Measuring the Effectiveness of Competition in Defense Procurement: A Survey of the Empirical Literature

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Abstract

This article surveys the empirical literature that has attempted to measure the effects of competition in defense procurement. Its focus is on the conceptual underpinnings of the empirical models rather than on the technical aspects of the estimation procedures. While the empirical studies provide some valuable insight, the studies are flawed because they assume an implicit model of the procurement environment that is inconsistent with reasonable economic behavior on the part of defense contractors and seems to be contradicted by the evidence. In general, the predictive power of the empirical models is also limited by a program-by-program estimation approach in which only a handful of data points are available to estimate two or more parameters. These empirical models could be improved by the use of structural models that assume reasonable economic behavior and provide a theoretical basis for cross-program analyses.

INTRODUCTION

In recent years, concerns with reducing defense procurement costs have led policymakers within the Department of Defense to increase the use of competition as a mechanism for procurement [Burnett, 1987; Fox, 1988]. For example, both the Air Force and the Navy are currently procuring their next-generation fighter aircraft through a two-phase competitive process in which two teams of contractors compete for the final design, after which the winning design team members will bid against each other for the production contract.[1] While competition in the design and development phase is important, much of the emphasis has been on competition in the production phase

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[1] Previous practice typically involved "leader-follower" procurements in which a second source was qualified after the initial source had begun production. In many instances teaming will have leader-follower aspects to it in the sense that the initial round "loser" may bid again as a potential second source in subsequent rounds of procurement.

of procurement when design considerations become secondary to price considerations.

Price competition between two or more potential contractors, it is argued, will limit sole-source monopoly profits and provide incentives toward cost-reducing design, manufacturing investments, and managerial efficiencies. While the downstream benefits to competition are clear in theory, in the case of complex technologies these benefits can be offset by the costs of introducing and maintaining competition. In addition, because production of complex technologies is characterized by relatively steep learning curves (marginal costs decline relatively quickly with cumulative production), all other things being equal, production by a single firm is often more efficient than production by two or more firms. Most informed policymakers appear to agree, therefore, that competition is not a remedy to be used blindly.

Determining which production programs can benefit from competition is not a simple matter. It depends, for example, on the steepness of the learning curve associated with the technology in question, the timing pattern and magnitude of purchase, the cost of technology transfer (which includes the technical data package provided by the developer to the second source), the degree to which design or production improvements by one producer can be copied by other producers, incentives provided by the competitive bidding process, and so on. While some questions can be answered through theory, calibration of any model that is intended as a prediction tool must ultimately depend on analysis of data.

We survey here the empirical literature that has examined the effects of competition in defense procurement. All the studies reviewed attempt to measure the program-by-program procurement price benefits that have resulted from past uses of competition; many propose forecasting models based on those measurements. Our assessment of these studies concentrates on the framework that underlies the empirical work. While some of the technical problems associated with the studies are addressed in this survey, most of our analysis concerns fundamental conceptual issues.[2] We conclude that existing studies are flawed because the implicit model of the procurement environment common to all is inconsistent with reasonable economic behavior on the part of the contractors.

THE PROCUREMENT CYCLE

The defense procurement cycle can be divided into four stages: initial design, development, initial production, and reprocurement. Typical practice is to hold a competition in the initial design and development phases that involves criteria such as design, capability of the contractor to deliver, and price. In the initial design phase more than one firm may be chosen; however, with a complex technology the field is usually winnowed down to one when development begins. When technological uncertainty is great, design and development contracts are often of the cost type (such as a cost-plus-incen-

[2] Berg et al. [1986] address many of the conceptual issues discussed in this paper from a different perspective than that adopted here. See Hampton [1984], Beltramo [1983], and Sherbrooke et al. [1983] for a detailed analysis of the technical problems.

tive-fee contract, in which costs are reimbursed and the allowed profit decreases with the size of cost overruns and increases with cost underruns relative to a negotiated target cost), whereas lower-risk procurements usually involve fixed-price contracts (such as a firm-fixed-price contract in which the contractor accepts all risks in exchange for the stated price, or a fixed-price-incentive-fee contract, which has cost reduction incentives similar to those in the cost-plus-incentive-fee contract, but also places a ceiling on the amount that will be paid regardless of actual cost). Current government procurement practice seems to favor the latter type of contract over the former.

When there is only one developer, initial production is almost always awarded to that developer.[3] In such cases, the contracts are generally not competitively bid; instead, a cost-plus-incentive-fee or a fixed-price-incentive-fee contract is negotiated between the developer and the government. Because this stage of procurement still involves a number of design and production changes, it is often infeasible to bring in a second contractor until the design has become sufficiently stable.

The division between initial production and reprocurement, while largely arbitrary, is meant to indicate the time in the procurement cycle when it becomes feasible to transfer technology and bring in a second contractor, either as an additional producer or as a replacement for the original developer.[4] Because of the difficulties associated with technology transfer in the early stages of production, competition usually takes place after some initial production by the developer. Thus, the production phase of competitive procurements typically involves a leader-follower relationship. The mid-1980s shift toward teaming as a procurement policy is meant to avoid this leader-follower asymmetry.[5]

In principle, competition can be introduced at any point in the procurement cycle. In practice, the range of uncertainty about design and demand as well as the inability of the government to make a long-term commitment combine to limit the extent to which an initial bidding competition will produce outcomes that reflect competition over the entire stream of future earnings. In addition, price considerations do not dominate the government's choice of a developer, and it is unlikely that the contractor's "buy-in" price at the development stage will be low enough to offset future supranormal economic rents.

The bulk of the research on measuring competitive savings has focused on the effects of initiating competition in the reprocurement stage. Competition in that stage typically takes the form of second-sourcing, in which the government decides to transfer technology and qualify a second source to compete with the original contractor. In this final stage of procurement, contractors are competing primarily over price (including warranties) rather than over design or production capability. Researchers have emphasized this phase of procurement because the dollar amounts are typically greater, and because it is easier to measure the costs and benefits associated with

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[3] The major exception to this occurs in shipbuilding where the design function is sometimes separated from the production function.

[4] For a case study see Daly and Schuttinga [1982].

[5] Teaming is being used for procurement of the Advanced Tactical Fighter (ATF) and the Advanced Tactical Aircraft (ATA), both of which are in the development phase of procurement.

production programs. We survey here these studies of reprocurement-stage competition.[6]

THE STUDIES

Researchers generally accept the proposition that the production cost of a complex system decreases as experience in manufacturing the system increases [Wright, 1936; Alchian, 1963; Preston and Keachie, 1964]. This fall in unit cost that comes with accumulated production experience is referred to as progress along the learning curve. In most of the efforts to measure the savings due to competition, the researchers begin with two assumptions: that the learning curve is the dominant influence on contractor costs, and that the price to the government tracks contractor costs very closely. They then estimate competitive savings by a method that uses the learning curve to predict what prices would have been in the absence of competition. Figure 1 provides an example of an estimated price curve that is based on the learning curve.

Because most of the studies have the learning curve as their core concept, we concentrate our discussion on the 1974 Institute for Defense Analysis report (henceforth IDA 74). It is representative of this approach and had great influence on later studies [Zusman et al., 1974].

The 1974 IDA Report

The IDA 74 report calculates the savings that result from the first competitive procurement in a given program by comparing the observed competitive unit price with a predicted unit price. The predicted price is an estimate of the unit price that would have prevailed if the current procurement round had been governed by a sole-source contract instead of a competitive auction.

The competitive price is not adjusted for post-competition settlements.[7] IDA 74 is the first study to recognize that, because unit prices generally decline with each additional procurement round, it is inappropriate to calculate savings based on the last observed price in the sole-source phase of procurement.

To generate a prediction for the sole-source price, the authors begin by assuming that production costs are characterized by a learning curve. This is specified as $MC = aN^b$, where MC is marginal cost for the current procurement round, N is cumulative units, a is the hypothetical first unit cost, and b is the learning-curve slope. Actual cost data were not available to estimate the parameters; however, it was thought that because the government closely monitored the costs associated with the sole-source contracts, prices would reflect costs plus some proportional markup for profits.

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[6] It is argued that prototype competition may lead to decreases in production-unit costs because of careful consideration of cost-performance tradeoffs, incentives to avoid costly design features, more innovative design, and so forth. Bell [1983] has looked at this topic in detail. Although his data provide some evidence that the cost growth for competitive versus noncompetitive programs is reduced, his estimation lacked power to show significance. This effect is hard to measure because of a lack of evidence with which to generate a no-prototype-competition unit-cost benchmark. See also Smith et al. [1981].

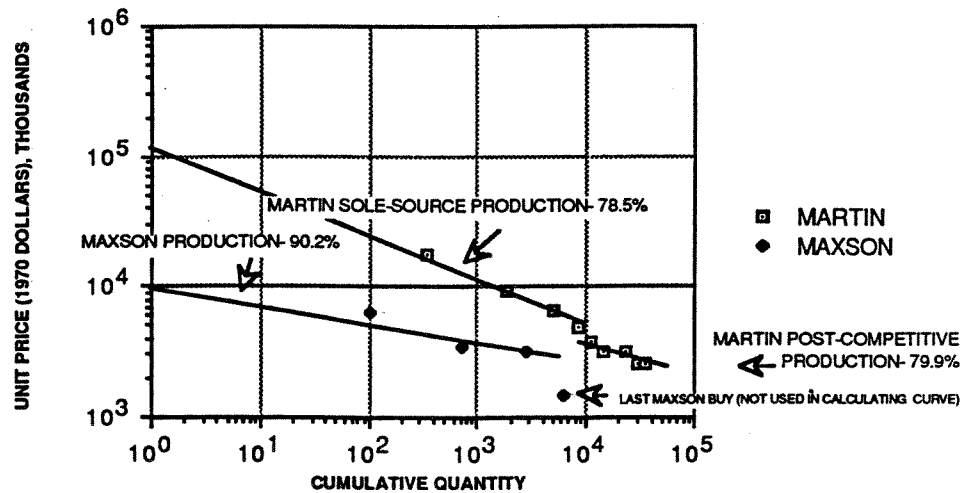[7] This was noted by Carter [1974].

Figure 1. Price-quantity relationship for the Bullpup missile (Source: IDA 74: Lot midpoints used in calculations).

The prediction equation for the sole-source price is specified as a log-linear regression of unit price against an intercept and cumulative units. The intercept and slope coefficient are estimated with price and quantity data from the sole-source phase; the prices include recovery of fixed costs. The estimated parameters are then used to predict the price that would have occurred if the next production lot had been awarded under a sole-source contract instead of under competitive bidding.[8]

In IDA 74, the data sample was limited to 20 items, almost all of which fell into a unit price range of $1000 to $7000 in 1970 dollars. In Table 1 and Figure 1, we provide data from the Bullpup missile guidance, control, and airframe procurement as an illustration. This procurement was made under a series of sole-source contracts to Martin Corporation beginning in FY 1958, followed in 1961 by a switch to competitive split-award contracts involving both Martin and Maxson. The initial split-buys were intended to allow Maxson to gain experience and catch up to Martin. In 1964 Maxson won a final winner-take-all competition. Although most of the programs in the IDA sample exhibited characteristics akin to the classical learning curve, some of the data clearly do not—for example, for production of the SPA-25 Radar Indicator, the second source's learning curve rises rather than falls. Because later quantities were far smaller than the initial quantity, however, lot size or production rate may explain this result.

In the IDA study, different parameters were estimated for each program. Thus, the number of observations presents a major problem. Of the programs examined in IDA 74, the majority had only four or five sole-source price-quantity data points, and only two of the programs had series with as many as seven sole-source data points. Lack of data partially explains the reluc-

[8] See Berg et al. [1986] for a discussion of a learning-curve specification with rate and lot-size effects.

Table 1. Bullpup missile guidance, control, and airframe contract data.

Contractor	FY	Contract	Quantity	Unit price (1970 $000)
Martin	58	sole-source	700	18.0
	59	sole-source	2,315	9.2
	60	sole-source	3,805	6.7
	61	sole-source	3,375	5.0
	61	competitive	1,078	3.7
	62	competitive	6,363	3.2
	62	competitive	9,541	3.1
	63	competitive	6,355	2.5
	63	competitive	2,800	2.5
Maxson	61	competitive	200	6.2
	62	competitive	1,000	3.5
	63	competitive	3,238	3.1
	64	competitive	3,580	1.5

tance of some researchers to examine the role of other factors such as production rate or lot size. Although the data set may dictate this choice, the omission of such variables introduces a bias in the estimates of the included parameters.

Another problem with the data used in the IDA 74 report is that fixed costs are not removed from the data used to estimate the learning curve. Therefore learning, which is normally attributed to decreases in variable costs, is obscured in the estimation by fixed costs. An examination of the levels of fixed-cost adjustment in the 1978 Army Procurement Research Office report, however, suggests that fixed costs were relatively small for the missile and electronics programs analyzed [Lovett and Norton, 1978].[9]

IDA 74 found that the median savings on the initial competitive procurement contract was 37% with a range from −0.2 percent to 60%. The mean of the learning curve exponents was −0.26. Standard deviations were not reported on a program-by-program basis. The analysis also indicated that winner-take-all competitions seemed to result in greater savings than split awards; flatter sole-source slopes resulted in greater savings; unit price reduction was negatively correlated with the ratio of the number of units bought under the first competitive award to the total number of units produced under sole-source contracts; and the number of bidders was not significant in predicting savings. One surprising feature of the programs in the sample was that the developer won only one of 17 winner-take-all competitions.[10]

[9] Part of the data for the APRO study was reported in Kluge and Liebermann [1978]. The extent to which fixed costs are sunk for each contractor can make a big difference in competitive bidding. If, for example, all of the developer's fixed costs are sunk, but the second source has yet to purchase its capital, then the second source would bid to cover its fixed and variable costs, whereas the developer would be willing to bid to cover only its variable costs. Since the government frequently allows the second source some educational production, the asymmetry in the sunk-cost position is not likely to be severe.

[10] In some instances where the second source experienced problems, the original contract was later renegotiated. See, for example, Beltramo [1983, p. 71] for a short case study of the AN/PRC-77 radio set, which involved such problems.

In addition, IDA 74 investigated the post-competitive learning curve and found it to be flatter than the developer's pre-competitive learning curve. The authors explain the flatness in terms of bidding theory and the learning curve: If the winner of the competition could win at a price x, why should it bid lower in the next competition when its opponent bids with the same production experience? The authors did not run a test to determine whether one could reject the hypothesis that the pre- and post-competition slopes were different; however, they did note that a flatter competitive curve implies that gross savings in subsequent competitions should decline because the "gap" between the extrapolated sole-source price curve and the competitive price curve narrows.

Other Major Studies

In this section we review some of the other major studies of the effects of competition on procurement prices. The studies are listed in chronological order, with the exception that closely related studies are grouped together.

ECOM 1972. In 1972 the U.S. Army Electronics Command (ECOM) released a study that indicated a recurring cost savings of 54% due to competition for 13 electronics procurements [U.S. Army, 1972]. The methodology used was simple: Subtract the competitive price from the last sole-source price. This approach did not incorporate learning considerations, nor did it adjust for inflation.

YUSPEH 1973. Data used in the IDA 74 study was also used by Larry Yuspeh [1973] to estimate savings due to competition. The method he used was similar to that used in the ECOM study and resulted in a savings estimate of 52%.

APRO Studies. The Army Procurement Research Office in its 1978 study (henceforth APRO 78) followed the same general method as IDA 74, but used actual cost reports, contract files, audit reports, post-competitive settlements, progress briefings, and interviews in place of contract price data [Lovett and Norton, 1978]. Cost reports allowed the authors to disaggregate the fixed from the variable costs in contract prices, which, if the reports reflected true cost, permitted the calculation of a true learning curve and thus avoided the problems associated with profit markups and fixed costs.

Savings were calculated net of nonrecurring start-up costs. The average savings estimated in the APRO 78 report are not comparable to savings figures of the other reports since they are estimated as a percentage of calculated total program costs. Five of 16 programs examined showed a loss.

A follow-up study done by the Army Research Procurement Office in 1979 examined repetitive competition in the procurement of 22 ammunition items [Brannon et al. 1979]. Because initial production of such items is generally produced under fixed-price contracts, the effects of the learning curve cannot be separated from the effects of competition. In order to calculate the benefits of competition, the authors used assumptions about learning-curve slopes (based on received wisdom) to net out the learning-curve effects. This study estimated that competition resulted in an average recurring buyer savings of 7.1% based on a learning-curve slope of 95 percent.

In 1981 APRO did a study of the procurement of 26 helicopter spare parts [Smith and Lowe, 1981]. Unit prices ranged between a few dollars and several hundred dollars. The study rejected the hypothesis that the learning-curve slopes are different for the sole-source and the competitive phase and

estimated a median rate of recurring buyer savings of 24 percent for the first competitive buy, with a 95% confidence interval of 3 to 37%.

IDA 1979. The 1979 Institute for Defense Analysis study (henceforth IDA 79) followed the same method as the earlier IDA report [Daly et al. 1979]. Data used were primarily from the IDA 74 study and the APRO 78 study. The authors categorized the decision to offer a project competitively as an investment decision in which the discounted costs of running the competition (technology transfer, duplicated capital, and start-up costs) need to be compared with the discounted decrease in unit price paid. In addition, this study partitioned the data into electronics and nonelectronics items and found that recurring buyer savings were 48 and 28%, respectively.

TASC Studies. A 1979 report by The Analytic Sciences Corporation (henceforth TASC 79) examined 45 procurements that had been studied in previous reports [Drinnon and Hiller, 1979]. Their savings estimate was based on a comparison of the actual competitive price to the hypothetical sole-source price. TASC 79 found a recurring buyer savings of 33%. In addition, their estimates of the competitive learning curve indicated not only a downward shift relative to the sole-source curve but also a steepening (rotation) of the slope of some 5%.

In a 1981 study, TASC (henceforth TASC 81) revised their 1979 "shift and rotation" model to incorporate production rate [Cox and Gansler, 1981]. The revised model included five parameters (production rate deviation from optimal, optimal production rate, intercept, sole-source learning curve, competitive learning curve) and was applied to four tactical missile programs. A steepening of the competitive learning curve was reported, although the findings are suspect because they emerge from as few as seven data points. Other researchers reanalyzed the four programs and found that the TASC 81 estimation did not include initial sole-source data. Studies by Craig Sherbrooke, J.W. Drinnon, and John Hiller [1983] and by Michael Beltramo and David Jordan [1982] found that when such data were included, the estimates for the learning curves were approximately equal.

Beltramo 1983. Beltramo [1983] reviewed 46 previously studied items with an emphasis on isolating the effects of split awards and dual-sourcing from those of winner-take-all competitions.[11] His results reinforced some of the observations made in other reports: Split-award competitions were less effective than winner-take-all competitions, and the procurement of electronic items resulted, on average, in significantly greater savings than that of nonelectronic items (40% savings). He argued that the savings resulting from competitive procurement of electronic equipment are greater than that from competitive procurement of other items because production of electronic equipment requires little capital outlay and the production apparatus can also be used to manufacture commercial electronics.

Greer and Liao 1986. Willis Greer and Shu Liao [1986] estimated savings for seven systems based on the volume of total production and on the degree to which contractors had excess capacity. They found that the coefficient for the effect of capacity utilization was positive and significant in half the cases and suggested that it was best to introduce competition for projects when capacity utilization in the industry was below 80%.

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[11] See U.S. Government Accounting Office [1984] for a discussion of the extent to which dual-sourcing is currently employed.

Bliss 1987. Gary Bliss [1987] estimated the benefits of dual-source procurement for the guidance and control assemblies of four different air-to-air missiles procured since 1975. He made savings estimates using three approaches: (1) the traditional approach of IDA 74 augmented by production rate factor, (2) an approach consistent with the "shift and rotation" theory discussed in TASC 81, and (3) a "worst-case sole-source" analysis. The second approach estimates a single price function for both the competitive and noncompetitive phases of procurement and uses indicator variables to allow for a shift and rotation of the price function when competition is introduced. Using estimated parameters from this price function, Bliss predicts the hypothetical sole-source price. This approach allows him to increase the degree of freedom in the estimation. The worst-case analysis extrapolates the sole-source price by assuming a very conservative 90% learning-curve slope along with an intercept derived from the initial production lot price and a rate adjustment factor.

Each contractor's bid in these programs involved prices for varying divisions of the total requirements of the government. Bliss estimates the rate factor separately from the other parameters of his model by exploiting this additional information. Although savings estimates under approaches (1) and (2) showed considerable variation, Bliss generally found that dual-sourcing was more expensive than sole-sourcing.

Summary of Results

All the studies except Bliss showed savings due to competition (Table 2); however, when start-up costs are netted out, it is not always clear that savings were achieved. Thus, most of the later studies tended to advise caution when considering a project for competition.

Note that the savings estimates for individual programs that were examined in more than one study often varied widely. IDA 79 pointed out that estimates of savings vary with the method used to estimate sole-source prices. A similar point was made by K. S. Archibald and colleagues [1981], who reported that estimates of savings for the Shillelagh missile program

Table 2. Comparison of competitive procurement savings.

	ECOM 72	IDA 74	APRO 78	IDA 79	TASC 79	Bliss 87
Learning-curve extrapolation	no	yes	yes	yes	yes	yes
Data used	price	price	cost	price	price	price
Number of cases	13	20	16	31	45	4
missiles	0	5	10	9	12	4
torpedoes/bombs	0	3	1	2	5	0
electronics	13	12	5	20	28	0
Avg. savings (%)	53	37	11[a]	34	33	(21)
missiles	—	26	13	17	22	(21)
torpedoes/bombs	—	27	(13)	(19)	43	—
electronics	53	44	12	47	36	—

[a] Over entire program cost.

ranged from 0 to 79% across various studies. They went on to point out that APRO 78 and IDA 79 would have had different ordinal rankings of the gross savings across programs that were common to both.

These differences in benefit estimates are the result of disagreement among the authors over the basic data set, especially in accounting for all purchasing rounds and nonrecurring costs, as well as extrapolating sole-source prices. Given the limited number of observations available for each program, the calculation of savings is necessarily very sensitive to any disagreement at this level.

All the aforementioned studies have contributed to a better understanding of the effects of competition on government procurement prices. Unfortunately, the limitations of the data base in the number of observations and type of information provided have confined the existing models to measurements of savings that can be judged tentative at best.

Below we sumarize the major results of the studies in terms of a set of stylized facts.

1. The sole-source contract price declines over time. (All studies find that unit prices decline with cumulative production.)
2. It is unclear whether the slope of the competitive price curve is steeper than that of the sole-source price curve. (This reflects a disagreement between TASC and IDA 74/Sherbrooke.)
3. The first competitive price is typically lower than the last sole-source price.
4. Electronics programs exhibit greater drops in price when competition is introduced than do other programs (IDA 79, Beltramo).
5. Dual-sourcing results in less savings than sole-sourcing. (Beltramo; Bliss found additional costs rather than savings.)
6. The second source won most of the competitions (IDA 74 and others), but experienced problems in the post-competitive phase of procurement (Beltramo).

Only the last of these facts poses a serious problem for interpretation. A learning-curve-based theory suggests that the developer will win most of the competitive auctions. Furthermore, problems with the second source suggest that the quality of production varies across the developer and second source. These issues will be discussed below.

Although it is clear that the data base for savings calculations is a real limitation, we are not prescribing a more concerted effort at data gathering (though that certainly couldn't hurt); rather, we believe that the first priority for empirical work is to identify the fundamental properties of the underlying economic structure of the procurement problem. The estimation efforts described above depend on a set of assumptions about the structure of procurement; confidence in the validity of savings calculations would be seriously undermined if these assumptions are found to be incorrect. In the following section, we examine these assumptions and contrast them with other plausible models of the economic structure of procurement.

AN ASSESSMENT

The studies exhibit a broad consensus about the conceptual framework that underlies the analysis. As introduced by IDA 74 and later formalized by IDA 79 in the form of a present-discounted-value investment criterion, compe-

titive effects on procurement prices are assessed on a program-by-program basis. The procedure is to predict what prices would have been if sole-sourcing had continued, and then compare those prices with observed expenditures after competition was introduced. The studies differ in their implementation of this estimation strategy. The differences in data sets and extrapolation equations for sole-source prices account for the wide variation in estimates of savings from competitive procurement.

Sample Selection Considerations

Because competitive savings are calculated on a program-by-program basis, the sample of acquisition programs examined consists only of those in which competitive bidding was introduced at some point in the production phase of the procurement cycle. Programs in which only sole-sourcing was used are thus excluded. Of the studies under review, only IDA 74 makes use of data from the programs that were governed exclusively by a sole-source relationship. These data, however, were used only to investigate learning-curve effects and not in the extrapolation method for predicting sole-source prices.

The findings of IDA 74 show that a comparison across projects can reveal important similarities and differences between competitive and noncompetitive acquisition programs. In particular, if the sample of programs were expanded to include both kinds of program, it would be possible to assess the extent of several potential biases in the competitive sample. For instance, competitive programs may be correlated with a number of quantitative measures of the developer's performance during the sole-source phase (such as slippage in the delivery schedule, failure to meet system specifications, and cost-overruns on the sole-source procurement contract).

Establishing the extent of these potential biases in the sample is important because calculations of savings from competition based on a selected sample may not be representative of potential savings from programs on average. In particular, because second sources tend to win far more often than theory suggests they should, it would not be surprising to discover that past programs were chosen for competition because the relevant program manager was dissatisfied, and that dissatisfaction may have reflected that the developer was an inefficient producer of that particular product.[12] Additionally, basic correlations may be useful for developing criteria or rules of thumb to identify programs that are attractive candidates for competitive procurement (for example, electronics as opposed to missile programs).

Anticipatory Pricing

More generally, comparisons across projects can support a number of tests on the consistency and validity of the methods employed in the measurement of competitive effects. Essentially, comparisons across competitively and noncompetitively procured projects test the hypothesis that the former programs are a random sample from the full set of programs. By focusing on

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[12] Suppose, for example, that not all manufacturers are capable of producing at the same cost. Then any particular sole source might be a lower- or higher-than-average producer. If program managers can sort the higher-than-average from the average-cost producers, then we should expect that programs chosen for competition had a larger proportion of higher-cost sole-source producers which, in turn, implies that second sources might frequently win competitive auctions.

the variation across projects, it is also possible to examine some fundamental aspects of the current framework.

The current procedure (comparing extrapolated sole-source prices and observed competitive expenditures) accurately measures the full extent of changes in acquisition costs for a given program only if the observed path of prices in the sole-source phase is similar to the path that would have prevailed had it been known with certainty that there would be no competition over the entire life of the project. Implicitly, this requires that neither the contractor nor the government exercise any strategic influence on the negotiated sole-source prices in anticipation of the subsequent competitive phase of the procurement process.

Evidence, however, suggests that prices are strategically determined. For instance, several studies noted that the estimated relationship between unit price and accumulated production was a poor predictor of unit price for the final sole-source purchase (just before competition commences). Beltramo (p. 65), for example, reported that the final unit price in the sole-source phase was well below its predicted value in 12 of the 18 programs studied and only slightly above in the remaining 6. The positive prediction residuals were also noted by Richard Hampton [1984].

A consistent overprediction for the last sole-source price suggests that the log-linear model for estimating sole-source prices is misspecified. If the relationship between sole-source prices and accumulated production is similar in both competitive and noncompetitive procurements, then we expect to find that the log-linear form also tends to overpredict prices in noncompetitive procurements when accumulated production is large. IDA 74 found just the opposite: The log-linear model for noncompetitively procured programs underpredicts sole-source prices at larger values of accumulated production.

Beltramo offers an explanation for the overprediction associated with competitive procurement. At the time of the final sole-source purchase, technology transfer and learning buys are in progress so that the developer is aware that the next procurement round is likely to involve competition. The drop in unit prices, he argues, is the result of a cost-cutting effort by the developer as part of an overall strategy to position itself for the impending competition. Whatever the reason, Beltramo's finding of an unexplained drop in unit prices just before competition supports the position that the developer can influence observed prices in the sole-source phase and that the prospect of a competitive phase can alter the way in which the developer exerts this influence.

The immediate implications of anticipatory sole-source pricing are straightforward. If the unit-price drop is concentrated in the tail end of the sole-source phase, then the slope estimate used for predicting sole-source prices is biased in the direction of a steeper slope. Hence, extrapolated sole-source prices are lower than their true expected value in the absence of competition, and expected savings are underpredicted. Further, the reduction in unit prices at the tail end of the sole-source phase should be incorporated in the calculation of competitive savings. One possibility for identifying this effect is to examine programs in which competition was contemplated but no competitive procurement took place.

A further implication of anticipatory sole-source pricing is that measuring competitive savings (or losses) on the basis of prices within a given program

is an incomplete assessment of the effects of competition. Empirically, the five (plus or minus) observations on price and quantity in the sole-source phase provide no realistic prospect for isolating the shift in prices due to altered incentives for the developer and the government. Theoretically, under a stable policy for implementing competitive bidding for production awards, the entire price-quantity relationship in the sole-source phase is influenced by the prospect of competition because the negotiating parties incorporate this prospect in their decision problems.

The within-program implications may be even more critical than the across-program implications in most of the available sample of competitive programs. Because a stable policy for initiating competition was not in place when most of the measured procurements occurred, the developer and the government may have heavily discounted the possibility of competition until well into the sole-source phase. Only Bliss estimated savings based entirely on programs in which each contractor anticipated future competition at the start of the project.[13] Nevertheless, at least for more recent procurements, variation in contracts across projects might provide additional information. For instance, by identifying a set of projects, competitive and noncompetitive, which used a similar contract form during the sole-source phase, we can look for a systematic effect of anticipated competition on prices.[14]

Structural Interpretation

Most of the studies place a structural interpretation on the estimated pricing equation for the sole-source phase, although a full justification for the interpretation is not made explicit. The main contribution of a structural model is that it provides a set of candidate explanatory variables. In the regression of unit prices against accumulated production quantity, the estimated slope coefficient is taken to be an estimate of the learning-curve parameter in the underlying production technology of the sole-source. This interpretation appears to be based on the (implicit) hypothesis of constant markup pricing and fixed quantity in the sole-source stage, according to which unit prices are a fixed, proportional markup on unit costs.

This cost-based framework for sole-source pricing also appears to have played a dominant role in the search for additional explanatory variables. This search has concentrated on current production rates, lot sizes, and measures of capacity utilization inasmuch as these variables are expected to have a strong influence on production costs.[15] Because procurement ranges

[13] Bliss's [1987] estimation does not measure competitive benefits that resulted from anticipated competition. Thus, Bliss's numbers may understate the benefits of competition. This might partially explain why Bliss is more pessimistic than the other researchers about the virtues of competition.

[14] If the only observable variables are prices and quantities, distinguishing between the extremes of markup pricing and monopoly pricing is very difficult. Generally, the ability of the sole source to exert a strategic influence on price depends on the extent to which the costs that the government observes in monitoring and negotiating the sole-source contracts are indicative of the true costs of production.

[15] Recent work on the effect of changes in production rate on costs (Dews in progress, reported in Rich and Dews [1986]) show a definite tendency for large changes in production rate to result in changes in unit cost. IDA 74 also found that lot sizes were significant predictors of costs in 14 of 24 aircraft programs analyzed.

over a diverse set of items and cost parameters are expected to be idiosyncratic, the focus on cost-based variables implicitly confines this effort to a program-by-program analysis. Again, the limited number of observations on each project has undoubtedly contributed to the lack of consistent results for these variables.

In this regard, one disadvantage of TASC's (1979) shift-and-rotation model is that it places no restrictions on the relationship between the sole-source and the competitive price curve. Thus, each curve is estimated independently using only the data from the corresponding stage. Bliss, in contrast, assumes a specific relationship between the noncompetitive and the competitive price curve, thereby allowing all the observations for a specific program to inform the estimation. Pooling the individual program time series data across programs may also prove fruitful. Greer and Liao [1986] adopt this approach when they hypothesize that savings to competition are influenced by industry capacity utilization, a nonprogram-specific variable that acts as a cross-equation restriction.[16]

Structural models derived from economic theory provide a systematic approach for identifying such regularities. A virtue of such models is that they typically provide tighter predictions than models that lack an explicit theoretical structure and, hence, (assuming that the theory is not rejected) are more valuable.[17]

A good candidate for a useful structural model in this environment is a strategic pricing model that incorporates learning and links prices in the sole-source and competitive phases of a procurement to government demand. Such models are relevant because it appears that contractors can create a false impression of costs by transferring costs from one program to another or by transferring costs between different lots of the same project.[18] The latter possibility may be important given that a learning curve implies that the *current* marginal cost of production diverges from the true economic cost of current output, which incorporates the reduction in future marginal cost arising from learning. This feature might encourage a contractor to shift costs from the current to the subsequent lot (although considerations such as cash flow will work in the opposite direction). Strategic pricing models are also consistent with the decline in unit prices with accumulated production as observed in the vast majority of procurement programs: but, in contrast to the markup model that treats quantity as an exogenous variable, the influence of demand is explicit in these models [Spence, 1981; Clarke, et al., 1982].

[16] While this work has weaknesses, it does represent a break from the program-by-program analysis favored in earlier studies. As we have emphasized, establishing regularities appears to be necessary for overcoming the estimation problems created by the limited number of observations of price and quantity for each program.

[17] Without the underpinnings of a clearly specified theoretical model, assumed relationships are essentially reduced-form representations of some (unspecified) model or a class of such models. This presents problems for both the interpretation and validation of the estimation. In the context of estimating market power, Bresnahan [1989] reviews models that use theory to structure estimation.

[18] Actions taken by a contractor can have a direct influence on the relationship between economic costs and accounting costs. Because many contractors are simultaneously engaged in work on a number of programs, the allocation of overhead and fixed costs across programs becomes an issue. See the Appendix of J. Ronald Fox [1988] for a long list of recent cases in which the government alleged that contractors mischarged and misallocated costs.

Models that seek to address the problems of strategic pricing necessarily involve demand considerations in addition to cost factors. For instance, if demand is highly inelastic, higher prices are less likely to translate into quantity reductions than if demand were elastic. Implicitly, most of the studies assume that demand is completely inelastic when they interpret the slope of the estimated-pricing equation as the learning-curve parameter.

Another potentially useful framework is provided by strategic cost models. Such models explicitly treat the economic tradeoffs (such as investment and process innovation expenditures) confronting a producer who is taking actions that influence costs [Laffont and Tirole, 1986].

Sources of Savings from Competition

A different set of issues arises in the competitive phase of procurement. An accurate accounting of incurred procurement prices, while not a trivial task, is certainly a manageable one. In assessing the historical sample, one is not tied to any particular explanation for the determination of these prices. For the prediction of savings, however, a conceptual framework is essential.

The studies identified two effects associated with competitive bidding that can reduce unit prices relative to prices in a sole-source relationship. First, competitive bidding may result in a lower profit margin relative to the sole-source phase because the bids involve a smaller premium over production costs. We should emphasize here that the direct savings to the government from competition is heavily influenced by the degree to which cost reductions are made by both bidders. The expected competitive price (net of risk considerations) reflects that of the highest-cost producer because the lower-cost contractor has no incentive to bid more than a small amount below the higher-cost producer's cost. For example, when bidders are well informed about each other's costs and the second source has extremely low costs relative to the original sole-source prices, the government will not necessarily benefit unless the original sole-source can reduce its costs as well.[19]

The second effect comes from an improvement in cost-effectiveness when the firms enter the competitive phase. APRO 78 emphasized that cost-reimbursement rules in the sole-source phase often result in distorted input choices by the sole-source producer. Under competitive bidding, this incentive is removed because the winning bidder has a strong incentive to choose factor inputs efficiently and produce at minimum cost.[20]

The incentives for pricing and cost reduction in the competitive phase of procurement may depend on the format of current and future bidding competitions. For example, James Anton and Dennis Yao show that split-award auctions can result in very different investments in process innovation than would occur under a winner-take-all format.[21] Procurement programs

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[19] As a polar example, consider a two-bidder case in which both contractors have perfect information about each other's costs. In that case the lower-cost contractor will bid a shade below the higher-cost contractor. Under asymmetric information, bidding is more complicated but still remains a similar feature.

[20] Another possibility emerges if the second source decides to use a different production technology.

[21] This can occur because a split-award auction allows both contractors to receive an award and earn profits, whereas a winner-take-all auction results in only a single award. See Anton and Yao [forthcoming].

exhibit a considerable degree of variation in the format for competition and the rules under which competitions are run. In some cases a winner-take-all bidding competition is held after a second source has been given a small amount of production (a "learning buy") that enables the second source to gain production experience. In other cases, one or more rounds involving split awards, which may have been used as a substitute for the learning buy, are followed by a single winner-take-all competition. In the case of the Sidewinder missile, six procurements held in the sole-source phase were followed by two split awards and then eight winner-take-all competitions.

The rules for determining awards effectively vary across projects. In several instances the high bidder emerged as the winner, thus indicating that these were not purely price competitions.[22] On other occasions the second source was allowed to renegotiate price, based on the claim that technology-transfer was ineffective. An additional complication arises from the failure of the second source to deliver on some awards; this suggests that quality differences are present and that the government is making a joint price and quality decision rather than just a price decision.

Based on the descriptions provided in the studies, much evidence relating to the timing of the decision to compete, bids (especially for split awards), auction rules, and final outcomes is still unavailable. Accounting for differences in rules of competition is important because the theoretical literature indicates that such differences have direct effects on pricing and bidding decisions.[23]

More subtly, the threat of competition will also affect sole-source pricing. A sole-source contractor may accept lower sole-source prices in order to decrease the probability that reprocurement competition will be introduced [Anton and Yao, 1987; Demski et al., 1987; Riordan and Sappington, 1987]. Similarly, if the sole-source producer is operating inefficiently, it may begin the process of increasing its efficiency so as to improve its chances in the competitive phase [Rob, 1986].

Other Concerns

Because performance of the sole source depends, in part, on the diligence of the program manager, relative savings are likely to be influenced by the incentives of program managers and other government personnel for reducing costs or, if expectations about competition are instrumental in changing sole-source behavior, for threatening competition. The literature we have reviewed treats government personnel as agents motivated to pursue price reduction. Nevertheless, other observers have noted repeatedly that controlling defense prices is difficult in the context of incentive schemes that induce program managers to act in ways that may undervalue price criteria and overemphasize performance. For example, Archibald and colleagues [1981] indicate that the program manager's incentive to initiate competition can be

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[22] Anecdotal evidence provided in the studies indicates that delivery times, quality, and later settlements vary depending on who is doing the producing and when. For example, Beltramo found that a number of split-buy competitions resulted in the higher-bid producer getting the higher share of production (Rockeye bomb, Shillelagh missile, Shrike missile). This suggests the possibility that the high bidder may have won in some of the winner-take-all competitions, but these bids are not reported because the original bid data is not generally available.

[23] There is also the possibility of cooperative behavior on the part of the contractors.

weak given the obvious and near-term difficulties involved in readying a second source and the nebulous future benefits of competition.

In addition, we need to make two caveats about the use of these estimates for forecasting and policy analysis. First, since most of the data used to build the forecasting models are from 1972 or earlier, the procurement environment may have changed in ways that invalidate the estimation of the forecasting parameters. Some evidence suggests that the procurement environment has indeed changed: Changes in procurement policy were initiated in the 1970s, and related measures (such as rate of cost growth) differed in the 1970s from what prevailed in the 1960s. Edmund Dews, G. K. Smith, and colleagues [1979] found, for example, that the annual rate of real cost growth for programs in the 1970s was one to three percentage points slower than in the 1960s. While cost growth comparisons are misleading if the initial estimates were made on a "more realistic" or more conservative basis, the findings suggest that the procurement environment may have altered and that results based on pre-1970s data should be applied with caution.[24]

Another potentially important problem with the use of single-project analysis is that it ignores systemwide effects. Such studies underestimate the benefits of second-sourcing by excluding the benefits that technology transfer will have on future projects or the insurance value of maintaining defense-production capability. On the other hand, the studies may overestimate benefits if it is possible for a contractor to transfer cost among programs so that decreased costs on one project are offset by increased costs on another project.

IMPLICATIONS FOR FORECASTING AND POLICY ANALYSIS

The primary value of procurement studies to decision makers rests with their usefulness in identifying programs in which the introduction of competition will yield the largest benefits. Given that the estimates of past effectiveness are highly suspect, it follows that forecasting equations based on these estimates are no more reliable.

Forecasts based on the above models suffer from two critical problems. First, as we emphasized in the last section, these models are based on strong assumptions about the nature of the procurement environment that not only seem to be unreasonable from a theoretical point of view, but also seem to be contradicted by the evidence. This problem stems from the considerable gap between empirical studies on procurement and the theoretical work in this field. The issues emphasized in theoretical models (such as information and strategic pricing) do not play a significant role in the empirical effort that attempts to assess the savings due to reprocurement competition. In other defense-related issues, there are examples in which theory and empirical work are more closely related.[25]

[24] See Summers [1965] and Rich and Dews [1986] for a discussion of cost-growth estimation. Biery [1985] also analyzed the cost growth of programs in the 1950s through 1970s. He found that while the annual growth rate for the early 1970s was about 2.8% lower than for the early 1960s, the overall program cost growth was 14 percentage points higher for the later programs because their average length had increased.

[25] See, for example, Rogerson [forthcoming] on profit rates and innovation, and Summers [1965] on cost growth.

Second, the paucity of available data imposes a severe limitation on useful forecasting. For a forecast to be useful, it needs to identify a dimension along which savings are correlated—such as the ratio of units to be competed versus sole-sourced, some measure of capacity utilization, the nature of subcontracting arrangements, or demand parameters. In other words procurement programs must be linked in some fundamental way; otherwise, attempts at forecasting are doomed to failure. Structural models provide a theoretical basis for expecting common features across programs. These predictions can be tested and, if not rejected, used to calculate future savings.

Taken together, these two problems lead to a pessimistic evaluation of the prospects for improvement based on the current empirical models. The theoretical framework employed in those models leads directly to a program-by-program analysis, while in the data sample, no single program has enough observations to provide any confidence in the estimated parameters. As a method for overcoming this restriction we have emphasized the role of comparisons across programs and, in particular, the added information content that can be derived from a judicious use of economic models.

This is not to deny the value of some of the insights produced by these studies: APRO's criteria for determining whether competition will be easy to implement and whether it is likely to be effective, and IDA's concern with competition as an investment decision are both sensible approaches. It is disappointing, though, that these insights were not guided by the empirical work—they could have been determined just as easily through armchair empiricism.

There is no question that the difficulties of measuring, much less forecasting, the benefits of second-source competition are immense, yet the magnitude of the problem is no excuse for models based on weak theory. The weaknesses inherent in the existing studies and the disagreements among them suggest that we still have a long way to go before we can accurately identify the settings in which competition will prove valuable. In our view a critical step in that direction is to tighten the connections between theory and empirics.

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