. We assume that $v_i(a_{ij})$ is scaled such that the minimum achievable value is zero, and the maximum achievable value is one. Note that since $V\left(A_j\right)$ is a weighted average of terms between zero and one, it also ranges from zero to one. We assume the buyer has an understanding of the range of attribute levels in determining the weights, and that the buyer explicitly shares the weights and the single-attribute value functions. It is necessary for the buyer to completely specify preferences to the vendors by providing w_i and $v_i(a_{ij})$, for $i = 1, \ldots, n$. The final stage of the model involves applying (1) to the set of vendor bids, and the buyer selecting the vendor that yields the highest value.

Given the buyer-determined set of desired attributes A, along with the weights and single-attribute value functions, and the set of possible budget levels B, each vendor produces an attribute bundle to submit to the buyer for each of the k possible budget constraints. Since vendors have private information about their own production capabilities and costs, each vendor forms his/her own private beliefs about the likelihood of a bid being accepted. We assume that all vendors believe the probability of a bid being accepted is increasing in $V\left(A_j\right)$ for all possible budget levels.

For simplicity, we also assume that each vendor has determined a desired amount of profit for each possible budget level, and that these fixed profit margins are incorporated into the attribute bundles offered. That is, we focus on the vendor's decision of how to allocate fixed amounts of money across the set of attributes to maximize the value provided to the buyer. Incorporating more detailed vendor behavior is not needed to obtain the main results in this paper, but would certainly be an interesting extension to the model. It is analogous to the problem of determining a bidding strategy for a Dutch auction (see McAfee and McMillan 1987 or Milgrom 1989), which requires a complete formulation of the bidder's beliefs, values, and risk attitude.

The problem faced by a representative vendor j for an arbitrary possible budget level b can be expressed as follows:

$$\max_{a_{ij}} \; V\left(A_j\right)=\sum_{i=1}^{n} w_{ij} v_i\left(a_{ij}\right), \; i=1,\ldots,n$$

$$\text{subject to: } \; C_j\left(v_i\left(a_{1j}\right),\ldots,v_n\left(a_{nj}\right)\right)\leq b, \tag{2}$$

where C_j is the total cost paid by firm j (with the desired profit margin included) to produce a set of single-attribute values. The cost incurred to generate the corresponding attribute bundle cannot exceed b. We assume that C_j is increasing in v_i for all i, and that C_j is strictly convex. This condition is not overly restrictive, since it simply implies decreasing returns from vendor investments to improve the individual attribute values. Because the objective function in (2) is linear, given the assumed properties of a representative vendor's cost function, a unique solution (vendor proposal) will exist.

For purposes of illustration, and ease of exposition, the remainder of this study focuses on two vendors and two (non-price) attributes. The two vendors can have different technologies with which to combine the two attributes, and may face different costs to improve individual attributes. The Lagrangian function to solve the vendor's problem is given by

$$L_j = w_1 v_1\left(a_{1j}\right)+w_2 v_2\left(a_{2j}\right)-\lambda_j\left(b-C_j\left(v_1\left(a_{1j}\right),v_2\left(a_{2j}\right)\right)\right), \text{ for } j = 1,2. \tag{3}$$

Since an improvement in either attribute increases the value of a particular attribute bundle to the buyer, or $\partial V / \partial v_i > 0$, each vendor will use the maximum available budget b to produce its attribute bundle proposal. In this case, first order necessary conditions for an optimum are given by:

$$\frac{\partial L_j}{\partial v_1}=w_1+\lambda_j \frac{dC_j}{dv_1}=0 \tag{4a}$$

$$\frac{\partial L_j}{\partial v_2} = w_2 + \lambda_j \frac{dC_j}{dv_2} = 0 \tag{4b}$$

$$\frac{\partial L_j}{\partial \lambda_j} = b - C_j\left(v_1\left(a_{1j}\right), v_2\left(a_{2j}\right)\right) = 0\,, \tag{4c}$$

where (4c) simply asserts that the entire budget is being used. Solving (4a) and (4b) yields

$$\frac{w_1}{dC_j/dv_1} = \frac{w_2}{dC_j/dv_2}\,. \tag{5}$$

This implies the optimum strategy for each vendor is to choose a bid that uses the entire budget, and for which the two attributes have equal ratios between the weight placed on the attribute by the buyer and the vendor's marginal cost of increasing the value provided by that attribute[3]. With two competing vendors, there will be two bids that can be represented by attribute bundles: $\left(a_{11}, a_{21}\right)$ and $\left(a_{12}, a_{22}\right)$.

Of course, cost functions are likely to vary across vendors, meaning that the marginal costs in (5) are likely to vary across vendors as well, resulting in a potentially diverse set of bids. Multiattribute auctions allow vendors to differentiate themselves in the auction process and to bid on their competitive advantages (Wise and Morrison 2000).

With the buyer's preferences and the vendor's bidding strategy in place, we now demonstrate how a buyer can explore important differences between vendors. Each vendor goes through the process described above for the *k* different budget estimates, each time producing a bid that satisfies (5) for each of the *k* possible budgets. This set of bids from a

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[3]Note that Equation 5 has a unique solution for each vendor when the entire budget is being used. Because the cost function is strictly convex, as we move along the budget constraint curve, the marginal cost of improving one attribute's value is increasing, and the marginal cost of improving the other attribute's value is decreasing.

vendor constitutes an expansion path. It tells the buyer precisely how a vendor's bid will change as the budget constraint is relaxed (or tightened). For purposes of illustration, throughout the remainder of the paper, we will use a set of six possible budget levels to simulate alternative possible funding constraints: ($5M, $10M, $15M, $20M, $25M, $30M) or simply (5, 10, 15, 20, 25, 30).

Consider the following functional form for the cost functions:

$$C_j\left(v_1\left(a_{1j}\right), v_2\left(a_{2j}\right)\right) = \alpha_{1j} e^{\beta_{1j} v_1\left(a_{1j}\right)} + \alpha_{2j} e^{\beta_{2j} v_2\left(a_{2j}\right)}, \quad \alpha_{1j}, \alpha_{2j}, \beta_{1j}, \beta_{2j} > 0 \text{ for } j = 1, 2. \quad (6)$$

This particular functional form is separable, in that it consists of the sum of cost functions on the individual attributes. Each individual attribute cost function is increasing and convex, where the exponent β_{ij} in (6) determines the convexity of each function. Although the results of the study do not depend on this particular functional form, this offers a relatively simple way to illustrate our expansion path approach to governments' vendor selection decisions.

Figure 2 offers an example of an expansion path. The buyer in this example places a weight of 0.7 on attribute 1, and 0.3 on attribute 2. The vendor represented in Figure 2, whom we will refer to as vendor 1, faces lower marginal costs to improve attribute 1 than to improve attribute 2 at low levels. Specifically,

$$\alpha_{11} = 2.2, \alpha_{21} = 2.7, \beta_{11} = 2.0, \beta_{21} = 1.7 . \quad (7)$$

*****INSERT FIGURE 2 HERE*****

Expansion paths will differ among vendors if the parameters of their cost functions (α_{ij}, β_{ij}) differ. Consider a second vendor (vendor 2) whose individual-attribute cost functions are more convex. Specifically,

$$\alpha_{12} = 1.5, \alpha_{22} = 1.5, \beta_{12} = 2.7, \beta_{22} = 2.7 . \quad (8)$$

Vendor 2 is symmetric in the sense that (s)he does not specialize in developing a particular attribute. Any asymmetry in vendor 2's expansion path is due to the buyer having asymmetric preferences over the two attributes.

Applying the parameters in (7) and (8) results in the expansion paths shown in Figure 3. The two piecewise linear expansion paths, one for each vendor, are based on the six possible budget levels[4]. They illustrate optimum combinations of attribute values that can be produced by each vendor, and offered to the buyer at the different budget levels.

*****INSERT FIGURE 3 HERE*****

Figure 3 reveals an interesting dynamic, which relates to one of the key insights of this study. Under optimistic assumptions about future budgets, it is clear that vendor 1 will be preferred and selected as the winner. At relatively high budgets, vendor 1 dominates vendor 2. However, the reverse is true under a more pessimistic budget. Under severe budget constraints (e.g. $5 million), it is clear vendor 2 will be preferred and selected as the winner. If a government buyer believes a significant budget cut is possible, then selecting a dominant alternative under the optimistic budget scenario (vendor 1) may be misleading. The dominated alternative (vendor 2) should not be prematurely eliminated since it may in fact end up being the preferred vendor.

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[4] Fitting a curve to the points might also be a reasonable approach. We use a piecewise linear form because we specifically would like every attribute bundle in the vendor's bid to fall on the expansion path, as we believe this

To illustrate this new expansion path approach more clearly, we compute $V\left(A_j\right)$ for each of the twelve attribute pairs shown in Figure 3. The two vendors' bids can then be plotted as curves in "budget-value" (or cost-effectiveness) space:

*****INSERT FIGURE 4 HERE*****

Related to the expansion paths, the bids illustrated in Figure 4 are piecewise linear curves. We can think of each one as a function expressing the value to the buyer of the attribute bundles each vendor will provide over the range of possible budget levels. We will write this function for vendor *j* as $\Omega_j(b)$, defined for all possible budget levels *b*.

The dynamic revealed in Figure 3 is illustrated more clearly in Figure 4. It is apparent from Figure 4 that vendor 2 dominates the competition for any positive budget below the switch-point, $b < b'$, while vendor 1 dominates for any budget above the switch-point, $b > b'$. As Quade (1989) also argues, this observation suggests rethinking the simpler definition of dominance, which refers to points (not functions) in cost-effectiveness space. Viewing alternatives as functions in budget-value space reveals that the point-based definition can be misleading. A static comparison that begins by assuming a relatively high fixed budget would eliminate vendor 2 from further consideration. For example, consider offers from vendor 1 and vendor 2 based on very optimistic budgets above b'. A technique that focuses on points and not functions would eliminate vendor 2. Yet, Figure 4 indicates that eliminating vendor 2 prematurely could lead to a less desirable outcome if subsequent budget

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makes the method more transparent. We would advise the analyst and the buyer to use their discretion on which approach to take, based on the particular context of the auction.

cuts resulted in an actual budget somewhere in the range of $0 < b < b'$. This observation suggests the need for a new approach to government's vendor selection decisions.

This switch-point phenomenon occurs as a result of differences in the two vendors' expansion paths. There is nothing unique about the particular functions chosen in our example. The same results can be obtained in many different ways, including with non-additive forms of the buyer's value function. In fact, non-linear interactions between attributes are likely to magnify this effect[5].

While the approach in this paper involves assessing the expansion paths by soliciting vendors' attribute bundle offers for multiple budgets, it may be possible for a government buyer to obtain similar information by soliciting price bids for multiple sets of performance requirements (i.e. specified attribute levels). This would have the advantage of not requiring the buyer to reveal a value function, but also the corresponding disadvantage of not allowing each vendor the flexibility to achieve the desired values with the least costly combinations of attribute levels. Using either approach, the buyer benefits by being able to incorporate affordability into the decision in a meaningful way when the budget is not known with certainty. In particular, the buyer gains the ability to view each alternative as a function in cost-effectiveness space, rather than as a single point.

Selecting a vendor based on points in cost-effectiveness space can lead to worse outcomes than expected, since there may be uncertainties present which are implicitly being ignored. One such example is the $8.8 billion US Navy and Marine Corps Intranet (NMCI) contract, which was awarded to Electronic Data System (EDS) in 2000. Wilson (2006) explains that EDS was the lowest bidder, and that problems arose due to the scope of EDS' task being much larger than expected by either party. Whether another vendor might have performed better than EDS given the expanded scope is unknown. (See Jordan (2007) for more information on NMCI.)

A second example is the US Air Force's acquisition of the Boeing (then McDonnell Douglas) C-17 Globemaster III. This aircraft, usually referred to simply as the C-17, is used as an airlifter for troops and cargo. The C-17 proposal was selected in 1981, effectively ending the bidding process. However, a dollar amount was not specified until 1986, when the Air Force awarded McDonnell Douglas a $3.39 billion contract. Even after 1986, the C-17 program was subjected to a great deal of change. Kennedy (1999) explains:

> In addition, how much airlift was required for war plans was largely undefined. Securing necessary funding for the C-17 was simply an ordeal. That the program's funding fell victim to the budget axes wielded by Congress, DoD, and Air Force undermined the ultimate goal — timely operational delivery of the C-17.

As in the NMCI example, it would have been very difficult to foresee the eventual outcome for the C-17 based simply on a cost-effectiveness point when the decision was made.

The sensitivity of vendor selection decisions to the budget is a fundamental result that arises in a wide variety of government procurement contexts, and places a premium on

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[5]For example, consider a multiplicative value function, and suppose that one vendor has to incur a large cost to increase the value from 0 to 0.1 for one particular attribute. This vendor will offer bids of little value for low budgets, but, depending on cost functions, may offer very attractive bids for higher budgets.

affordability. In a constrained fiscal environment, we strongly recommend the adoption of an expansion path perspective to guide governments' vendor selection decisions.

3. Budget Uncertainty

A natural extension of the model is to consider a procurement auction in which the buyer assigns a probability distribution over the set of possible budgets. If the buyer believes the realized budget will be b with probability $p(b)$, or, in the continuous case, that b has a probability density function $f(b)$, then the government's vendor-selection problem can be examined using a decision under uncertainty approach.

This adds another interesting layer to the problem: We must now include the buyer's risk attitude, because (s)he will be evaluating gambles over multiple possible values. We express risk attitudes through a utility function U, which takes the overall multiattribute value measure as its argument (see Dyer and Sarin 1982 or Matheson and Abbas 2005 for details). This approach allows us to separate attitude toward risk and strength of preferences over the attributes.

Given a value function V and maximum and minimum achievable values, U can be assessed using simple binary gambles. For example, the buyer could specify an attribute bundle a^0 providing the minimum value (zero) and an attribute bundle a^* providing the maximum value (one), and then consider a hypothetical gamble in which (s)he receives a^* with probability p, and a^0 with probability 1-p. For any other attribute bundle a', $U(V(a'))$

would simply be the value of *p* for which the buyer is indifferent between receiving the gamble and receiving *a'* for sure.

The government buyer's problem is to select a vendor *j* to maximize

$$\sum_b p(b)U\left(\Omega_j(b)\right), \tag{9}$$

or in the continuous case, to maximize

$$\int f(b)U\left(\Omega_j(b)\right)db\,. \tag{10}$$

That is, the government buyer wishes to maximize the expected utility provided by the vendor, incorporating both the strength of preferences over the attribute bundle offered (expressed by Ω_j), and the buyer's risk attitude (expressed by *U*).

Consider both the buyer and vendors' information used to generate Figure 3. Recall that the buyer places weights of 0.7 and 0.3 on attributes 1 and 2 respectively, while vendor characteristics are given by the parameters in (7) and (8). Now suppose the buyer has the exponential utility function[6]

$$U(V)=\frac{1-e^{-2V}}{1-e^{-2}}, \tag{11}$$

[6] We chose the exponential function because it has constant absolute risk aversion, measured by a risk tolerance parameter (in this case, 0.5), making its assessment reasonably straightforward and understandable. It is commonly used in decisions under uncertainty, but the analysis could certainly be carried out using a different class of utility function if desired.

where V varies between zero and one over the possible attribute bundles, as described previously. The function and parameters given by (11) represent a decision-maker who is risk averse. Note that since the minimum value of V is zero and the maximum is one, $U(V)$ also varies between zero and one. Figure 5 illustrates the values and corresponding utilities to the buyer of each vendor's attribute bundle proposals under the six possible budget scenarios, overlaying them on the utility function defined by (11):

*****INSERT FIGURE 5 HERE*****

Consider an example scenario in which the buyer believes that b_1, …, b_6 will occur with probabilities 0.1, 0.15, 0.35, 0.25, 0.1, and 0.05, respectively. Given these probabilities for the six budget levels and this particular buyer's preferences, the expected utility if vendor 1 is selected is 0.771, as opposed to 0.800 if vendor 2 is selected. While this aggregate result suggests our buyer should select vendor 2, disaggregating the vendor selection problem offers additional insights.

The bundle of attributes provided by vendor 1 would be more desirable for budgets of 15, 20, 25, and 30, one of which will occur with a probability of 0.75. However, vendor 1's attribute bundle would be far less desirable in the case of a very low budget. Moreover, the expected values of the two bids are nearly identical. Such a conclusion would be nearly impossible to foresee when presented only with a single bid from each vendor for the most likely budget, $b = 15$.

If a vendor's bid consists of only one attribute bundle rather than a set of attribute bundles, then constructing a gamble over possible overall values is extremely difficult. A decision under uncertainty approach requires that the decision maker place a value on all possible outcomes. The procurement auction framework advocated in this paper ensures that these outcomes can be fully specified.

4. Conclusion

This paper offers a new approach to government's vendor selection decisions in major public procurements. The paper describes a simple three-stage, multiattribute procurement process for public vendor selection decisions. It operationalizes a version of the popular concept of cost as an independent variable (CAIV).

The model developed in this paper allows vendors to submit bids for a range of possible budget levels. This leads to the generation of an expansion path for each vendor, which illustrates how the vendor's bid improves as budgets increase. Most importantly, it is demonstrated that a vendor whose bid is dominated at one particular budget level can easily end up being the winner at another budget level. This makes it vital for procurement agencies to rethink traditional public sector bid solicitations. Instead of viewing each vendor as a single point in cost-effectiveness space, it is important to view each vendor as a curve in budget-value space. In economies where affordability is a priority and where budgets are likely to change over time, this approach can result in better choices for voters and taxpayers, since it ensures vendors are not prematurely eliminated from consideration.

Finally, given the acknowledgment that the budget level may not be known when the decision is made, we explicitly model vendor selection as a decision under uncertainty. The buyer assigns a probability distribution over all possible budget levels, while a utility function captures the buyer's attitude towards risk. This methodology enables buyers to generate expected utilities from vendor proposals.

The approach in this paper can be thought of as a strategic choice of auction mechanism for a buyer when a range of budget authorities for the program can be estimated/forecasted, and products are differentiated and complex. It combines the competitive advantages of auctions with the flexibility of decisions based on multiple attributes of a product, while incorporating considerations of affordability when the budget level is not known with certainty.

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Written testimony of M. Sullivan,Government Accountability Office, before the Committee on the Budget, House of Representatives, 111th Cong. (2009, March 18)

Figures

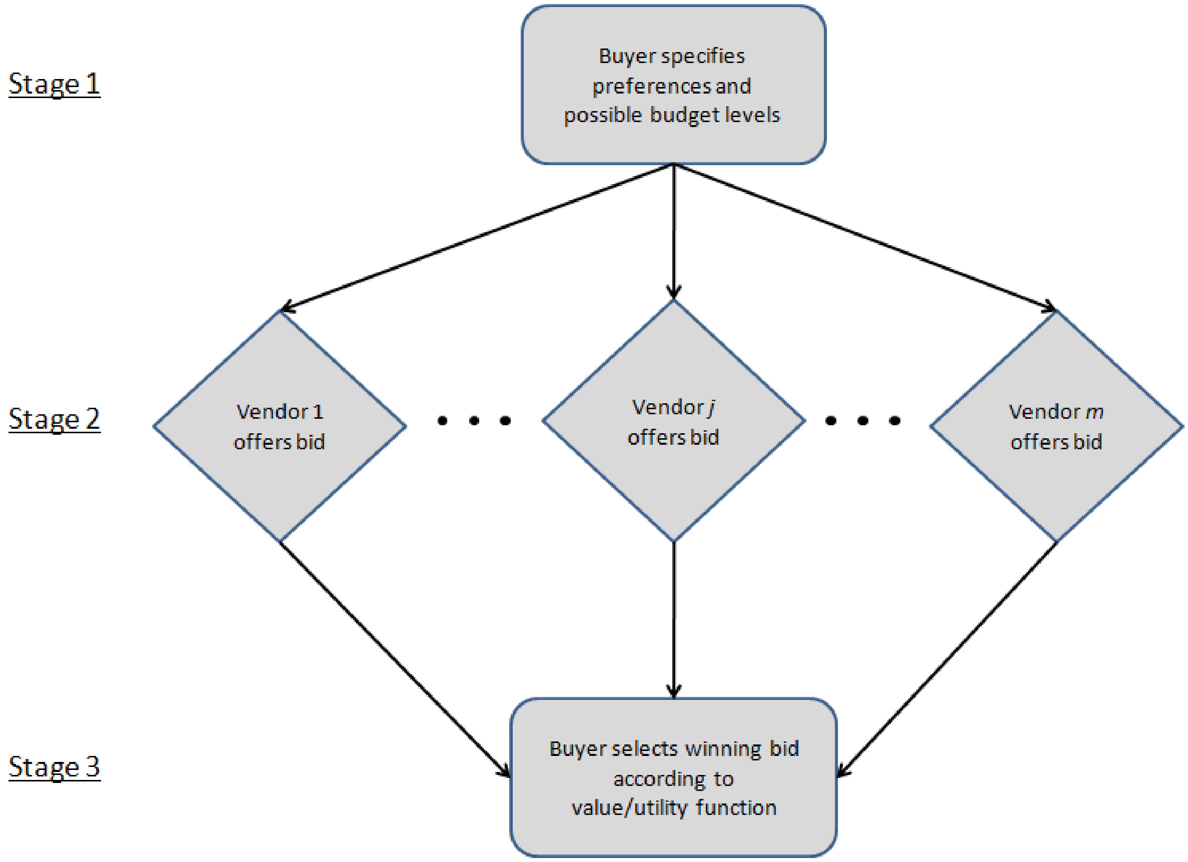

Figure 1. The three-stage procurement model.

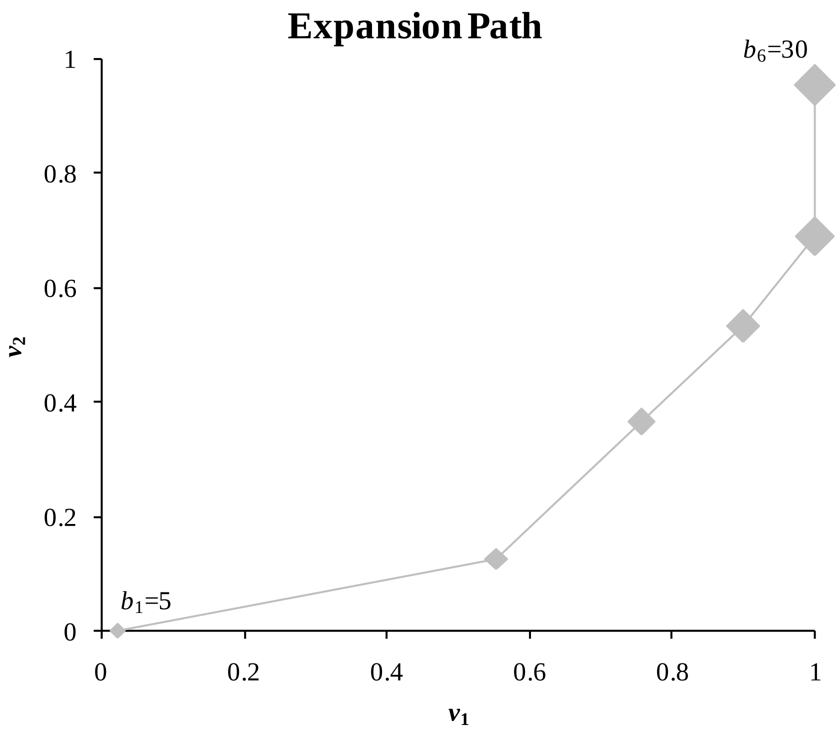

Figure 2. This graph shows the expansion path for a vendor as the budget increases from 5 to 30. The markers of increasing size show the vendor's attribute bundle proposals as the budget increases in increments of 5.

Expansion Paths - Differing Cost Functions

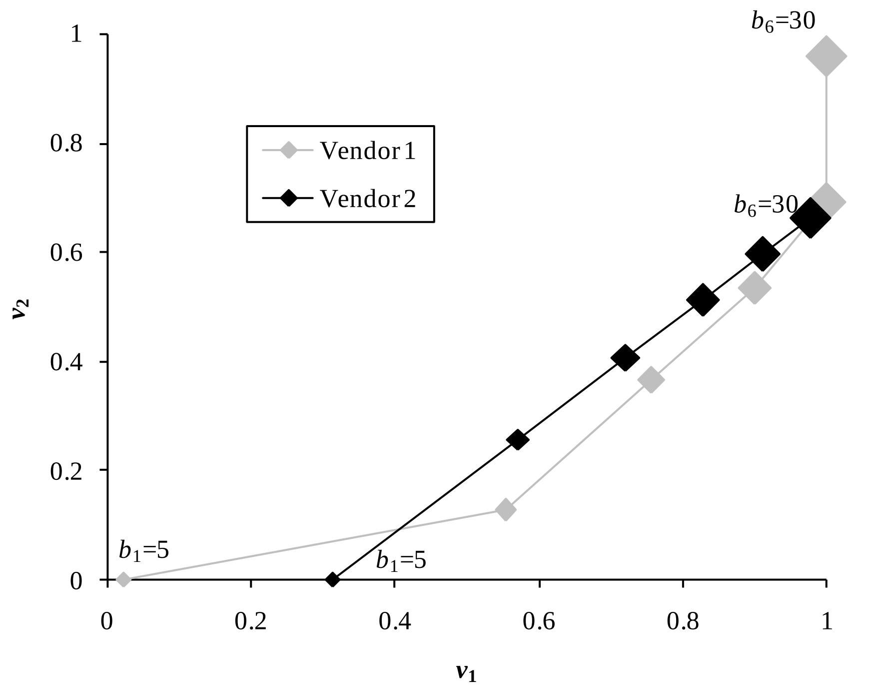

Figure 3. This graph shows the expansion paths for two vendors with differing cost functions as the budget increases from 5 to 30. The markers of increasing size show each vendor's attribute bundle proposals as the budget increases in increments of 5.

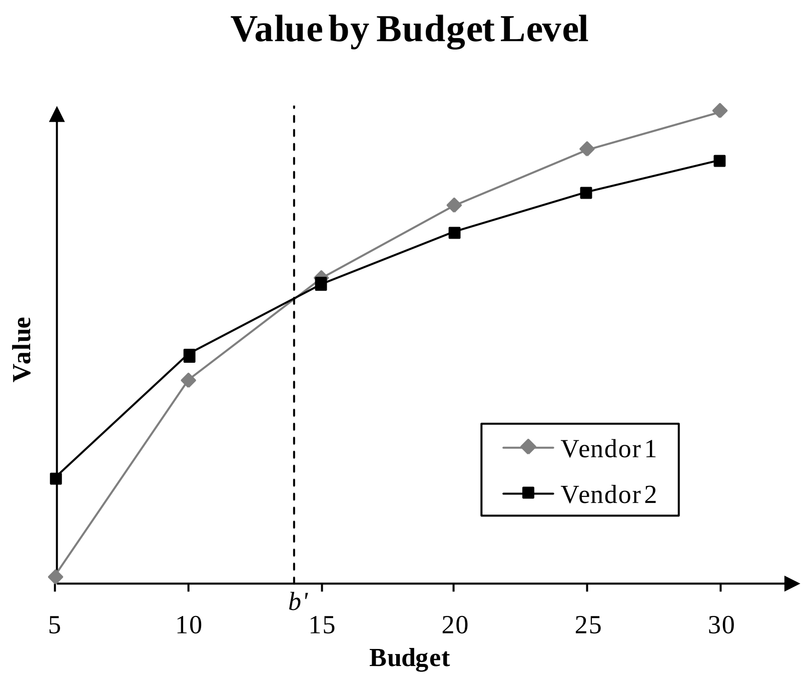

Figure 4. The value provided by each vendor's bid for various budget levels.

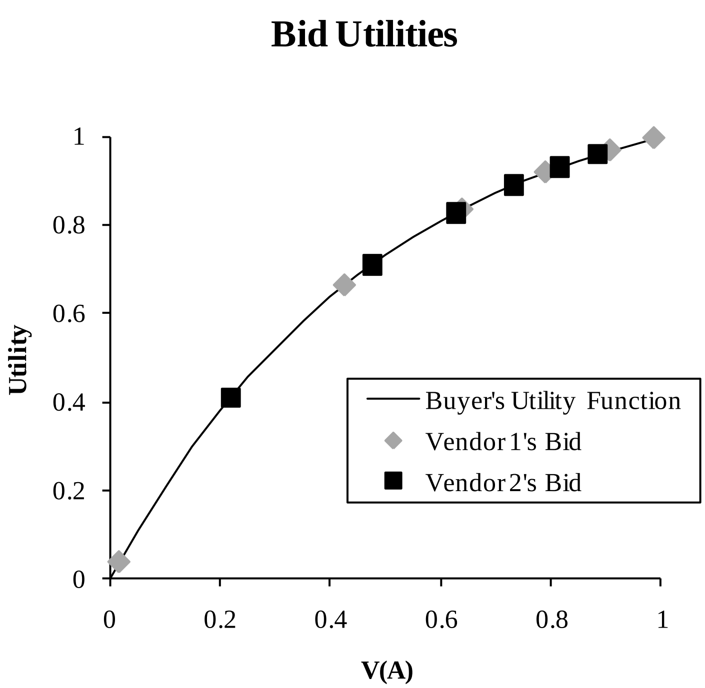

Figure 5. The buyer's utility function and the value and corresponding utility offered by each vendor for the six budget scenarios in the decision under uncertainty example.