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A New Approach to Governments' Vendor Selection Decisions: A Three-Stage, Multiattribute Procurement Auction

30 September 2010

by

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Abstract

The current fiscal crisis has placed unprecedented pressure on public procurements. A major target of future public spending cuts is likely to be defense expenditures. Within the defense budget, the biggest and most immediate targets are likely to be the acquisition of new equipment, facilities, services, and supplies. Addressing the growing global challenge of affordability, this paper offers a new approach to government's vendor selection decisions in major public procurements. In the absence of profits to guide public procurement decisions, the challenge that faces a government buyer is to select the vendor that delivers the best combination of desired non-price attributes at realistic funding levels. The governance 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 bundles of desired non-price attributes. The first iteration of the model is a multiattribute auction in which a fixed budget constraint is specified. Next, the model is expanded to incorporate a range of possible budget levels. This expanded model reveals the benefits to the buyer of defining a procurement alternative (vendor bid proposal) 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. The final extension of the model explicitly examines the buyer's decision problem under budget uncertainty.

Keywords: Public procurement; defense acquisition; affordability; vendor selection; auctions; multiattribute first price, sealed bid procurement auction; vendor bid proposal; buyer's decision problem.

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I. 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. The DoD's goal is to "achieve a balanced mix of weapon systems that are affordable" (GAO *Written Testimony*, 2009). Focusing on affordability, this paper describes a multiattribute first price, sealed bid procurement auction that extends traditional price-only auctions to one in which competition takes place exclusively over specific bundles of desired non-price attributes or characteristics.

In our model, prices/costs do not appear in the value function. Instead, the price appears in an affordability constraint in the spirit of cost as an independent variable (CAIV). Larsen (2007) offers the following explanation of CAIV:

> 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)

In another context, Michael and Becker (1973) also argue for costs to be excluded from measures of value. The focus of this paper is on performance and affordability: Vendors compete for a government contract based on their relative costs of producing different components of quality (attributes or characteristics), and based upon their unique (sunk) technology investments that define their ability to offer different tradeoffs among these components.

The proposal is for the buyer (procurement agency) to provide each vendor (bidder) the same budget authority guidance, and to solicit its best and final offer of a non-price attribute bundle (e.g. for computers, vehicles, weapon systems, logistics packages, etc.) for the projected funding (budget) forecast issued by the procuring agency. Competition between vendors takes place exclusively over collections of products (goods & services), and proposals are evaluated by the buyer as bundles of attributes. A vendor's attribute bundle proposal (bid/offer) depends on the budget specified by the buyer, the vendor's costs for each attribute, and the production technology the vendor has in place to combine those attributes.

Expanding this approach, the model is modified to allow the buyer to offer a range of possible budgets, soliciting proposals for each one. 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, and thus providing a more complete view of the vendor’s ability to provide performance. This idea was also discussed in the context of public decisions by Hitch & McKean (1967) and Quade (1989). The general motivation expressed succinctly by Keeney (2004) emphasizes: “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 for alternatives to be adequately described, and that any budget uncertainty be explicitly acknowledged.

This approach can be thought of as a strategic choice of auction mechanism for a buyer when overall 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.

In our formulation, both the seller (vendor) and the buyer (government) suffer from imperfect and asymmetric information. While the seller does not know the relative weights the buyer assigns to the attributes, the buyer does not know the sellers' costs of producing a particular attribute, nor the technologies (production functions) that combine those attributes into the products under consideration.

Parkes and Kalagnanam (2005) describe the sellers' 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). Loerch, Koury, and Maxwell (1999) discusses a *Value Added Analysis* approach for applying multiattribute preferences to weapon system acquisition. Our approach differs from theirs, in that we incorporate vendors' decision making into the model, along with issues of asymmetric information. Blondal (2006) discusses a 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. The US Federal Acquisition Regulations (2005) provided guidance in subpart 14.5 on a two-step 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)

Our proposal is related but different than this two-step bidding process because the competition is over non-price attributes, and the price is captured in the funding (budget authority) constraint.

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 (auctioneer's) value/utility function.[2] While this approach is appropriate in many private-sector contexts, it can generate complications in public procurements and defense acquisitions. In the private sector, a decision-maker likely seeks to maximize profit. In the public sector

[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 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 proposal emphasizes an MOE that includes exclusively non-price attributes.

the government is generally not permitted to make a profit. Rather, government decision-makers attempt to maximize value to the public given budget constraints. The latter may not be known precisely throughout the entire decision process. Two pioneers in defense economics, Hitch and McKean (1967), have advocated determining the maximum effectiveness for a given budget and examining how each alternative fares for several different budget levels. Our proposal emphasizes 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 method of evaluation to be constructed independently of the particular alternatives offered.

Finally, after the vendors' bids (attribute bundle proposals) have been identified for various budget levels, we expand the formulation of the buyer's problem to explicitly include their beliefs of the probability of various possible budget levels. We apply a decisions under uncertainty approach similar to that introduced by Pratt, Raiffa, and Schlaifer (1964). In addition to expressing their beliefs of various budget levels as probabilities, the buyer is assigned a utility function that incorporates his/her risk attitudes, which enables the calculation of a new expected utility metric to evaluate each vendor.

II. Model

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

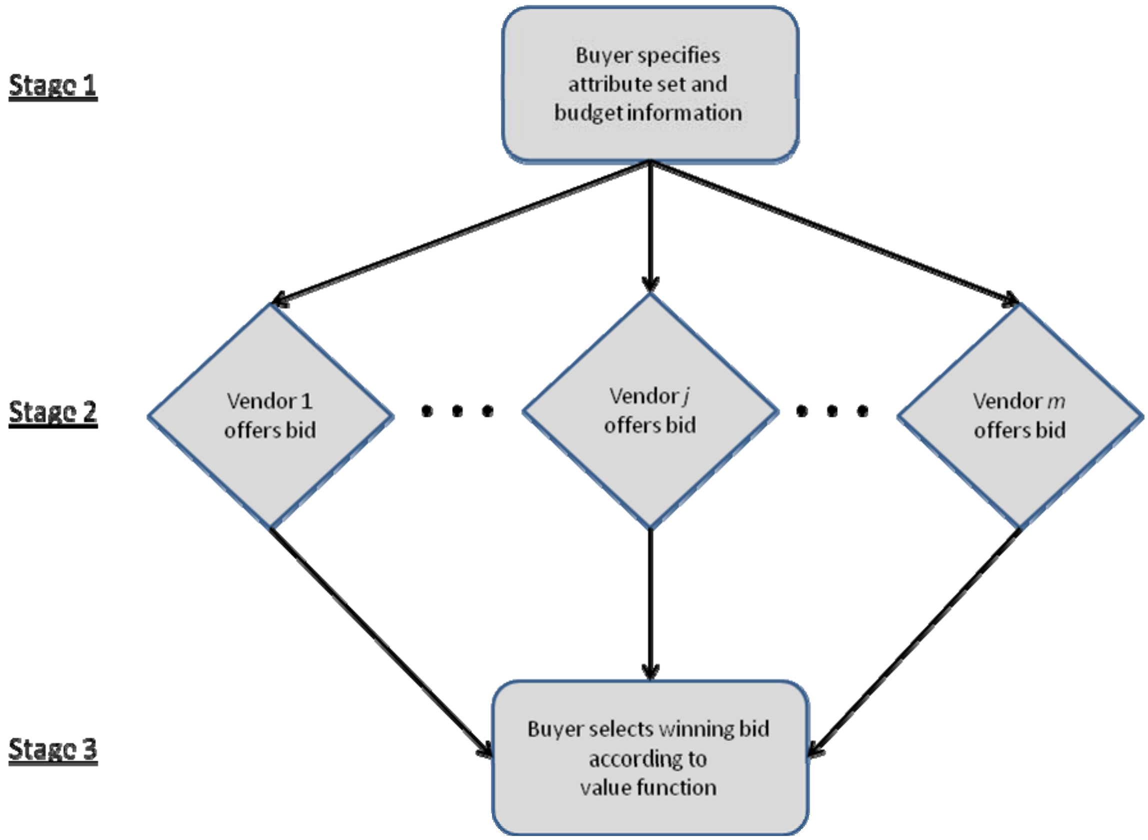

Figure 1. The Three-Stage Procurement Model

The procurement agency (buyer) begins by specifying a set of attributes *A* and a budget level *B*. There are *m* vendors, each of whom will respond with a bid. A bid is simply a set of attribute levels that will be produced given *B*. We express vendor *j*'s bid as $A_j = \left[a_{1j}, \ldots, a_{nj}\right]$ for $j = 1, \ldots, m$, where a_{ij} is the level of attribute *i* offered by vendor *j*. The buyer's ultimate decision (the third stage) is to select a vendor $j \in [1, m]$, and thus a set of attribute levels $A_j = \left[a_{1j}, \ldots, a_{nj}\right]$ to maximize a measure of effectiveness (MOE), which we express as the value function $V\left(A_j\right)$.

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

For simplicity, attribute levels are treated as performance ratings on a constructed scale, similar to those used by Ewing, Tarantino, and Parnell (2006). Since it is not the central focus of our paper, another simplifying assumption is that the process to construct a scale that translates natural units into a value measure has already been accomplished. Thus, we refer simply to a_{ij} rather than using the more common notation $v(a_{ij})$, with the understanding that a_{ij} is an agreed-upon value measure. If necessary, these measures could be specified explicitly by the buyer. Finally, each attribute in the model is assumed to have a minimum value of zero, and a maximum value of four.

The buyer's objective is

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

where w_i is the weight that the buyer places on attribute *i*. We assume the buyer has an understanding of the range of attribute levels in determining the weights. Importantly, the weights in (1) are assumed to be private information to the buyer. Asker and Cantillon (2008) refer to this as an “unannounced” scoring rule (p. 78). The final stage of the model involves applying Equation 1 to the set of vendor bids, and for the buyer to select the vendor that yields the highest value.

Given a buyer-determined set of desired attributes, *A*, and a forecasted budget for the program, *B*, each vendor chooses to produce an attribute bundle to submit to the buyer that meets the budget constraint. While vendors have private information about their own production capabilities and costs, since the final scoring rule is unannounced, they each form their own private beliefs about the likelihood of a bid being accepted.

We model the formulation of these beliefs by having each vendor generate a best guess of the weights in the buyer's (additive) value function, which we can express as $W_j = \left(w_{1j}, \ldots, w_{nj}\right)$. We refer to this subjective (projected) value function as $Q\left(A_j\right)$. The higher the value of $Q\left(A_j\right)$, the greater the probability the vendor believes an attribute offer (bid) will be accepted. Since a rational vendor will only offer a buyer attribute bundles they believe have the highest probability of being chosen, we can restrict our attention to ordinal rankings.

We can express the problem faced by a representative vendor *j* as follows:

$$\max_{a_{ij}} \; Q\left(A_j\right) = \sum_{i=1}^{n} w_{ij} a_{ij}, \; i = 1, \ldots, n \text{, subject to: } TC_j = \sum_{i=1}^{n} c_{ij}\left(a_{ij}\right) \leq B, \qquad (2)$$

where total cost TC_j is the sum of the costs paid by firm *j* to produce each attribute level. The total cost a vendor incurs to generate the attribute bundle cannot exceed the buyer's budget, *B*.

Individual attribute cost functions are given by $c_{ij}\left(a_{ij}\right)$, and each one is increasing in a_{ij}. Because the objective function in (2) is linear, a unique solution (vendor proposal) will exist, provided that $c_{ij}\left(a_{ij}\right)$ is strictly convex for $i = 1, \ldots, n$. This condition is likely to be satisfied since it simply implies decreasing returns from investments to improve a particular attribute level.

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 may have different technologies to combine the two attributes, and may face different attribute cost functions. The Lagrangian function to solve the vendor's problem is given by

$$L_j = w_{1j}a_{1j} + w_{2j}a_{2j} - \lambda_j\left(B - c_{1j}\left(a_{1j}\right) - c_{2j}\left(a_{2j}\right)\right), \text{ for } j = 1,2. \tag{3}$$

Since an increase in either attribute increases the vendor's (subjective) projected value of a particular attribute bundle to the buyer, or $\partial Q\left(A_j\right)/\partial a_{ij} > 0$, 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

$$\frac{\partial L_j}{\partial a_{1j}} = w_{1j} + \lambda_j c_{1j}'\left(a_{1j}\right) = 0 \tag{4a}$$

$$\frac{\partial L_j}{\partial a_{2j}} = w_{2j} + \lambda_j c_{2j}'\left(a_{2j}\right) = 0 \tag{4b}$$

$$\frac{\partial L_j}{\partial \lambda_j} = B - c_{1j}\left(a_{1j}\right) - c_{2j}\left(a_{2j}\right) = 0\,, \tag{4c}$$

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

$$\frac{w_{1j}}{c_{1j}'\left(a_{1j}\right)} = \frac{w_{2j}}{c_{2j}'\left(a_{2j}\right)}\,, \tag{5}$$

meaning the optimum strategy for each vendor is to choose a bid that uses the entire budget for which the two attributes have equal ratios between the vendor's (subjective) belief of the weight (marginal benefit) placed on the attribute by the buyer and the vendor's marginal cost of producing that attribute.[3] With two competing vendors, there will be two bids, represented by attribute bundles: (a_{11}, a_{21}) and (a_{12}, a_{22}). The buyer ultimately selects the vendor that maximizes its private value function, *V*.

Of course, the subjective assessment by a vendor of the buyer's marginal valuation of a particular attribute, w_{ij}, is likely to differ among vendors. Similarly, the marginal cost of producing a particular attribute, c'_{ij}, is also likely to vary across vendors. Multiattribute auctions allow vendors to differentiate themselves in the auction process and to bid on their competitive advantages (Wise & Morrison, 2000).

[3]Note that Equation 5 has a unique solution for each vendor when the entire budget is being used. Because both cost functions are increasing and strictly convex, as we move along the budget constraint curve, one marginal cost is decreasing and the other is increasing.

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III. Multiple Budgets and Expansion Paths

With the basic model in place, we now demonstrate how a buyer could more fully explore important differences between vendors. Rather than the buyer specifying a budget *B*, the buyer could specify a set of (increasing) budgets $b_1, \ldots, b_k$ to tease out which vendors might be favored under different budget scenarios.

Each vendor goes through the process described in Section II with *k* different budget estimates, each time producing a bid that satisfies Equation 5 for each of the *k* possible budgets. This set of bids from a 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, for example ($5mil, $10mil, $15mil, $20mil, $25mil, $30mil) or simply (5, 10, 15, 20, 25, 30).

Consider the following convenient functional form for the attribute cost functions:

$$c_{ij}\left(a_{ij}\right) = \alpha_{ij} e^{\beta_{ij} a_{ij}}\ ,\ \alpha_{ij}, \beta_{ij} > 0 \text{ for } i = 1,2\ ,\ j = 1,2\ . \tag{6}$$

Desirable characteristics of this particular functional form are that each cost function is increasing and convex. In Equation 6, the exponent β_{ij} determines the convexity of each cost function. Although the results of the study do not depend on this specific cost function, it offers a relatively simple way to illustrate our new approach to government's vendor selection decisions.

Expansion paths (attribute bundle proposals for different budgets) can differ among vendors for two reasons. The parameters of their cost functions can differ (α_{ij}, β_{ij}), and/or their beliefs about the buyer's value function (w_{ij}) used to select a winner.

The first case assumes both vendors believe the buyer will place equal weights on the two attributes, but that they differ in their capabilities to produce those attributes. Specifically,

$$\alpha_{11} = \alpha_{21} = 2.0, \beta_{11} = \beta_{21} = 0.6, \alpha_{12} = \alpha_{22} = 1.0, \beta_{12} = \beta_{22} = 1.0, w_{11} = 0.7, w_{12} = 0.7 . \qquad (7)$$

Equation 7 is symmetric in the sense that neither vendor specializes in producing a particular attribute. This symmetry assumption is convenient and will be used throughout this section. It also illustrates that while asymmetric vendor production and cost parameters in the production of bundles of attributes is sufficient to illustrate the benefits of the expansion path approach, it is not necessary.

Applying the parameters in (7), results in the expansion paths shown in Figure 2. The two piecewise linear expansion paths, one for each vendor, are based on the six possible budget levels.[4] They illustrate optimum combinations of attributes that can be produced by each vendor, and offered to the buyer, for the different budget levels.

[4] Fitting a curve to the points might also be a reasonable approach. We used a piecewise linear form because we specifically wanted every attribute bundle in the vendor's bid to fall on the expansion path, as we believe this makes the method more transparent. We would advise the analyst and the buyer to use their discretion on which approach to use, based on the particular context of the auction.

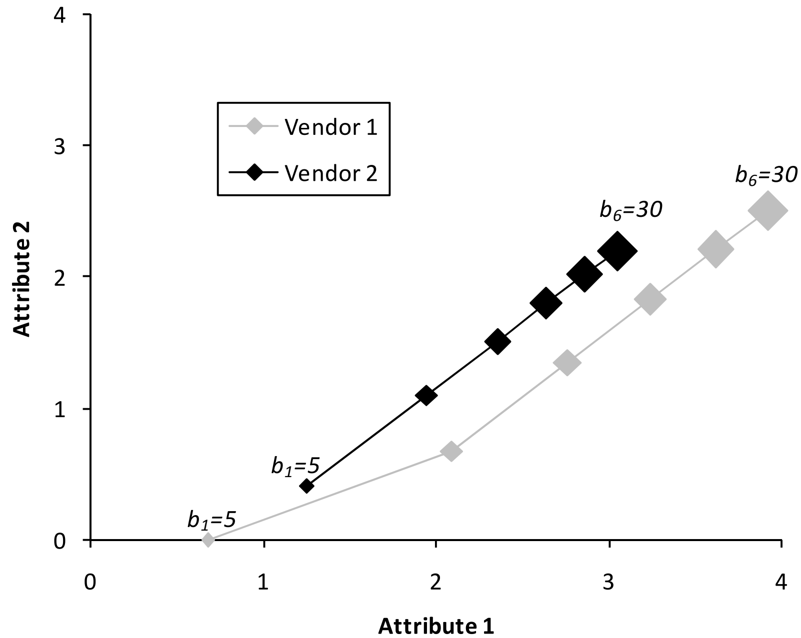

Figure 2. Expansion Paths for Differing Cost Functions
(*Note*. This graph shows the expansion paths for two vendors with differing cost functions as the budget increases from 5 to 30. The markers of increasing size show each vendor's attribute bundle proposals as the budget increases in increments of 5.)

The second case assumes vendors face the same cost functions, but have different beliefs about the buyer's attribute weights. Specifically, suppose the vendors have the following parameter values:

$$\alpha_{11} = \alpha_{21} = \alpha_{12} = \alpha_{22} = 2.0, \beta_{11} = \beta_{21} = \beta_{12} = \beta_{22} = 0.6, w_{11} = 0.5, w_{12} = 0.7 \text{ . } \quad (8)$$

That is, Vendor 2 believes the buyer will place a slightly greater weight on Attribute 1, while Vendor 1 believes the weights placed on Attribute 1 and Attribute 2 will be the same. This results in the piecewise linear expansion paths shown in Figure 3.

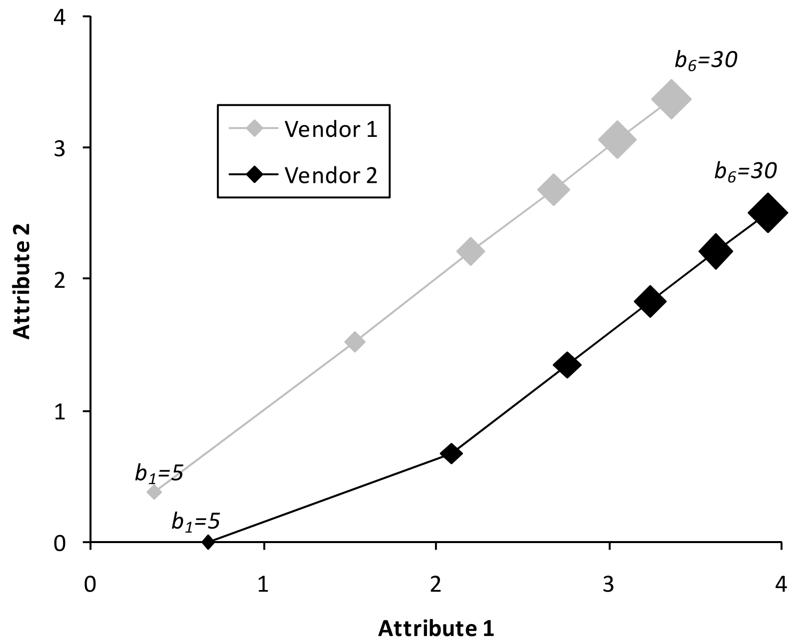

Figure 3. Expansion Paths for Differing Beliefs
(*Note*. Expansion paths for two vendors with differing beliefs on attribute weights as the budget increases from 5 to 30. The markers of increasing size show each vendor's attribute bundle proposals as the budget increases in increments of 5.)

While the parameters assumed in (7) and (8) provide interesting cases where vendors differ either in their costs *or* in their beliefs, a third case is possible—when two vendors differ in both their costs *and* their beliefs. Consider two vendors with

$$\alpha_{11} = \alpha_{21} = 2.0, \beta_{11} = \beta_{21} = 0.6, \alpha_{12} = \alpha_{22} = 1.0, \beta_{12} = \beta_{22} = 1.0, w_{11} = 0.5, w_{12} = 0.7 . \qquad (9)$$

This reveals an interesting dynamic illustrated in Figure 4.

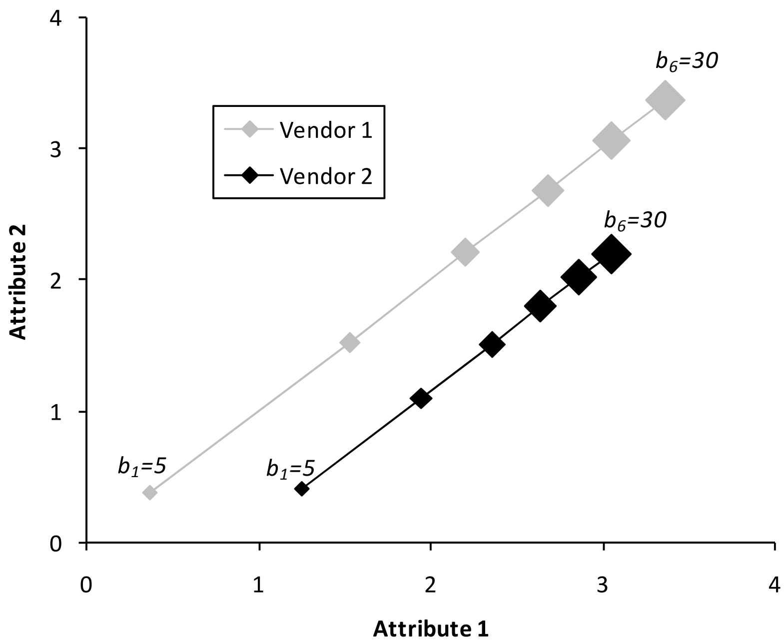

Figure 4. Expansion Paths for Differing Beliefs and Cost Functions
(*Note*. Expansion paths for two vendors with differing costs and beliefs on attribute weights. The markers of increasing size show each vendor's attribute bundle proposals as the budget increases in increments of 5.)

At relatively high budgets, Vendor 1 dominates Vendor 2. Under optimistic assumptions about future budgets, regardless of the buyer's preferences, Vendor 1 will be preferred and selected as the winner (provided the buyer's value function is monotonically increasing in each attribute). An important consideration is that a static comparison that begins by assuming a relatively high fixed budget would eliminate Vendor 2 from further consideration. For example, in a static evaluation of the two vendors with a projected budget level of 20 (i.e. $20 million), Vendor 2 would be eliminated from further consideration. However, what is critical to note in Figure 4 is that the reverse would be true with a low budget. Vendor 2 dominates Vendor 1 at lower budget levels.

In fact, under severe budget constraints (e.g. $5 million), regardless of the buyer's preferences, Vendor 2 will be preferred and selected as the winner (provided the value function is monotonically increasing in each attribute). One of the main insights of this study is that if a government buyer believes a significant budget cut is possible, identifying a dominant alternative under the optimistic budget scenario (i.e. Vendor 1) may be misleading, and the dominated alternative (Vendor 2) may in fact be the preferred vendor. This suggests a new approach to government's vendor selection decisions.

To clearly illustrate this new approach, we first assign attribute weights to the buyer's value function. Suppose the buyer assign a weight of 0.7 to Attribute 1 and 0.3 to Attribute 2. The two vendors' bids illustrated in Figure 4 can then be plotted as curves in "budget-value" (or cost-effectiveness) space:

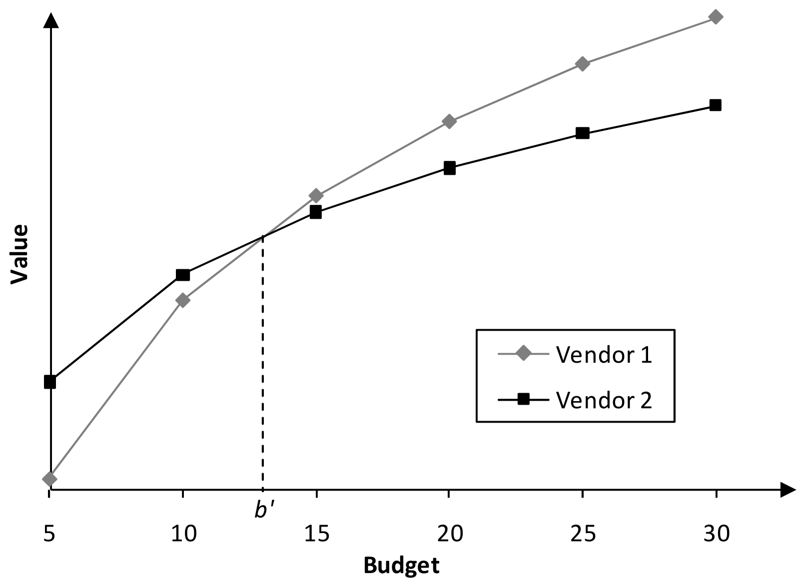

Figure 5. Value by Budget Level
(*Note*. Value provided by each vendor's bid for various budget levels.)

Related to the expansion paths, these bids are piecewise linear curves. We can think of each one as a function expressing the value of the attribute bundles each vendor will provide over the range of possible budget levels. We will write this function for vendor i as $\Omega_i(b)$, defined for all possible budget levels b.

It is clear from Figure 5 that Vendor 1 dominates the competition for any positive budget below the switch-point, $b < b'$, while Vendor 2 dominates for any budget above the switch-point, $b > b'$. This observation suggests, as Quade (1989) argued, rethinking the typical definition of dominance, which refers to points (not functions) in cost-effectiveness space.

Viewing alternatives as functions (instead of points) in budget-value space reveals the traditional definition of dominance can be misleading. For example, consider offers from Vendor 1 and Vendor 2 based on very optimistic budgets above b'. A traditional technique focusing on points and not functions would likely eliminate Vendor 1, as Vendor 2 provides greater value. Yet, it is clear from Figure 5 that eliminating Vendor 1 prematurely could lead to a less desirable outcome if subsequent budget cuts result in actual budgets somewhere in the range of $0 < b < b'$.

This switching point (or crossover) 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; they were selected for simplicity and ease of exposition. The same results can be demonstrated with non-additive forms of the buyer's value function. Moreover, non-linear interactions between attributes are likely to magnify this effect.[5]

The sensitivity of vendor selection decisions to the budget is a fundamental result that arises in a wide variety of defense acquisition decision contexts. In many countries, budget uncertainty is growing, placing a premium on affordability. In the increasingly constrained fiscal environment generated by the global financial crisis, we recommend this new approach to government's vendor selection decisions be urgently adopted and widely applied.

[5]For example, consider a multiplicative value function, and suppose that one vendor has to incur a large cost to provide anything above the minimum level for one particular attribute. This vendor will offer bids of little to no value for low budgets, but, depending on cost functions, may offer very attractive bids for higher budgets.

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IV. 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 that 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 decisions 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 Chapter 7 of Kirkwood, 1997, for details). Thus, the government buyer would like to select a vendor *i* to maximize

$$\sum_{b} p(b)U\left(\Omega_i(b)\right), \tag{10}$$

or in the continuous case, to maximize

$$\int f(b)U\left(\Omega_i(b)\right)db\,. \tag{11}$$

Consider the buyer and vendors' information used to generate Figure 5. That is, 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 (9). Now suppose the buyer has the exponential utility function[6]

$$U(z) = \frac{1-e^{-2z}}{1-e^{-2}}, \tag{12}$$

[6] We chose the exponential function because it has constant absolute risk aversion, measured by a risk tolerance parameter (in this case, 0.5), and because it is commonly used in decisions under uncertainty. An example could be easily constructed using a different class of utility function.

where *z* represents the overall value of an attribute bundle, scaled to vary between zero and one. The function and parameters given by Equation (12) represent a decision-maker who is modestly risk averse. In this case, $z = 0$ corresponds to the value provided by Vendor 1 with a budget of 5 (the lowest possible budget), and $z = 1$ corresponds to the value provided by Vendor 1 with a budget of 30 (the largest possible budget). Note that $U(z)$ will also vary between zero and one.

Consider an optimistic, pessimistic and most likely budget. Assume the buyer believes the most likely budget, with a probability of 0.6, is $b = 15$. Similarly, suppose the buyer estimates the probability of a pessimistic budget, $b = 5$ is 0.2, and that the probability of an optimistic budget, $b = 20$, is also 0.2.

Figure 6 illustrates the utility values to the buyer of each vendor's attribute bundle proposals under the three different budget scenarios by overlaying them on the utility function defined by Equation (12):

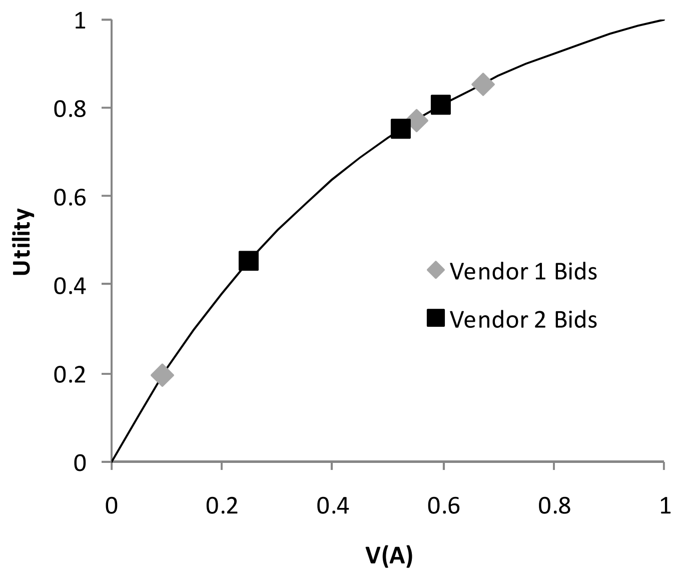

Figure 6. Bid Utilities
(*Note*. The buyer's utility function and each vendor's attribute bundle proposals under the three budget scenarios for the decisions under uncertainty example.)

Given these probabilities and this particular buyer's preferences, the expected utility if Vendor 1 is selected is 0.673, as opposed to 0.703 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 both the most likely and the optimistic budgets, but it turns out Vendor 1's attribute bundle would be far less desirable in the pessimistic case. 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 single budget, b = 15. More careful and robust analysis is only feasible if the buyer solicits bids from the vendors over multiple possible budget levels.

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

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V. Conclusion

The current fiscal crisis has placed unprecedented pressure on public procurements. A major target of future public spending cuts is likely to be defense expenditures. Within the defense budget, the biggest and most immediate targets are likely to be the acquisition of new equipment, facilities, services, and supplies.

Addressing the growing global challenge of affordability, 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 allows the buyer to incorporate the government's preferences over multiple attributes, and it allows each vendor to offer their best possible bid based on a budget estimate for the program, and on each vendor's cost structure and private beliefs. The model operationalizes a version of the popular concept of "Cost as an Independent Variable" (CAIV). The results of this study reveal the importance of including price/costs as part of a budget constraint, rather than in the buyer's value/utility function.

The basic model is first extended to allow vendors to submit bids for a range of possible budget levels. This extended model leads to the generation of an expansion path for each vendor. The expansion paths illustrate how vendors' bids improve 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 of vital importance for procurement agencies to rethink their traditional bid solicitations. Instead of viewing each vendor as a single point in cost-effectiveness space, it is critical to view each vendor as a curve in budget-value space. In an economic environment in which affordability is a growing priority and where budgets are likely to change over time, this expanded approach ensures vendors are not prematurely eliminated from consideration.

Finally, given the growing uncertainty over federal budgets, we explicitly model vendor selection as a decision under uncertainty. In this case the buyer assigns a probability distribution over all possible budget levels (e.g. optimistic, pessimistic, and most likely), while a utility function captures the buyer's attitude towards risk. This methodology enables buyers to generate expected utilities from vendor proposals, providing a valuable new approach and metric for government's vendor selection decisions.

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