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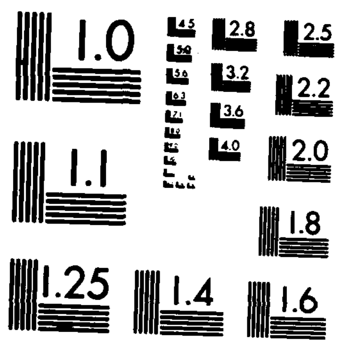
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RESEARCH MEMORANDUM

EVALUATION OF MODELS AND TECHNIQUES FOR ESTIMATING THE EFFECTS OF COMPETITION

Robert M. Berg
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James M. Jondrow

A Division of CNA Hudson Institute

CENTER·FOR·NAVAL·ANALYSES

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This research memorandum presents an evaluation of past efforts to estimate the savings due to the use of competition in weapon system production programs. The evaluation was based on the research literature available from the historical efforts. The evaluation of the literature discusses in detail the analytical models and techniques used in the analyses of price formation in sole-source and competitive production programs, the data bases used and reported for the programs studied, and the results and conclusions reported in the literature. The memorandum concludes that the models and techniques used to assess the price effects of competition are immature and inadequate to sort out the effects of competition sought by the analyses; that the data bases used in the literature are incomplete, of uneven quality, and may be seriously biased; and that the resulting estimates of savings due to the use of competition are of uneven validity.

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EVALUATION OF MODELS AND TECHNIQUES FOR ESTIMATING THE EFFECTS OF COMPETITION

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ABSTRACT

This Research Memorandum presents an evaluation of past efforts to estimate the savings due to the use of competition in weapon system production programs. The evaluation was based on the research literature available from the historical efforts. The evaluation of the literature discusses in detail the analytical models and techniques used in the analyses of price formation in sole-source and competitive production programs, the data bases used and reported for the programs studied, and the results and conclusions reported in the literature. The memorandum concludes that the models and techniques used to assess the price effects of competition are immature and inadequate to sort out the effects of competition sought by the analyses; that the data bases used in the literature are incomplete, of uneven quality, and may be seriously biased; and that the resulting estimates of savings due to the use of competition are of uneven validity.

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INTRODUCTION

Competition has been the policy in defense procurement for a number of years. In fact, competitive procurement was one of the improved management practices instituted in 1962 as part of a 5-year program for reducing procurement and logistic costs. One of the goals of this program was to have 40 percent of defense procurement done competitively by FY 1965 [21, pp. 114-115].

The DOD policy of competition is based primarily on a belief that competition creates cost savings. It is not unusual for a discussion of the effects of competition to include a statement that competition reduces costs by "X" percent. The value and base of the "X" percent vary from study to study. A study done by the Army Procurement Research Office in 1978 notes that "Traditionally, a 25 percent reduction is expected, but there is no empirical support for such expectation" [3, p. 1]. In this particular instance the base for the 25 percent reduction was acquisition costs.

The purpose of this paper is to evaluate the literature dealing with retrospective estimates of savings from competition in production programs. While there have been a number of papers with the same purpose (Beltramo and Jordan [9], Sherbrooke [13], and Beltramo [17] are three of the better ones), they have tended to focus rather narrowly on specifics such as data manipulation or the applicability of a particular assumption. This paper will be broader and deal with three topics covered in the procurement literature. The first topic, which receives cursory treatment in the other reviews, will be the model that appears to dominate studies of defense prices in both sole-source and competitive production environments. The second topic will be the statistical techniques applied to the analysis and their appropriateness for forecasting the effects of competition. The final topic, which is a strong point in the reviews cited above, will be the data and results that appear in the literature.

MODELS

Most analyses of production competition focus on how competition will change the price the government pays for a weapon system. The focus on price arises from the fact that any savings that result from competition are derived from reductions in unit procurement prices over the life of the system. The economic question, in the case of competition, is whether the future savings are large enough to offset those current, nonrecurring costs of implementing competition that the government incurs directly, such as government-furnished tooling and test equipment. The analyses of price formation and competition in the literature reviewed here attempt to answer this question.

In these studies the models address the unit prices to the government under sole-source and competitive production contracts. This comparison yields an estimate of gross savings due to production competition. Estimates of net savings are obtained by subtracting from gross savings the nonrecurring costs to the government of establishing the competition. In the literature considered here, these nonrecurring costs are estimated independently of the price analysis. These off-line estimates are then subtracted from the gross savings to yield net savings due to competition.

The off-line estimates of nonrecurring cost to the government will be addressed in the data section. The models of price formation used in this literature are addressed in this section.

The Basic Model

Virtually all of the recurring price/cost models in defense procurement are based on the learning-curve paradigm. In its original form, the learning curve arose from an observation that the number of manhours required to produce an airframe fell with an increase in the total number of airframes. This learning effect was generalized to all inputs and, subsequently, to unit production costs.

The procurement literature tends to push the generalization of the learning effect a step further by assuming (implicitly) that the effects of learning are pervasive and that any cost reductions are passed through directly to prices. Given this implicit assumption, the learning curve is transformed into a price improvement curve (PIC).[1] The PIC may take any one of several forms:

- A simple PIC in which cumulative quantity is the only independent variable
- A rate-adjusted PIC that includes a production-rate variable
- Other forms of adjustment to the simple model (see Greer and Liao [16] for an example using industry capacity utilization as a key variable influencing price behavior).

1. The dominance of this concept is evident in the fact that [2, 3, 4, 5, 8, 9, 10, 12, 13, 16, 17, 20] all use a learning curve or PIC-based approach. Of the remaining references, only [1] is concerned with estimating the effects of competition on procurement costs.

The typical, rate adjusted, PIC is given by:

$$P = P_1 Q^a R^b \quad , \tag{1}$$

where

P = price of the Qth unit

P_1 = price of the first unit produced at a rate of one per period

Q = cumulative output

R = production rate (quantity per period of time)

a = learning parameter

b = rate parameter.

The learning and rate parameters, a and b, are generally transformed into percent terms in specific discussions of price behavior. For example, a value for a of −0.2 corresponds to an 87 percent learning rate.[1] Assuming a constant production rate, an 87 percent learning rate, in the PIC context, means that the price of the second unit is 87 percent of the price of the first, the price of the fourth unit is 87 percent of the price of the second, the price of the eighth is 87 percent of the price of the fourth, etc. The rate parameter b is interpreted analogously.

Given the basic PIC model of price formation, hypotheses on the effects of competition are generally represented as:

- A shift in the PIC, i.e., a change (reduction) in P_1
- A rotation in the PIC, i.e., a change (reduction) in a
- Both a shift and a rotation in the PIC.

Figure 1 illustrates these effects using the logarithmic version of the PIC. The shift is represented by the downward displacement of the curve and the rotation by the increase in the steepness. These shift-and-rotation hypotheses assume that the structure of the price formation process changes with the introduction of competition. Given the increasing emphasis on competition, a detailed understanding of the assumed structural change is required if procurement resources are to be allocated efficiently.

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1. The percent learning rate (or percent slope) is defined as 2^a.

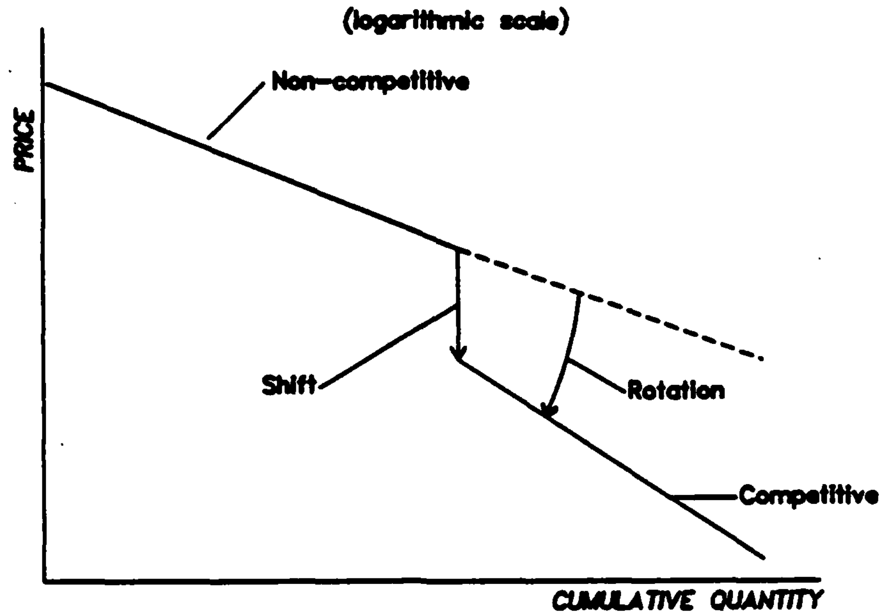

FIG. 1: THE EFFECT OF COMPETITION ON THE ORIGINAL SOURCE

An Evaluation of the PIC Methodology

How well do these hypotheses reflect the effects of competition on the prices the government pays for goods and services? This question can be addressed on both the theoretical and empirical levels. The answer depends on how well the underlying PIC hypothesis reflects the price formation process in the procurement of weapons. Since advocates of competition appeal to economic theory to support their arguments, the theoretical foundations of the PIC will be considered first.

Theoretical Evaluation

If an economic model of defense procurement prices is to contribute to an understanding of the effects of competition on weapons system acquisition, it must consider the institutional, technical, and behavioral characteristics of the defense procurement process. In general, the institutional characteristics (e.g., the extent of competition and the Federal Acquisition Regulations), and the technical characteristics (e.g., the type of product being purchased (missile, ship, etc.)), constrain the behavior of the participants in a particular acquisition. When behavioral assumptions (e.g., firms wish to maximize their profits) are combined with the institutional and technical constraints, a model of the decision-making process and its effects on factors of interest, in this case procurement prices, can be formed.

The PIC, as an economic model of procurement prices as used in the literature, is too narrowly based. It lacks sufficient consideration of the characteristics outlined above to provide even a minimal understanding of the price formation process. In particular the PIC approach ignores, with one exception (see the discussion of [16] below), any consideration of the behavioral or institutional factors, and the discussion of the technical factors contained in the literature (i.e., learning and rate effects) is both incomplete and confused.

Behavior and Institutions. Of the papers examined for this study, only Greer and Liao [16] and Beltramo [17] discuss the institutional/behavioral aspects of the procurement process. Greer and Liao approach the behavioral aspect by citing three alternative strategies a firm may choose in response to competition:

- Constant percentage profit--price is a constant percentage markup over cost.
- Penetration (limit) pricing--if the government has not committed to competition, the firm sets a price that is low enough to discourage the introduction of competition.[1]
- Skimming pricing--if the government is committed to competition, the firm sets a high price and lowers it as necessary to meet competition.

Greer and Liao never follow up explicitly on these particular alternatives. However, their empirical work does include a measure, industry capacity utilization, that reflects some consideration of the behavioral alternatives available to a firm.

Beltramo [17, pp. 40-41] notes that a variety of economic models can be used to describe the behavior of a firm and that the particular model depends upon the situation. Beltramo suggests that the approach found in the Stackelberg duopoly model might be appropriate for dealing with dual-source competition.

The Stackelberg model recognizes two types of firms. A firm may choose to be a leader and pursue a dominant market position by using aggressive strategies in areas such as price and quality. Alternatively, the firm may choose to be a follower and adopt a set of passive strategies in areas of potential competition. In this instance the follower firm will serve that segment of the market that the leader firm cannot supply, possibly ending up with a small but profitable market niche.

---

1. If a contractor knows the government's criteria for introducing competition, the limit price can be calculated and the profitability of this approach compared to that of other pricing strategies.

Although the loser in a dual-source competition may receive a zero award, it is not a common occurrence, and often the loser is guaranteed some part of the fiscal-year buy. This quantity guarantee can provide a substantial incentive for passive pricing behavior by the firms involved. Only when both firms desire to win the competition and choose aggressive pricing strategies can the government have a reasonable expectation of financial benefits from dual-source competition.

While Beltramo's discussion is an excellent beginning toward development of a complete model of pricing behavior, the determinants of pricing strategy and the implications for empirical models are not explored. Ultimately, Beltramo relies on the PIC formulation for empirical work.

Technical Considerations. The PIC model, as found in the literature, is essentially a cost-based model of price. However, the only technical factors included are the production rate and the cumulative quantity. The exclusion of other relevant variables, such as resource prices and system characteristics, suggests that the PIC is an incomplete model of prices. This conclusion is reinforced by the universal failure of the literature to explain how the firms transform their costs into price offers.

The incomplete specification of price formation represented by the PIC is a critical problem for two reasons. First, the failure of the literature to include a number of potentially important factors in the model, factors that are recognized as important at other levels of analysis, implies a fundamental conceptual incompleteness in the treatment of both price formation in general and competition in particular. The danger is that the simple model will result in simple and inappropriate solutions to a complex problem.

Second, the exclusion of important variables from the analysis implies that the empirical effects of competition on prices may be estimated with systematic, but unknown, errors. This statistical problem compounds the conceptual problem cited above.

The fundamental problems associated with an incomplete specification are compounded by the widespread confusion over what the rate term is supposed to represent. Most discussions of the effect of the production rate on price focus on the cost-based concept of economies of scale. Economies of scale are an important consideration in planning the optimal level of tooling, but they are not necessarily relevant in an evaluation of rate effects on prices in the short run. In terms of the effect on cost, the question to be considered in the economies-of-scale context is the rate at which a facility is designed to produce, i.e., actual scale, relative to the optimal scale.[1]

---

1. One factor that may reduce the importance of the economies-of-scale issue is that the optimal scale may not be unique, i.e., there may be a range of facility sizes that produce at equivalent average unit costs.

To the extent that cost variations are an important influence on a firm's pricing, the relevant production rate concept is one associated with the operating costs of the producer. In this context a measure of the production rate relative to the design rate or plant size, not the absolute production rate, would appear to be a better approach for estimating rate effects. The importance of this factor depends on the technology of the process used in manufacturing the particular product and the planning horizon used in the analysis.

As noted above, the PIC models do not explicitly address the behavioral or institutional aspects of pricing, and they incompletely address the technical considerations. Consequently, the application of the PIC, given by equation 1, implicitly assumes that the only factors important to the price are the costs and that these costs are passed through directly to the government. The shift and/or rotation of the PIC when competition is introduced amounts to an assumption that competition causes firms to become technically smarter, more efficient, or less concerned with profits, or some combination of these factors. An adequate understanding of the potential benefits of competition is hindered by the failure of the PIC methodology to address the mechanism that causes the firms to change their behavior.

Stability. The fundamental empirical problem with the PIC approach to competition analysis is that the learning curves that form the foundation of this price analysis tend to be highly unstable. The evidence on stability comes from work done by Alchian [22] during World War II but not available for public release until 1963. Alchian estimated learning curves for the production of World War II military airframes using direct labor hours per pound of airframe as the independent variable.

The principal purpose of the research was to evaluate the learning curve as an analytical tool by examining the stability of the learning phenomenon. In this instance, stability was defined in terms of the ability of the model to predict the cumulative manhours required to produce the 1000th airframe, and the best model was defined as the one with the lowest mean absolute error of prediction. Alchian's best model had a mean absolute prediction error of 22 percent with a range of errors between -44 percent and +116 percent [22, p. 690]. In addition, this best model used the initial program-specific data, rather than historical data from other programs, to define the parameters of the learning curve.

Since price analysis in the literature has generally been done on a program-by-program basis, the results cited above have important implications for the degree of confidence that should accompany estimates of sole-source and competitive program costs. The instability of the underlying relationship is compounded by the lack of consideration for the linkages among production inputs, costs, and prices. This evidence on the instability of the basic learning curve reinforces the view that the simple PIC-based analysis ignores too many factors to be of much use in evaluating the effects of competition on procurement.

Survivability. Despite these serious problems, the learning-curve based PIC has endured in some aspects of DOD/DON price analysis, such as GFE. This survivability reflects the perception that defense procurement prices tend to fit the implied learning-curve pattern. This is particularly true of sole-source programs, and the rate of learning is often a point of discussion in negotiations over sole-source prices.

There are a number of theoretical considerations that would tend, in a stable environment, to reinforce a firm's incentives to establish the PIC pricing pattern. First, the observed pattern of prices may reflect a case of self-fullfilling expectations. If the government accepts the PIC as the way prices should behave, a firm can minimize negotiation costs and reduce the potential for other problems by having prices behave in the expected manner.

Second, there is the question of contractor performance. In the early stages of a program the contractor may not know if the system can be delivered. This risk of nonperformance may be reduced with more resources, i.e., a higher price. As the program progresses successfully, both the risk of nonperformance and the price may fall.

Third, there is the question of government performance. Since programs are typically funded by Congress one year at a time, there is the risk that the government will cancel or substantially alter the program. An example of such an alteration is the program stretchout.

The government performance risk can influence the firm in two ways. First, there are set-up costs associated with establishing a program, and these costs are independent of the quantities produced. Given the risk of program cancellation, the firm has an incentive to charge a higher price early in the program in an attempt to cover these set-up costs. As the program continues, the unrecovered portion of these costs and the associated risk falls. Second, since materials used in many weapons systems must be ordered well before they are actually required, the contractor must obtain resources based on the proposed program. A program cancellation or stretchout leaves the contractor with higher costs than if the program were operated as planned, again providing an incentive for a high initial price. As the program progresses, the plans are likely to become more stable, reducing the risk of cancellation. This progressive reduction in risk may be reflected in progressively lower prices.

When the risk factors are combined with the government's expected price profile, the corporate negotiators have strong incentives to establish high first prices, which then decline with cumulative production. The important factor here is that the declining price profile may be due as much, or more, to the government's way of doing business as it is due to learning on the part of the contractor.

Prediction. Another important characteristic of the PIC approach used in the literature is the fact that most analysis and estimation are performed on a program-by-program basis. Consequently, on any particular program, the data base consists of a small number of annual observations[1] that are the outcomes of a sequence of decisions made in a relatively stable environment. It is common to find a strong correlation between sets of time-series observations, whether or not there is a good theoretical explanation for the relation.

Even so, it is important to keep in mind that the predictive accuracy of the PIC (such as it is) only holds within a single program. This accuracy pertains to predicting the prices of later buys given the prices of earlier buys. There is no ability at all to predict the earlier prices themselves. As is argued in the next section, it is crucial to be able to predict these early prices, since competition may change all prices.

Structural Change. The PIC analysis in the literature is based on data drawn from an era in which competition was used early in the program life cycle--such as a sustained concept or design competition between two or more contractors. Competition for full-scale engineering development (FSED) was common, but competition between two sources during FSED was not common. Dual source production competition was used only for exceptionally strong reasons. The introduction of competition as the baseline approach to production procurement represents a major change in the way DOD does business. If firms change the way they price their products, which should be expected since firm pricing decisions are based on the business environment in which the firm operates, then the simplistic PIC approach taken in the literature will be an even less adequate base for analysis.

A prime example of this structural change phenomenon can be drawn from the economics literature. From the late 1950s until the mid-1970s the Phillips Curve was one of the principal conceptual and empirical tools for macroeconomic policy makers. The Phillips Curve was based on the observation that high rates of inflation and high rates of unemployment never occurred simultaneously. Consequently, by following an inflationary policy, government could keep unemployment at low levels. However, in 1975 the inflation rate and unemployment rate both hovered around 7 percent, an impossible combination given the conventional wisdom of the Phillips Curve. Subsequent research into the phenomenon found that the supposed tradeoff was only valid for random variations of

1. A typical number of observations on a program would be five or six, so ten would appear to be a large number of observations for this approach to price analysis.

inflation around a stable mean, and that the advent of systematic increases in the inflation rate changed the relationship substantially.

The acquisition community is likely to experience considerable difficulty in evaluating prices in general, and the effects of competition in particular, during the transition to the new way of doing business. This difficulty is likely to persist until the procurement environment stabilizes and both firms and government have had an opportunity to sort out the available information and determine appropriate rules of behavior.

The Anticipation Hypothesis

The discussion above concentrated on general problems associated with the PIC approach to price analysis and the potential problems in applying the PIC to a competitive environment. Even if one discounts the general considerations outlined above, there are specific problems with any application of the shift-and-rotation model. The best way to illustrate the problems is to present an alternative hypothesis of the behavior of a first source faced with the possibility of competition. This hypothesis states that, in anticipation of competition, the first source increases its initial price and reduces the rate of price improvement during the period of sole-source purchases. By responding to the threat of competition in this manner, the first source increases the current flow of profits in response to the increased risk of lost revenues and profits due to the introduction of the second source.

The anticipation hypothesis is particularly important (and damaging to the standard methodology) because it has the same implications for the change in the parameters of the PIC as the shift-and-rotation hypothesis, i.e., a decrease in the first unit price and an increase in the learning rate after the introduction of competition. Consequently, no empirical evaluation of competition based on the PIC formulation can distinguish between the shift and rotation hypothesis and the anticipation hypothesis. The conclusions on the effects of competition depend crucially on which hypothesis is correct. Acceptance of the shift-and-rotation hypothesis when the anticipation hypothesis is correct will result in overestimation of the benefits of competition.

The overestimation results from the fact that under the shift-and-rotation hypothesis the entire downward movement of the PIC is credited to competition. However, if the anticipation hypothesis is correct, the observed movement of the PIC should be decomposed into two parts. First, there would be an upward movement of the PIC as firms anticipated competition, and second, a downward shift as competition becomes effective. The increased costs associated with the upward shift should be subtracted from the reduced costs observed when competition becomes effective.

Summary

Three points need to be made with respect to the PIC model. Point one is that the PIC, as applied in the literature, has minimal theoretical content. The implicit assumption of the PIC approach is that, given an initial price, only learning and production rate effects are important in determining price. This assumption is maintained in spite of the recognition of other factors that are believed to influence cost and price.

Point two is that the ability of the PIC to predict prices depends on the stability of the procurement environment. If the only variable in a program is the production rate (and consequently, cumulative output), the PIC may prove adequate for predicting future program costs once initial values are established. However, the introduction of competition as the rule in procurement may represent a fundamental change in the business environment. If so, firms can be expected to change the way they price their products, and the PIC approach, unless modified, will be inapplicable, since it is based on information drawn from a different environment.

Point three is, from a practical view, the most damaging to the PIC approach to estimating the effects of competition. It is simply that there is an alternative hypothesis, the anticipation (skimming) hypothesis, with the same measured effects on the PIC as the shift-and-rotation hypotheses and substantially different conclusions about the cost effectiveness of competition. In particular, savings calculated under the shift-and-rotation hypotheses will overestimate the benefits of competition if the anticipation hypothesis is correct.

TECHNIQUES

Estimating Equations

While equation 1 represents the basic model of the price improvement curve (PIC), it does not represent the estimating equation that is typically used in evaluating the behavior of prices in specific cases. The application of equation 1 would require detailed observations on the price charged for each unit of the product. The information that is typically available consists of the number of units purchased in a given year and the total cost of that particular buy.

One of the techniques used in the literature, and the one most widely used, is to estimate a log-log form of equation 1 as given by:

$$\log(p) = \log(P_1) + b[\log(R)] + a[\log(Qm)] \quad , \qquad (2)$$

where the unit of observation is the annual buy, p is the average price of the units in the buy, R is the lot (buy) size, and Qm is the lot mid-point. Qm is calculated as the sum of all units produced prior to the current lot plus half the current lot.

One criticism of the log-linear technique is directed at the use of the lot mid-point, Qm. Given the observed average lot t price, $\hat{P}_t$, the true lot t mid-point value, $\hat{Q}_t$, is given by:

$$\hat{Q}_t = \left[\frac{\hat{P}_t}{P_1 R_t^b} \right]^{1/a} \qquad (3)$$

which in general does not equal Qm $\left(= Q_{t-1} + R_t/2 \right)$. The consequence of this measurement error is that the values of the price improvement parameter, a, and the production rate parameter, b, are estimated with systematic but unknown errors. These errors will be carried through in the evaluation of both sole-source and competitive pricing behavior.

A second technique for estimating the parameters of the PIC has been used [29]. The estimating equation, which avoids the measurement problems of the log-linear approach, is derived by integrating equation 1. The equation is given by:

$$TLC_t = P_1 R_t^b \left[Q_t^{1+a} - Q_{t-1}^{1+a} \right] / (1 + a) \quad , \qquad (4)$$

where

TLC = total cost of lot t

P_1 = first unit price

R = production rate proxy, i.e., size of lot t

Q_t = cumulative output through lot t

Q_{t-1} = cumulative output through lot t - 1

a = learning parameter

b = rate parameter.

The estimation procedure uses a complex iterative procedure to find the values of P_1, a, and b that minimize the sum of squared errors. Even if the underlying problems of the PIC model are ignored, there is still a fundamental problem with this complex iterative approach. The properties of the estimators from the procedure are unknown for small samples. As noted previously, in attempting to estimate effects of competition, a large sample would be 10 observations. However, a sample of 10 observations is considered to be small for purposes of estimation. Consequently, there is no applicable statistical technique for expressing the degree of confidence in the estimates.

How the PIC Is Used To Estimate Cost Savings

There are several detailed descriptions in the literature of how cost savings are estimated from a PIC (see, for example, APRO78 [3, pp. 8-16]). The general procedure is illustrated in figure 2. A PIC is fitted to the observations on price before competition is introduced--shown as the solid line. The estimated PIC is then used to forecast the prices that would have been charged if the program had remained sole source. These forecast prices are shown as the dashed line. Savings in recurring costs, by lot, are estimated as the differences between the forecast prices and the post-competition observations.

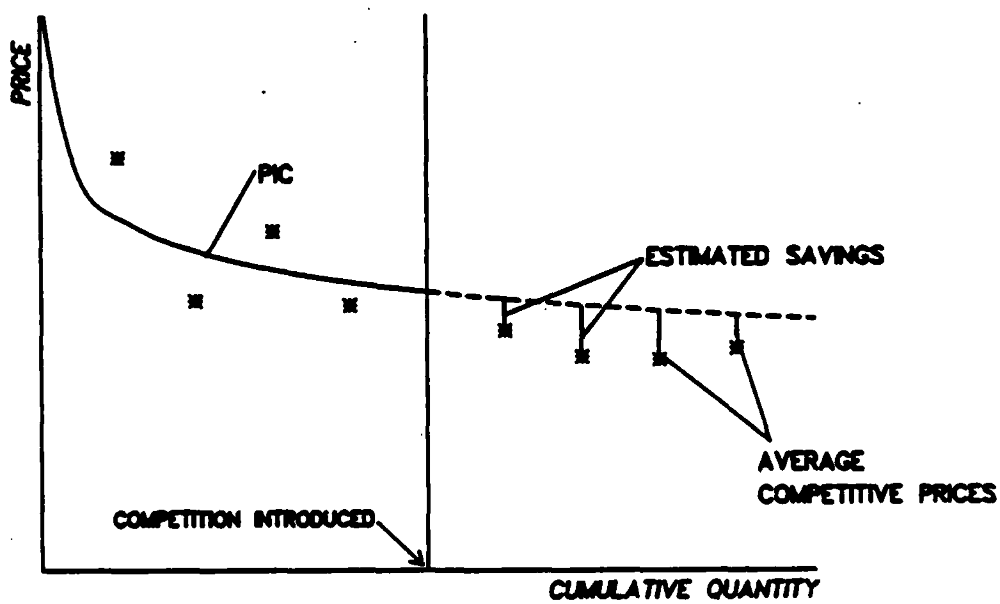

FIG 2: THE PIC AND ESTIMATED SAVINGS

Given the estimated savings for each lot, the procedure for calculating total program savings varies depending on the availability of other data and on the judgement of the researcher. For example, if data on nonrecurring costs are not available, then the sum of the individual lot savings may be presented as the estimate of gross savings. If nonrecurring costs are available, then the researcher must decide whether to discount the savings to account for the time-value of money and what discount rate to use. Whether discounted or not, the result will be presented as net savings.

One of the consequences of the small sample sizes common in the literature is an inability to estimate a PIC from the available data. As a consequence, a price-improvement parameter or production-rate parameter often is imposed on the data by the researcher(s). The imposition of an incorrect value for either of these parameters can have a substantial effect on the estimated savings from competition.

The effect of imposing too high a rate of price improvement is illustrated in figure 3. The imposed PIC is illustrated by the solid line. The estimate of savings is definitely low compared to the savings that were realized relative to the "true" PIC, illustrated by the dashed curve.

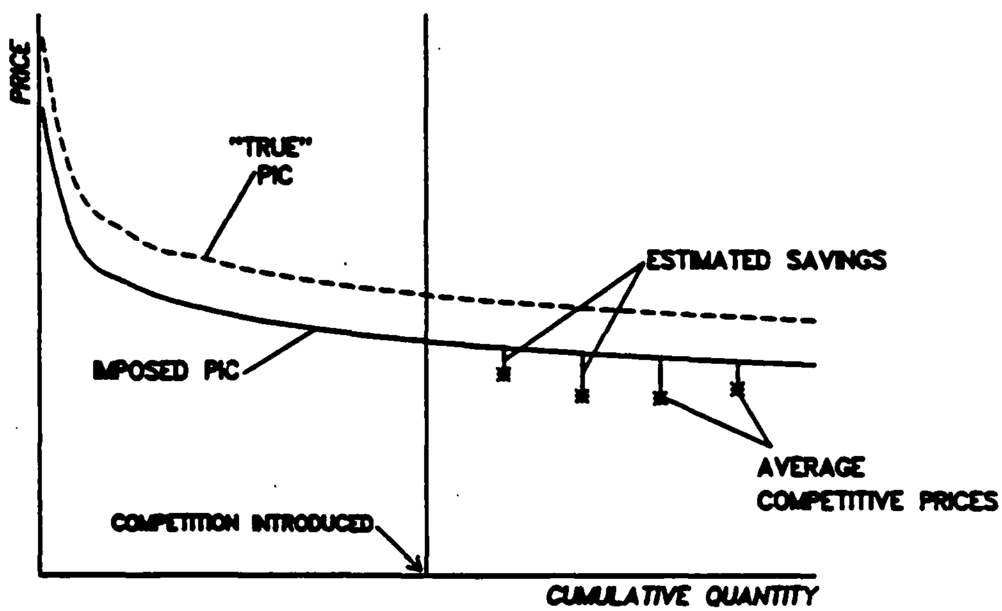

FIG 3: TOO HIGH A RATE OF PRICE IMPROVEMENT

The discussion above has presented the theoretical and empirical underpinnings of the PIC approach to price analysis and the effects of competition. The remainder of the paper will consider the characteristics of the data base used in estimating the effects of competition and the robustness of the resulting estimates of the effects of competition.

DATA BASE

This section describes a typical sample in the literature, indicates which cases have been analyzed, and identifies variables used in the analyses.

The Sample

A typical sample consists of the different production lots within a single program. As a consequence, samples tend to be small (usually with fewer than ten observations).

Figure 4 shows the data from the AGM-12B missile program for the original producer (Martin). An important feature is the paucity of data, with only three data points before competition and six after. The AGM-12B program is typical in this respect.

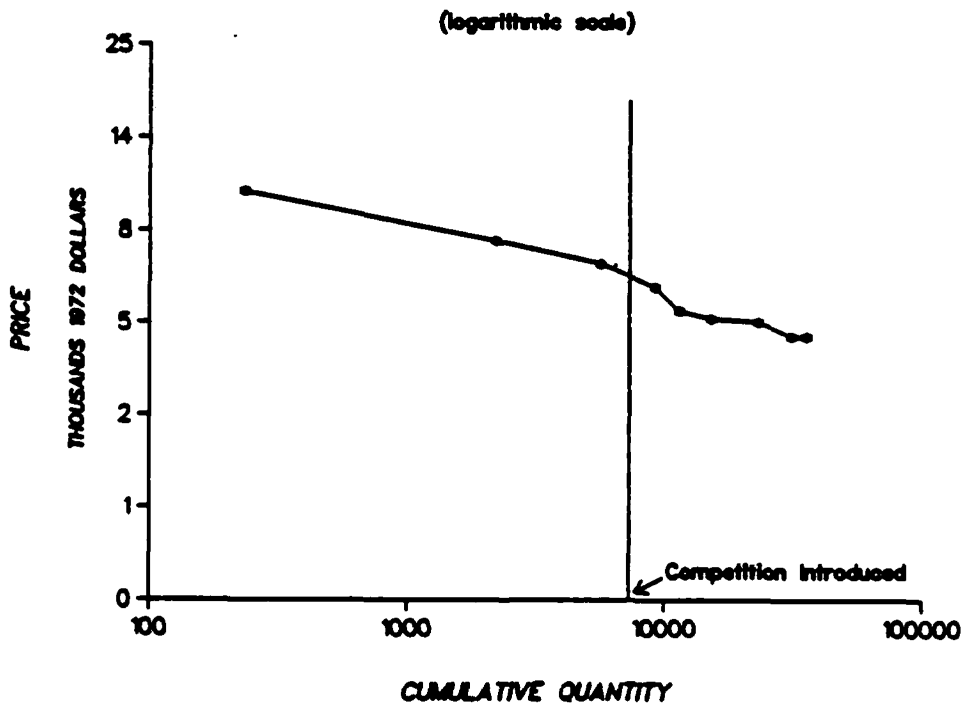

FIG. 4: PRICE IMPROVEMENT CURVE FOR THE AGM-12B MISSILE MANUFACTURED BY MARTIN

Small samples make statistical estimation difficult, and the resulting estimates have large variances. The AGM-12B program is a case in point. Although Martin appears to have changed pricing behavior after competition was introduced, the data fail to show statistically significant differences. In this instance, the availability of only three data points before the beginning of competition did not provide sufficient information for comparison to the competitive situation.

Cases

The literature review touched on 53 cases analyzed in 13 different studies. One study typically covered several programs; however, each program was analyzed separately, without comparisons across programs.

Table 1 displays some of the characteristics of these cases. The subheadings in the first column categorize the items being procured: munitions, missiles, or electronics. The second column describes the type of competition: winner-take-all or split buy. The third column lists the years of production.

To summarize, of the 53 cases, there were 30 electronic subsystem or component programs, 13 missile or missile parts programs, 5 bomb or munitions programs, and 5 torpedo programs.

Over half of the programs (33) had used the winner-take-all competitive method, in which the entire production quantity is awarded to the winner. Three programs divided the production between two or more competitors in what are called dual-source or split buys. Twelve programs were competitive split buys in some years, winner-take-all in others, usually a buyout after the competitive split buy. The procurement methods for five programs were not identified.

Selectivity Bias

Several aspects of the cases used in this literature suggest the possibility of selectivity bias. That is, the cases may not be typical of what can be expected from competition in the future, particularly the results of cost savings.

- The PIC methodology that is standard in this literature for estimating competitive cost savings can use only cases that are sole source initially and then competitive. Thus, production programs that were competitive from the outset were excluded.

TABLE 1

CASE STUDIES AND RESULTS OF COMPETITION

	Type	Time[a]	IDA74	IDA79	TASC79	APRO78	APRO79	SAI82
			Percentage savings to government estimated by:					
MUNITIONS								
Rockeye bomb	Split	1967 to 1973		-23.0	-4.5			3.7
750-pound M117 bomb	Split	1965 to 1972					9.30	
{M223 grenade fuze	Winner	1973 to 1974					11.20	
{M223 grenade fuze	Split	1976 to 1978					12.90	
{M489 projectile (tracer)	Winner	1968 and 1970					9.36	
{M489 projectile (tracer)	Split	1965 to 1979					4.97	
M103 cartridge case	Split/winner	1970 to 1978					11.60	
TORPEDOES								
Mk 48 warhead	Winner	1970 to 1973	53.2		48.6			
Mk 48 electronic assembly	Winner	1970 to 1973	37.5		47.0			
Mk 48 exploder	Winner	1970 to 1973	61.2					
Mk 48 test set	Winner	1970 to 1973	61.8					
Mk 46 torpedo	Split/winner	1964 to 1969						-36.4

NOTE: IDA74 = Institute for Defense Analyses, 1974 [2]
IDA79 = Institute for Defense Analyses, 1979 [4]
TASC79 = The Analytical Sciences Corporation, 1979 [5]
APRO78 = Army Procurement Research Office, 1978 [3]
APRO79 = Army Procurement Research Office, 1979 [23]
APRO80 = Army Procurement Research Office, 1980 [26]
SAI82 = Science Applications Incorporated, 1982 [9].

a. The time period for which information is available to allow classification by type of competition.

TABLE 1 (Continued)

	Type	Time[a]	Percentage savings to government estimated by: IDA74	IDA79	TASC79	APRO78	APRO79	SAI82
MISSILES								
TOW	Split/winner	1969 to 1975	48.1	8.9	12.3	8.5		11.0
TOW launcher	Split/winner	1969 to 1975		44.2	30.2	30.2		
Dragon	Split/winner	1967 to 1980			2.8	2.7		
Dragon tracker	Split/winner	1967 to 1980				12.0		
Shillelagh	Split/winner	1964 to 1970	-0.2	-8.0	9.4	5.9		-10.4
Talos	Winner	1958 to 1966	42.3	40.8	39.8			
Bullpup 12 (Martin)	Split/winner	1958 to 1963	13.9	31.7	26.5			25.8
Bullpup 12 (Maxson)	Split/winner	1961 to 1964	45.8					
AIM 9B	Split/winner	1955 to 1964		1.6	-5.6			
AIM 9D/G	Split/winner	1960 to 1971		-4.6	0.7			
RIM 66A	Winner	1966 to 1971		-4.2	59.2			
RIM 67A	Winner	1966 to 1971	34.0					
Hawk motor parts	Winner	1957 to 1964	6.4	45.7	49.9			
AIM 7F(GC)	Split	1972 to 1980						-31.4
ELECTRONIC COMPONENTS								
FAAR radar	Winner	1968 to 1974			16.6	16.6		
FAAR TADDS	Winner	1968 to 1974			18.2	18.2		
AN/ARC-131 airborne radio	Winner	1967 to 1972/6			-16.2	-2.1		
UPM-98 test set	Winner	1968 to 1975			11.5	3.0		
PP-4763/GRC power supply	Winner	1969 to 1976			0.5	0.3		
TD-204 cable combiner	Winner	1967 to 1969	50.2	62.1	42.9			
TD-202 radio combiner	Winner	1965 to 1968	52.5	46.8	40.2			
TD-352 multiplexer	Winner	1965 to 1969	57.8	58.0	55.6			
TD-660 multiplexer	Winner	1967 to 1969	30.2	38.3	28.4			

a. The time period for which information is available to allow classification by type of competition.

TABLE 1 (Continued)

	Type	Time[a]	IDA74	IDA79	TASC79	APRO78	APRO79	SAI82
			Percentage savings to government estimated by:					
ELECTRONIC COMPONENTS (Continued)								
60-6402 electronic control	Winner	1966 to 1972	57.0	49.4	52.7			
APX72 airborne transponder	Winner	1970 to 1972	32.6	27.1	23.3			
AN/ARC-54	Winner[b]	1964 to 1966		55.0	63.1			
AN/PRC-77 manpack radio	Winner	1967 to 1978		20.5	41.9	34.8		
AN/GRC-106		1966 to 1967		43.3	41.8			
AN/GRC-103	Winner[b]	1966 to 1969		58.7	60.1			
AN/APM-123	Winner[b]	1965 to 1969		61.2	67.7			
SPA-25 radar indicator	Winner	1964 to 1972	21.3	48.8	10.7			
USM-181 telephone test set	Winner	1967 to 1972	36.0	56.0	36.3			
FGC-20 teletype	Winner	1967 to 1970	32.0	23.7	39.9			
MD-522 modulator/demodulator	Winner	1966 to 1970	60.3	58.6	51.9			
CV-1548 signal converter	Winner	1965 to 1969	53.7	64.0	45.4			
AN/ARA-63 radio	Winner	1969 to 1972			57.9			
AN/SQS-23 208A transducer	Winner	1967 to 1973			32.3			
AN/PRC-25	Winner[b]	1962 to 1963			55.0			
AN/ASN-43		1967 to 1969			10.7			
AN/FYC-8X		1966 to 1969			43.2			
MK-980/PPS-5		1966 to 1970		56.0	66.5			
PRT-4				42.3				
Aerno 42-0750 voltage regulator	Winner	1966 to 1972		54.8				
Aerno 42-2028 generator	Winner	1967 to 1970		0.9				

SOURCES: Beltramo [17, pp. 59-61]; Sherbrooke and Associates [13, pp. 25-26]; APRO79 [23].

a. The time period for which information is available to allow classification by type of competition.
b. No information is available to confirm Beltramo's classification. Some of these cases are from [1], which the study team was unable to obtain.

- That the cases were first sole source, then competitive, raises the possibility that some of the competitions may have been used as a means of solving problems with sole-source programs. A sole-source program with problems may have been a high-cost program as well.

  Without these problems, competition might have a much lower payoff. As Beltramo notes, "A sole-source procurement that is being kept 'on track' by an innovative, well-motivated contractor with a steep learning curve may not be affected by the introduction of a competitive procurement."[1]

  Another indication that competition might be a product of poor sole-source performance is discussed by Beltramo [17], who traces it back to IDA 1974 [2]: in only one of the 17 cases considered in IDA 1974 did the sole-source supplier win the ensuing competition. Beltramo accepts the IDA explanation that the sole-source producer had gotten trapped by his own inefficiency. Beltramo offers no explanation of how the producer was trapped, but one mechanism might have been the development of inefficient but comfortable ways of doing business. Another mechanism might have been that the sole-source producer felt he was committed to the cost estimates by which he justified his earlier sole-source prices. He could not drastically reduce his bid without implying that he had been overpricing. An alternative explanation for the poor performance during competition of the original sole source would be that the competition was applied expressly because the sole-source producer was performing poorly.

  An exception to the exclusive focus on programs that have experienced at least some competition is found in APRO 80 [26]. This study examined four sole-source buys, but only to determine the rate of cost improvement, not as a standard of comparison for competitive buys.

- Over half of the 53 cases reviewed involved electronic components and subsystems. Electronic components are usually part of a weapon system and therefore are inherently less complex than the entire system. Also electronic components may be more like commercial products than are weapon systems themselves. For these reasons, there may be more qualified competitors, and thus more effective competition and greater savings, for component production than for system production.

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1. Beltramo [17], quoting from a study by ARINC.

- More than half of the cases were winner-take-all competitions, which may generate greater savings than split buys—a possibility discussed later under "Hypotheses."

- From column 3 of the table, it is clear that many of the programs were active during the period of the large Vietnam buys. During that period, even a split-buy might have been efficient because output exceeded the minimum effective scale of two plants (Beltramo [17], quoting a study by Rucker).

Variables

The variables used to analyze competition in the literature have tended to be limited to those needed for a "learning curve": inflation-adjusted price, cumulative quantity, and production rate (table 2).

Table 2 also lists several promising variables that rarely or never appeared in the literature. The particular product characteristics listed in the table (weight, speed, complexity) would be suitable for a missile or airframe. The other variables are economic variables such as market structure (e.g., how many other firms have produced this type of product?), capacity utilization (is the industry particularly hungry?), expectation of competition (was it expected all along so that the prospect of competition would have an effect even before the actuality?), and prices of earlier versions (was any money being made on previous buys or previous versions?).

TABLE 2

VARIABLES USED IN ANALYZING COMPETITION

Commonly Used

Inflation-adjusted price

Cumulative quantity

Production rate

Not Commonly Used

Product characteristics: weight, speed, complexity, capacity utilization, and market structure

Expectation of competition

Price for earlier versions

Profit rate on earlier buys

Wages, materials prices, etc.

These additional variables have cross-sectional variation as well as time-series variation--that is, they vary across different items as well as over time. The literature so far has taken a time-series approach almost exclusively in which data for one program, considered over time, are analyzed without reference to other programs. The introduction of variables such as those listed in table 2 as "Not Commonly Used" is a step toward adding a cross-sectional perspective to the analysis.

Screening Criteria

The literature devotes much attention to the question of what determines whether a program is a promising candidate for competition, and, if so, whether dual sourcing is a promising form. Table 3 lists the factors discussed in the literature. The current state-of-the-art, however, has not gone beyond discussion. For many of the factors on the list, there appears to have been no serious attempt at quantification, so their importance is unknown. It may be that the factors explain much of the variation in savings from competition, or almost none. It may be that competition almost always saves money, that it almost never does, or that these determinants make the crucial difference. The quantification step remains to be addressed in future research.

RESULTS FROM THE LITERATURE

This section describes hypotheses in the literature about the effects of competition and the evidence for them. It also reviews the issues covered in the literature with great frequency and those covered hardly at all. Finally, it describes the rudiments of a cross-section methodology currently in the literature.

The literature has focused mainly on calculating savings for individual programs, not on discovering general principles that would involve hypothesis specification and testing. Among the few hypotheses that are stated explicitly, the most common is the one mentioned earlier--that the price improvement curve (PIC) shifts and rotates when competition begins. Other explicit hypotheses hold that competition increases learning, and that the prospect of competition itself can lower price. Two other hypotheses are not stated directly but can be inferred from the literature: (1) winner-take-all competition creates larger savings than split buys, and (2) results vary sharply both by program and by study.

There are differing degrees of theoretical reasoning and empirical evidence behind these hypotheses:

Hypothesis 1: Learning Proceeds Faster Under Competition

This hypothesis has two closely related interpretations, both of which help distinguish it from the shift-and-rotation hypothesis. The first interpretation has to do with the prospect of competition. It

TABLE 3

HYPOTHETICAL DETERMINANTS OF WHICH PROGRAMS SHOULD BENEFIT MOST FROM COMPETITION

Determinant	Source
Substantial production rate	GAO [19], Trainor [20] Beltramo and Jordan [10] Beltramo [17]
Long, stable production period	Trainor, APRO78 [3]
Short lead time to qualify second source	Trainor, Beltramo
Prime contractor make rather than buy	Trainor
Short time required to stabilize design	Trainor
Steep learning curve	Trainor
Nonrecurring/recurring cost low	Trainor, Beltramo
No special production skills, facilities, unique production processes	Trainor, APRO78
No proprietary data	Trainor, Beltramo and Jordan, APRO78
Absence of other cost-reduction incentives	Trainor
No technical assistance needed from initial source	Beltramo and Jordan
Traditional rivals for initial source	Beltramo and Jordan, Beltramo
Technically simple	Beltramo and Jordan
An "inefficient" sole-source producer	Beltramo
Low start-up costs	APRO78
Firm technical data package	APRO78
Lack of Congressional resistance to up-front costs	APRO78
Slack industry demand	APRO78

holds that this prospect of competition changes the learning curve, even before competition itself arrives. The second interpretation, more sweeping than the first, has to do with "what if" types of questions (e.g., "how would things have been different (before or after competition) if competition had been expected or in force from the outset?") Both interpretations can be explained with the use of the PIC.

The first interpretation, given the prospect of competition, means that the PIC, even before competition, will be different from what it would have been without the prospect of competition. This possibility is illustrated in figure 5, where the dotted lines suggest several possibilities had competition not been in prospect. Without limit pricing--that is, reducing prices in hopes of discouraging competitors--the initial prices would have been higher, as shown by the upper dotted line. Without skimming--that is, raising initial prices to take profits before competition arrives--initial prices would have been much lower, as shown by the lower dotted line.

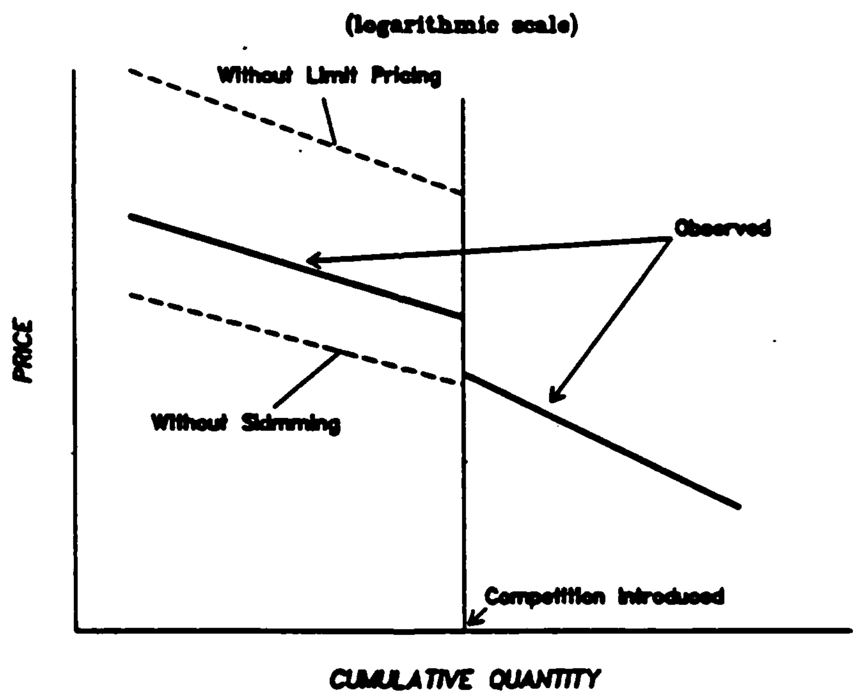

FIG. 5: OBSERVED AND HYPOTHETICAL PRICE IMPROVEMENT CURVES

Note that this interpretation contradicts the central hypothesis of the shift/rotation literature--that the initial segment of the PIC is independent of competition. This paper has described ways in which this maintained hypothesis can fail--the skimming hypothesis, the limit-pricing hypothesis, etc.

The second, more general interpretation is that no part of the PIC, before or after competition, is untouched by the presence of competition, prospective or actual. To represent this situation, figure 5 would have dotted lines after competition as well as before. This interpretation contradicts the shift/rotation assumptions even more than the first interpretation does.

There is only scant evidence in the literature to support either interpretation:

- With respect to the first interpretation, the effect of the prospect of competition, there is some evidence in a paper by Science Applications Incorporated (SAI) on the AIM-7F [12]. The paper noted that the learning curve for this version of the Sparrow missile had a steeper slope than earlier versions. Since the procurement of earlier versions was not competitive, the steeper slope is consistent with the hypothesis that competition steepened the slope. In estimating the cost savings from competition, the paper takes as the baseline rate of learning the rate for the AIM-7C, the first production version of the Sparrow. Though this evidence supports the hypothesis, the support is weak. The evidence pertains to only one program, and no alternative explanations for the steepness are considered.

- With respect to the second interpretation, evidence comes from a study by Scherer of World War II bomber production. Scherer noted that the rate of learning was greater with competition than without (Scherer [28, pp. 120-121]).

Hypothesis 2: The Threat of Competition Can Be Effective

This hypothesis is distinguished from the previous one in that competition need not actually materialize. Nevertheless, the evidence, which is anecdotal, pertains only to those cases in which the threat was genuine. Consider one case, from APRO79 [23, p. 58]. For the M103 brass cartridge case, Amron had been the sole producer for several years. Then, in 1978, it lost a winner-take-all competition to National Eastern. Immediately Amron offered a deep cut in the price of an option on a still-current contract, from an expected 60.72 cents per cartridge case to 43.93 cents, a drop of 27.7 percent.

Hypothesis 3: Winner-Take-All Competition Creates Larger Savings Than Split Buys

There are several reasons why this hypothesis seems plausible on theoretical grounds. First, winner-take-all does not sacrifice economies of scale the way dual sourcing does. Second, winner-take-all puts more pressure on the competitors; there is no second place. Third, less complex items are likely to be those selected for successive winner-take-all competitions. Successive winner-take-all competitions are infeasible for complex items without close commercial counterparts because the loser is unlikely to maintain idle production capacity until the next competition. Fourth, all cases in this literature occurred before the recent emphasis on split-buy competition during production. The driving reason for split-buy competition during that earlier era may not have been expected cost savings.

The hypothesis of greater savings for winner-take-all has been discussed several times in the recent literature [5, 10, 11, 17]. Beltramo [17, pp. 79, 82, 109], in reviewing 7 split buys and 18 winner-take-all competitions, arrived at the following conclusion about this era: "Thus, all types of competition do not produce the same results: Winner-take-all competitions usually result in savings; split-buy competitions often increase costs."

A larger sample of cases is depicted in figure 6. The vertical axis represents percentage savings so that the vertical scatter of points shows the range of results for different programs with a particular type of competition.

From figure 6 and table 1 it is clear that the literature often attributes substantial savings to competition. Note, however, that the gains from competition seem to depend on the type of competition--that winner-take-all competitions generate larger savings than split buy/winner-take-all, and there have been almost no pure split buys. Thus, the distinction between types of competition is important, and that distinction has not been emphasized in the literature. There is a tendency to talk about the gains from competition without distinguishing among the different types.

Note too that the results in figure 6 refer to recurring costs only. This does not imply that the study from which estimates were taken is inferior; a number of other studies also omit the nonrecurring costs of competition (such as government-supplied tooling and test equipment) as well as other costs such as the extra expense of the educational or directed buy. Some of the recent studies have tried to include such costs but have found it difficult--the data are hard to obtain and hard to reconstruct in retrospect. What may be needed is a mechanism for systematically gathering data as it is generated and making it more broadly available to the research community.

Future research needs to focus in more detail on nonrecurring costs. Even a single case study would be useful in documenting how estimated savings vary in response to the way in which these costs are handled.

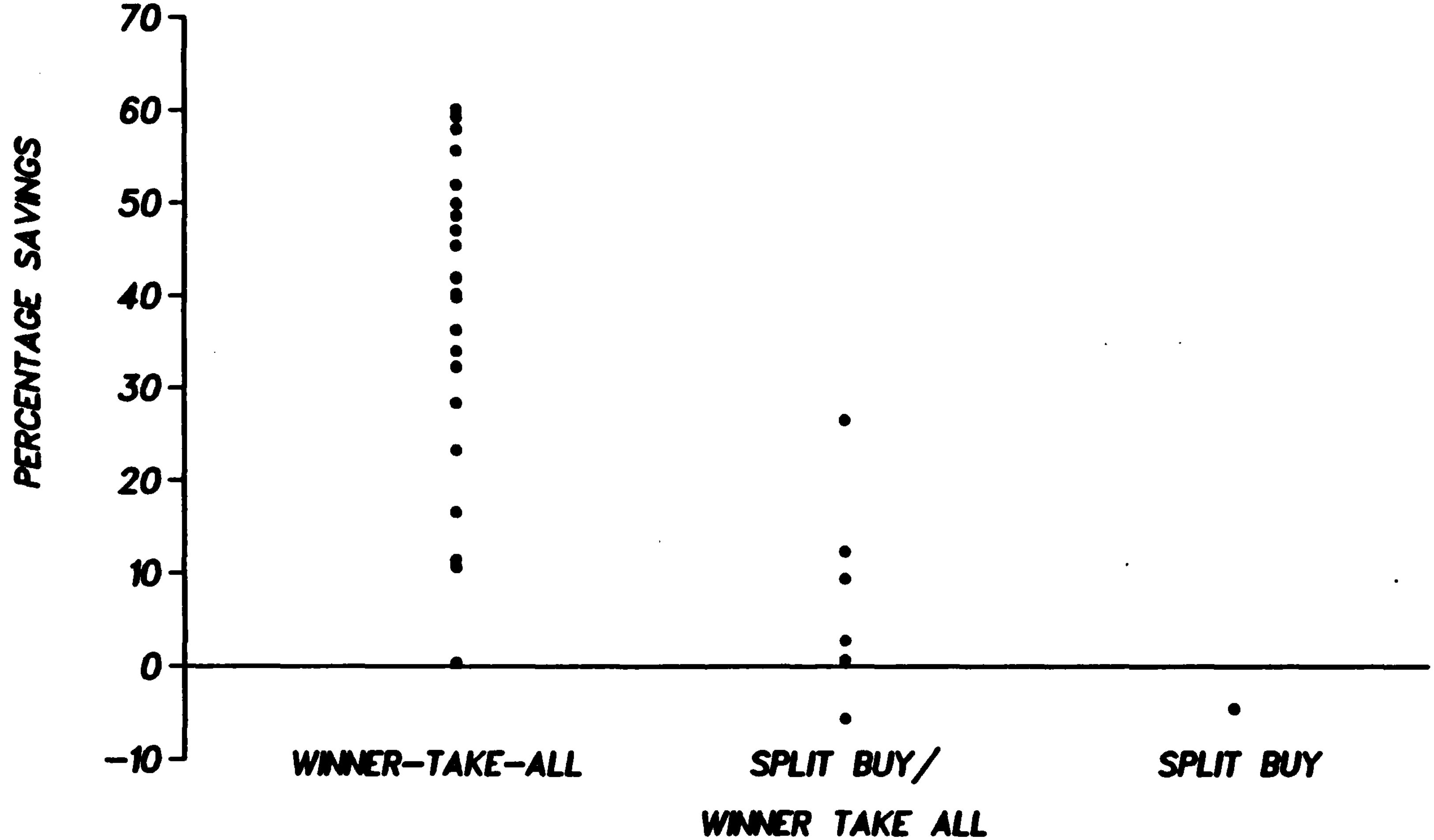

FIG. 6: ESTIMATED SAVINGS BY COMPETITION TYPE

Sources -- Type of Competition Beltramo[17]

-- Estimated Savings TASC79[5]

Until there is such a case study, only a rough idea of the importance of nonrecurring costs can be gathered from the current literature. Beltramo and Jordan [10, p. 10] estimate that incorporating the costs of the directed or educational buy would cause the following changes in estimated savings from competition: TOW, from 22.6 to 11.0 percent; Shillelagh, from -6.3 to -10.4 percent; and, as discussed above, AIM-7F, from -20.5 to -31.4 percent. These changes are from 4 to 10 percent of total cost. In another study, Beltramo and Jordan [12, p. 12] project that nonrecurring costs may make up about 6 percent of recurring cost for a buy of 10,000 AIAAMs.

Hypothesis 4: Results Vary Substantially by Program and by Study

There is already a great deal of evidence in the present literature that results do vary by program and study. This evidence is summarized below. The remaining issue is whether this variation will diminish over time or at least become predictable. Reduction in the variation by program is essentially a matter of finding determinants of savings that can predict the variation. Reduction in the variation by study would require increased agreement on assumptions and techniques. Such reduction might be accomplished by fiat, but it would be more informative if it were accomplished by testing the predictive ability of different assumptions and techniques. Such testing does not appear to be part of the present literature.

Turning to the evidence of *variation* in the present literature, figure 7 illustrates the variation in results by program and by study. A subset of programs was selected for which there were at least three estimates of cost savings among the five references listed in the figure. Plotted on the vertical axis are percentage savings; the horizontal axis lists the different programs. The variation in the horizontal dimension, from program to program, makes it harder to predict in advance how a given competition will do.

Most of the cases in the diagram showed estimated savings from competition. Nevertheless, it should be noted that none of them were pure dual-source competition. All were either winner-take-all or dual source followed by a winner-take-all buyout. Further, the accounting for nonrecurring cost was sketchy. Thus, the point of this diagram is not that there have or have not been sizeable gains from competition reported in the literature, but rather to point out the range of variation in the estimates of those gains in this literature. Indeed, the variation in the vertical dimension of figure 7, from study to study, suggests that the details of the calculations can have a large effect.

One of the best examples of study-to-study variation of estimated savings for any given program is the AIM-7F program, which is too recent to have been included in the studies from which the figure is drawn. The different estimates of savings for the AIM-7F are given in table 4.

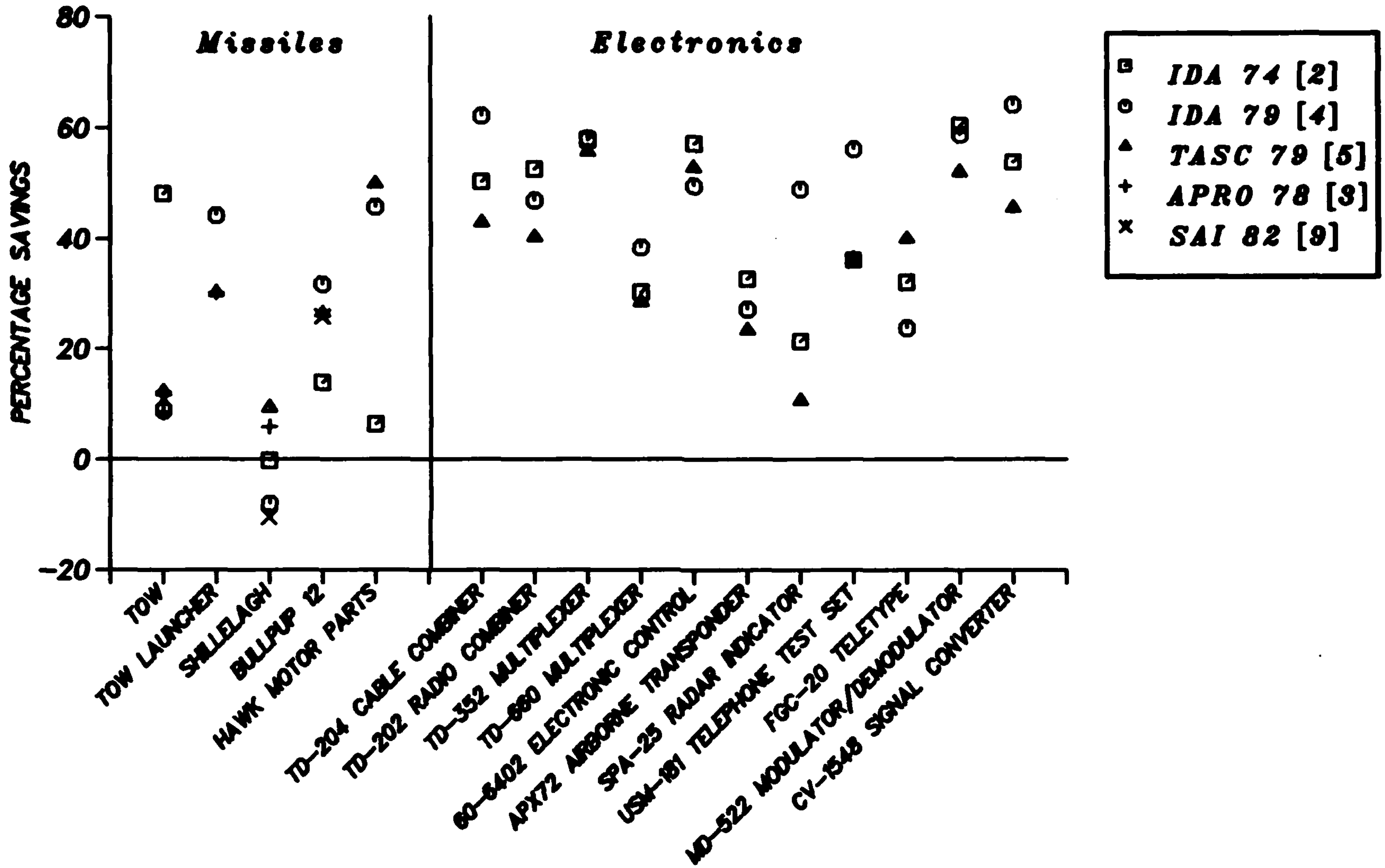

FIG. 7: ESTIMATED SAVINGS FOR DIFFERENT PROGRAMS AND DIFFERENT STUDIES

TABLE 4

ESTIMATED SAVINGS FOR AIM-7F

Source	Estimated savings
SAI (August 1982)[a]	-20.5%
SAI (September 1982):[b] Effect of educational or directed buy	-30.4%
SAI (March 1983):[c] Effect of competition on slope of sole-source learning curve	+11.0%

a. [9].
b. [10].
c. [12].

An SAI study in August 1982 [9] estimated that competition actually resulted in a 20.5 percent increase in costs (a -20.5 percent "savings") as shown in table 4. When the study was updated for publication in September 1982, the extra costs of the directed or educational buy were taken into account, increasing the loss to over 30 percent. Then, another assumption was changed. The prospect of competition was assumed to have steepened the learning curve, even before competition started. When that assumption was incorporated into the analysis, estimated savings went from about -30 percent to about +11 percent. So within these three studies, all by the same authors, there was a variation of about 40 percent, depending on assumptions.

Consider a different effect of competition on the slope of the learning curve. APRO79 [23, p. 27, observation 9] reported that the percentage savings for the 1976 procurement of the M223 fuze ranged from 6.1 percent to 27.3 percent as the assumed rate of price improvement ranged from 10 percent to 0 percent.

The final SAI study discussed above noted even further uncertainties in results. For instance, how would the long-run state of the market differ from the present? One of the companies producing the AIM-7F claimed to be losing money, suggesting that the savings might not have persisted. Were savings genuine? Did savings from competition on one program show up as higher overhead costs allocated to another program?

There are a number of other reasons for variation in estimated savings from study to study. There are even cases in which different studies seem to draw different numbers from the same data set. Table 5 summarizes some of the reasons for these differences.

TABLE 5

SOME REASONS FOR DIFFERENCES ACROSS STUDIES

1. Different data. For example, studies differed on which buys were production (and therefore included in the learning curve) and which were R&D (and therefore not appropriate for the learning curve).

2. Differing degrees of including nonrecurring costs, e.g., government-paid tooling and test equipment.

3. Differing degrees of including other costs, e.g., the cost of the directed or educational buy.

4. Different ways of estimating the hypothetical rate of learning during the competitive period:

   a. Estimated from early production lots with and without directed buy

   b. Inferred from another program

   c. Assumed from general knowledge.

5. Different ways of correcting for inflation.

6. Discounting or not.

7. Differences in assumptions about percent of program competed.

8. Whether production rate is included as a determinant of price.

9. Differences in estimating equations for learning curve.

ISSUES

The literature on competition in procurement has discussed some issues frequently, others hardly at all. As is evident from table 6, the issues discussed often tend to be learning-curve type issues, such as uncertainty about the rate of learning.

Price and Cost

Little effort has gone into distinguishing between price and cost, even though reducing the difference is a major way in which competition works. Fee or profit rate is a major element of price where the effects of market conditions should show up most readily. Interpreting price as cost can create misleading estimates of the effect of competition. For

TABLE 6

DISCUSSION OF ISSUES IN THE LITERATURE

<u>Discussed Often</u>

Nonrecurring costs:

- -- Start-up costs
- -- Educational buy
- -- Purchase of data rights
- -- Creation of technical data package

Rate adjustment

Effect of cumulated quantity

Estimation of log-log form

Shape of learning curve

Discounting

Inflation correction

Transferability of learning curve

<u>Discussed Rarely</u>

Nonrecurring costs:

- -- Forfeiture
- -- Expectations

Extent of preexisting competition

Standard of comparison

Distinction price/cost:

- -- Distinction price level/rate of change

Market structure

Long-run equilibrium

instance, if producers were losing money just before competition and responded by raising prices, it would appear that the competition, not the previous losses, caused the rise in prices. Here is an actual case, the M223 fuze, as described in APRO79 [23, pp. 52-53].

> "Before this acquisition, Honeywell was producing the fuzes for a unit price of $0.512 (FY 1978 dollars) and the projected price was $0.4977. After the acquisition the weighted average price for all six producers was $0.6225, giving an estimated loss of 25.1 percent.
>
> Discussions with government contracting personnel reveal the reason for this price increase. The experienced contractors, AVCO, Dayron, and Honeywell, had lost money on their previous contracts, and they now bid at a more realistic level."

<u>Price and Change in Price</u>

Just as the literature has failed to distinguish between price and cost, it also has failed to distinguish between price and the change in price. A program whose price is falling rapidly is considered to be efficient, without consideration of the possibility that the reason for the rapid fall in price may be that the price started off unusually high. A falling price does not necessarily mean that either the final price is low or the program is efficient.

The failure to distinguish between price and its change shows up most prominently in the shift/rotation methodology: When the sole source has a steep learning curve, estimated gains as a result of competition will tend to be small or negative. But if the steepness of the curve actually results from the unusually high initial price, then competition may actually create large savings, which the shift/rotation methodology has no way of uncovering.

Though typically ignored in the literature, the conceptual distinction between price and its change is not new: Scherer [28, pp. 123-125] reviews research by Asher indicating that for a sample of post-World War II fighter aircraft, those with steep "progress" (learning) curves tended to have high values of T_0 (the manhours per pound for the first unit). Further, it turns out that for the actual quantities, the effect of the steep slope was dominated by the effect of T_0 so that a steeper progress curve actually indicated more total manhours.

As Asher [27, p. 83] himself states:

> "Since World War II, the consensus of the Air Force and the airframe industry has been that steep progress curves showing rapidly declining costs indicate

efficient production, and that flat progress curves showing slowly declining costs indicate inefficient production. The analysis presented here, however, suggests that such a view may not be warranted. It is obvious from Fig. 4.6, that there are more total manhours beneath a steep curve than there are beneath a flat curve."[1]

Others, too, have recognized the distinction between the level of price and the rate of change of price. IDA79 [4] includes a comparison of the price of military and nonmilitary items of the same type, concluding that the military items are no more expensive. Greer and Liao [16] evaluate the effects of competition on the level of price for different missiles. Both correctly use the level of price as the variable for analysis.

Other Issues

As shown in table 6, it should be noted that even those issues listed as "discussed often" in the literature have often not been incorporated into estimates of savings. A prime example is "nonrecurring costs."

Similarly, the issues listed in the table as "discussed rarely" have not been neglected altogether. For example, Beltramo and Jordan [12, p. 34], implicitly note the issue of long-run equilibrium when they point out that savings resulting from major losses to the contractor are not necessarily a cause for rejoicing. The likely result is fewer contractors and higher prices in the future. They also note other possible sources of spurious savings: loading of overhead onto other government contracts and scrimping on engineering manpower used to develop future missiles.

Long-Run Equilibrium

A final issue, treated rarely in the literature, is the long-run state of the market. For instance, is it possible that competition can squeeze a company to greater efficiency or lower profits in the short run, but force it out of business in the long run? Similarly, competition may reduce price if it surprises a producer, but in the long run such surprises will be built into expectations. Producers may either require long-run guarantees or build in an extra margin of profit on each program to cover such contingencies.

1. Figure 4.6 displayed the family of progress curves implied by Asher's estimate of the relation between slope and intercept. Steeper curves lay above flatter curves.

SUMMARY

The research described in this paper evaluated the literature reporting research on estimated savings due to the use of competition in weapon system production. It focused on the following three aspects of the literature: the analytical models and techniques used for analysis of price formation in sole-source and competitive productions, the data bases used and reported for the programs studied, and the estimated savings reported as results.

Models and Techniques

All of the studies examined used the Price Improvement Curve (PIC) model for estimating savings due to competitive pricing in production programs relative to estimates of prices of the programs had they continued as sole source. The studies analyzed each program separately as a time series of production lots. The number of lots for each program was usually 10 or less. Such samples are far too small to use in making any statements on the statistical significance of price differences before and after competition.

The PIC was found to be too narrowly based on cumulative production quantity and production rate to provide any assistance in forecasting pricing behavior. It tries to explain too much with too few variables. The literature discussed many possible additional candidate variables, but only one study [16] explored an alternative variable, industrial capacity utilization, in its empirical work. CNA's research on expanding the set of variables will be reported in subsequent Research Memoranda.

Data Bases

A major concern is representativeness of the data. The programs used in the reported studies might be viewed as being from a quite different era regarding the motivations for competition and its use in production, particularly dual-source production. There are potential biases in both the generation and selection of types of competitive programs for study. There may be biases toward:

- Using the winner-take-all form of competition
- Using winner-take-all competition on programs that were less complex and were similar to commercial programs
- Using competition on programs that were experiencing trouble as sole-source procurements.

The winner-take-all competition type had the largest representation by far of the types presented in all studies. The documentation and analyses of the data in the literature were found to be uneven in many

respects. Several studies had incomplete or no nonrecurring cost data, which biased estimated savings upward. The categorization of data by types of competition was inconsistent across studies, particularly regarding dual-source procurements and educational buys. The documentation of data and data sources was uneven, making replication of many of the analyses impossible.

Estimated Savings Results

The estimated savings reported in the literature should be used with great caution because of the limitations of the data bases and analytical methods as summarized in the preceding sections. A reasonable generalization of the estimated savings results might be as follows:

- Savings from winner-take-all competitive procurements are likely, although uncertain and highly variable.

- No generalization on estimated savings from dual-source competitive procurements is possible based on the literature examined.

Several programs reported in the literature were dual-source procurements for a part of their history, with a winner-take-all procurement for the balance of the program. The results for the two different types of competition generally are not reported separately.

Further research is required on both methodology and data bases if more reliable estimates of savings due to competition are to be achieved.

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