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COST ANALYSIS FOR COMPETITIVE MAJOR WEAPON SYSTEMS PROCUREMENT: FURTHER REFINEMENT AND EXTENSION

by

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Aerospace industry capacity utilization (CU) rate was found to be a major price determinant of major weapons systems. This study examines the feasibility and desirability of using more firm-specific measures of CU. A reliable method of forecasting the aerospace industry's CU is developed. Our study also finds that the sole source program costs are also related to the level of CU. In addition to CU, the magnitude of savings from second sourcing is also affected by the quantity split between the two suppliers. Contractor teaming as an acquisition strategy is assessed.

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September 1984

PREFACE

This study was conducted for Naval Air Systems Command, Cost Analysis Division, under ONR contract number N0001484WR35075, dated 10 January 1984. The work statement which specified the task to be accomplished reads as follows:

> This study will study and respond to criticisms of our prior efforts, attempt to expand the data base of competitively acquired major weapon program cost, and establish whether more specific production capacity utilization data can be used to improve the precision of savings estimates produced by a quantification model. A method for more reliably forecasting capacity utilization will be specified. The objective is to develop and document an easy-to-implement, computer-based model for forecasting the savings obtainable from competitive procurement of major weapon systems. The effectiveness of contractor teaming approach as a competition tool will be examined. Framework for future research plans will be established.

This final report, along with a diskette containing programs for forecasting, is submitted in fulfillment of the contractual requirement. The diskette is not available for public release.

EXECUTIVE SUMMARY

The aerospace industry capacity utilization rate (CU) was identified in our earlier study as a strong determinant of weapon systems cost savings under dual source production competition. This study reviews and responds to comments on and criticisms of our earlier efforts, expands the data base for further analysis, examines the feasibility and desirability of using more firm-specific measures of CU, and develops a more reliable method of forecasting the aerospace industry's capacity utilization. This study also examines the contractor teaming approach as a competitive procurement tool and develops plans for future research on weapon systems competition.

Two observations may be made from our analysis of firm-specific measures of business conditions. First, none of these alternative measures consistently satisfied testing for statistical significance. Second, for those alternative measures of business conditions which were significant in an isolated case, the R^2 values were higher than those obtained using the industry capacity utilization rate.

One way to interpret these findings is that some firms may put more weight on alternative measures of business conditions than on industry capacity utilization in making their pricing decisions, but different firms opt to use different measures. It is even possible that different measures may be emphasized by the same firm at different times.

It can be concluded that, for cost estimation purposes, the aerospace industry capacity utilization is more reliable than other measures of business conditions.

Our effort to build a reliable model for projecting aerospace industry CU resulted in a dynamic model which expresses the percentage change in capacity (CAP) for the next FY (t+1) as a function of the present and recent past state of CU and the percentage change in output (OUT) expected for the next year. This model proves to be a reliable, accurate forecasting model.

Based on the forecasts shown in Table 3.7, it appears that conditions will be relatively favorable for dual sourcing during most of the next decade. However, there will be a brief period during the mid-to-late eighties during which especially alert management of the procurement process will be necessary if net financial benefits are to be expected.

Our analysis has shown that advance knowledge of aerospace industry capacity utilization can improve the Government's ability to plan for economical procurements of major weapon systems. This ability is useful in both cost estimation and procurement policy-setting.

The cost savings which result from dual sourcing are a function of CU and the division of the procurement between the original supplier and second the source. As CU rises the amount of the savings declines. The best results have been achieved when the division is such that the second source is called upon to supply no more than about 10-15% of the dollar amount of the procurement: that is, when the division of dollars to the original source, D_1, is in a range of 85-90%. The net financial benefit (NFB) from dual sourcing can be approximated with the following equation:

$$NFB = 27.38 - 1.267\ CU + .942\ D_1.$$

Historically, dual sourcing has generated positive NFBs only when CU has been below about 80%. But savings should be obtainable when CU is as high as 85% with proper control of D_1.

When procurements are conducted under sole sourcing the direction of the impact of CU changes on prices is just the opposite. A parametric pricing model for missiles which includes a CU term in addition to the conventional quantity (Q) and production rate (R) terms was derived:

$$P = k\ Q^{-.327}\ R^{-.339}\ CU^{-1.205}$$

This model should enable the use of CU forecasts to assist in the refinement of cost estimates when a procurement is to be conducted using sole sourcing.

We were able to identify several additional programs that appear to be suitable for inclusion in studies of dual source competition procurement. A quick validation check was performed for each of the additional programs and none of the results contradicted our basic conclusion that the aerospace industry capacity utilization (CU) is a strong determinant of savings from dual-sourcing.

Appendix B contains a separate report which examines the contractor teaming approach as a competitive procurement tool. Suggested plans for future research on weapon systems competition are discussed in Chapter 6.

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Chapter 1

A BRIEF REVIEW OF PRIOR WORK

Aerospace industry capacity utilization was identified in our earlier study[1] as a strong determinant of weapon systems cost savings under dual source production competition. This study reviews and responds to comments on and criticisms of our earlier efforts, expands the data base for further analysis, and develops a more reliable method for forecasting production capacity utilization. This study also examines the contractor teaming approach as a competitive procurement tool and develops plans for future research on weapon systems competition.

In this chapter, we will provide a brief summary of our earlier work. We will also review and respond to comment and criticism.

SUMMARY OF PRIOR EFFORTS

Using economic theory as the conceptual underpinning, we hypothesized that the price the Government has to pay for major weapon systems is dependent on, apart from the well known learning curve phenomenon, the degree of competition. The degree of competition, in turn, may be a function of the firm's general business condition and the alternatives available to it.

As a simple check of the plausibility of the hypothesis, the data reported in Table 1.1 were assembled. The program

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[1]W. R. Greer, Jr., and S. S. Liao, "Cost Analysis for Dual Source Weapon Procurement," Naval Postgraduate School Technical Report, NPS54-83-011, October 1983. (A135351)

savings (loss) data were taken from a report prepared by the Sciences Application Inc.[2] (SAI) The capacity utilizations were averages of the annual figures for the aerospace industry for the years during which dual source procurement was in effect for each program.

Table 1.1

Competition Savings (Loss) and Capacity Utilization

Procurement Program	Percent Savings or (Loss) Due to Competition*	Annual Average Capacity Utilization During Dual Source Phase+
Tow	26.0	63.5
Rockeye Bomb	25.5	70.9
Bullpup AGM-12B	18.7	76.2
Shillelagh Missile	(4.7)	87.0
Sparrow AIM-7F	(25.0)	81.6
MK-46 Torpedo	(30.7)	91.6
Sidewinder AIM-9D/G	(71.3)	82.3

Source: * Beltramo and Jordan [1982].

+ Federal Reserve Board

Our interpretation of this preliminary check was that it tends to support the general hypothesis. Greater savings do appear to have resulted from competition when industry capacity utilization was relatively low. Encouraged by these results,

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[2]M. N. Beltramo and D. W. Jordan, "A brief Review of Theory, Analytical Methodology, Data, and Studies Related to Dual Source Competition in the Procurement of Weapon Systems," (Preliminary report), Division of Cost Analysis (MAT-01F4), Headquarters, Naval Material Command, 27 August 1982.

we went ahead with the actual analysis of the determinants affecting the price paid by the Government for weapon systems.

Most recent attempts to sharpen our cost estimation abilities have focused on adding a production rate term to the conventional learning curve model.[3] We replace the production rate term with a capacity utilization term and added an additional parameter to capture the effect of different forms of competition (dual source or winner-take-all).

We felt that the result of this attempt should be compared for performance with the best learning curve/production rate model we could construct. Due to the limited number of histories for major weapon systems which have been dual sourced, the only available data for testing the two models' performance was the set used for the derivations. The basic plan of the test was to use each model to forecast <u>at the onset of procurement</u> what the total procurement cost "will be" for each of the seven programs, then to compare the actual cost to the forecast. From Table 1.2, one can clearly see that the capacity utilization model has outperformed the rate model in every test. The average arithmetic and absolute errors are lower for both versions of the capacity utilization model than for either version of the rate model. In addition, the lower standard deviations (shown in parentheses) indicate the program-to-program variations of actual from forecasted cost are also lower for the capacity utilization model. We

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[3]C. H. Smith, "Production Rate and Weapon System Cost: Research Review, Case Studies, and Planning Model," U. S. Army Procurement Research Office, Report No. APRO-80-05, November 1980.

Table 1.2

Comparative Performance of Models

	Learning & Rate Model	Learning & Capacity Utilization
Mean Arithmetic Percentage Error:		
If Median Parameters are used	27.2	4.0
	(93.1)	(38.2)
If Mean Parameters are used	41.4	6.0
	(81.7)	(41.4)
Mean Absolute Percentage Error:		
If Median Parameters are used	64.3	30.6
	(68.6)	(19.8)
If Mean Parameters are used	60.6	34.7
	(66.2)	(18.6)

view this outcome as strong support for our original hypothesis that industry capacity utilization is a strong determinant of major weapon system prices under competitive procurement.

In short, the major conclusion of our prior work is that, while the production costs of weapon systems are affected by a host of factors, including cumulative quantity and production rate, these variations alone do not explain the full variation in prices paid by the Government. Based on our statistical analysis, we find a major price determinant (neglected by previous researchers) to be the state of industry capacity utilization. Figures 1.1 and 1.2 illustrate the evolution of competition studies and contrast our approach with prior studies.

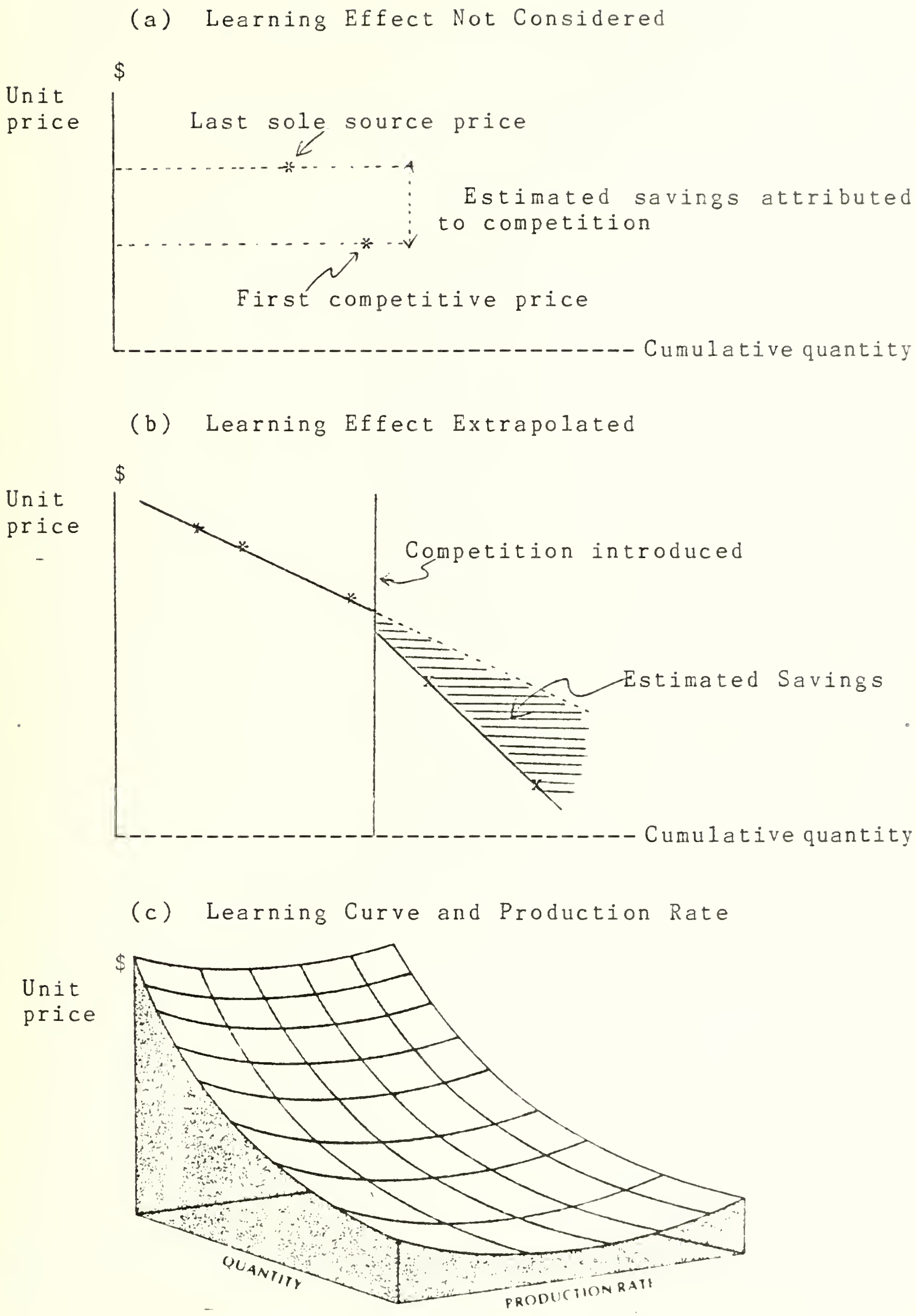
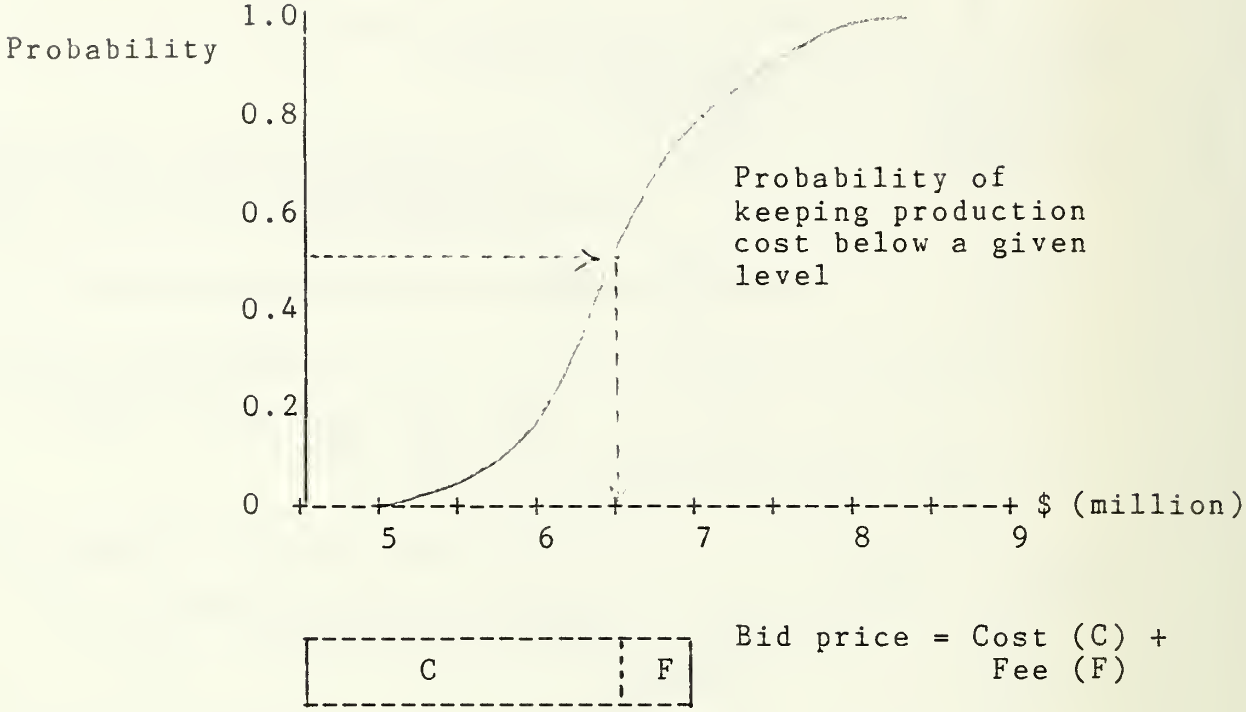


Figure 1.1 Evolution of Competition Studies

(a) During Economic Slump



(b) During Economic Boom

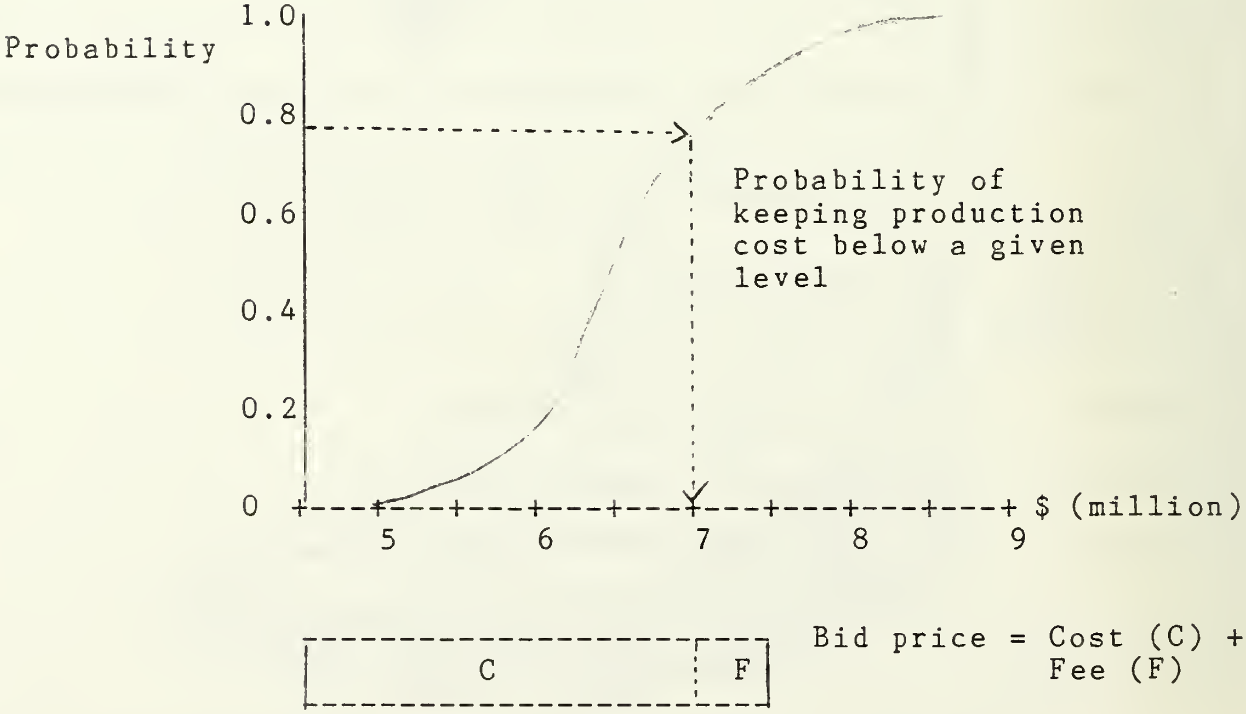


Figure 1.2 General Economic Condition As A Price Determinant

Given the limited data base for dual source weapon systems research, the task faced by an analyst is to identify dominant factors. Our analysis showed that industry capacity utilization can be used as a proxy of general business conditions, along with the learning curve effect, to explain the change in the prices of weapons systems procured under dual source competition.

SUMMARY OF COMMENTS AND REVIEWS ON OUR PRIOR WORK

In addition to the presentation to the sponsors (NAVAIR and NAVCOMPT), the results of our prior work were presented, in part or in their entirety, at the DARE (Defense Acquisition Research Elements) meeting and the Federal Acquisition Research Symposium. While the great majority of reactions were favorable, there have been comments and criticisms that merit further attention. Some comments are constructive in nature, while others, although well intentioned, appear to stem from misunderstanding. Although the results of our prior work are all defensible statistically, it is necessary to examine all available comments to determine which should be incorporated into our model and which should not.

Two written reports were prepared by SAI.[4] The general comments may be classified into the following categories:

(1) Definition of risk and riskiness of defense business.

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[4]M. N. Beltramo and D. W. Jordan, "A Review of Material Prepared by NPS for NAVAIR on Dual Source Competition," Science Applications, Inc., 20 September 1983, and "A Detailed Review of Cost Handbook for Dual-Source Weapons Procurement," Science Applications, Inc., 5 November 1983.

(2) Profit reduction and the erosion of defense industrial base.

(3) Amortization of fixed cost and profit variation.

(4) The necessary requirements for dual sourcing.

(5) The relationship between production cost and production quantity.

(6) The validity of using an approximate capacity index.

(7) The ability to forecast industry capacity utilization.

(8) The reliability of parameter values due to the limited data available.

(9) The time lag between negotiated sales and deliveries.

(10) Inappropriate test of model performance.

(11) The use of the "80% rule."

(12) The need for recalculation of Savings/losses figures.

In this section, we will discuss the comment and criticism in detail.

Definition of Risk and Riskiness of Defense Business

SAI criticized our earlier work for failing to explicitly define risk, and argued that risks should be related to potential loss of capital. According to this definition, SAI argued that defense business is not risky relative to commercial business because of four peculiar arrangements in major weapon system contracting: (1) government-funded development cost, (2) government-funded facilities and government-furnished equipment, (3) cost-plus profit contract, and (4) allowance of certain termination costs.

Risk is a concept which is frequently referred to in normal everyday social interchange. It is a concept which is easy to understand but difficult to define. For decision model application, a definition more relevant to the decision in question is necessary. Defining risk as relating to potential loss of capital is, of course, valid; but it is most relevant when making an initial capital investment decision. For an aerospace company, already in the defense business, the decision is not whether to enter the defense business and run the risk of losing the investment. Instead, the more relevant decision is how much in the way of resources, including fixed assets and working capital, should be allocated to the defense sector; that is, how much defense business should the firm be willing to handle. Clearly, the choice is not one of entry but rather one of allocation. For this reason, we chose to use three different definitions of risk.

First, we viewed risk from inside the firm, through the eyes of management, by stressing that management must budget cash flows and exhibit appealing pictures of net income growth. These tasks are made easier if earnings are stable and predictable. Second, we tried to view risk through the eyes of the financial markets by examining the total risk as measured by Value Line with its "Price Stability Index". In both cases, the result consistently showed that higher risk measures are associated with higher percentages of government business. Although the third definition of risk, beta (systematic risk), is not significantly correlated with higher percentages of government business among aerospace firms, we did find the betas for aerospace firms to be higher than the market average. Thus, in the context of resource allocation, government business generally is considered both by management and the financial markets to be riskier, or less desirable, than other segments of business in the aerospace industry.

It should be noted that how the concept of risk should be defined is not a central issue. We can even say that risk is not a relevant issue. We used risk as a convenient but not a necessary tool to denote the variability of profit.

Even if we accept SAI's definition of risk, defense business still is not as attractive as SAI indicated. Even though contractors are eventually reimbursed for facility investment, the contractor's reluctance to invest in facilities is evident in Defense Procurement Circular 76-3. What is relevant to the contractor is the actual capital used on a given contract, which is difficult to determine[5] and is almost always under-reimbursed by the Department of Defense.[6]

Profit Reduction and the Erosion of the Defense Industrial Base

The SAI report[7] maintained that further reductions of profits through driving hard bargains when industry capacity utilization is low would be likely to accelerate the erosion of the defense

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[5] Air Force Systems Command, "Profit Study '82," Summary Report, Andrews Air Force Base, undated.

[6] Simonson, G. R., "Misconceptions of Profit in Defense Policy," National Contract Management Journal, Winter 1982, Vol. 15, issue 2.

[7] Beltramo and Jordan, "A Review," cp. cit.

industrial base. SAI's position was that the cost component of the price of weapon systems normally accounts for more than 90% of the government's expenditure for a product, and that any reduction in price must come in the form of greater efficiency.

A necessary condition for SAI's position to be valid is that the cost and profit figures can be determined with a reasonable degree of accuracy. On the surface this is a reasonable assumption, as cost and profit figures are routinely scrutinized by contract negotiators and contract auditors. However, there is a fallacy rarely recognized by users of accounting data. The precise numbers contained in accounting reports give an aura of accuracy to the numbers. In reality, as we pointed out in our earlier report, the cost of a product cannot be precisely determined. It can only be approximated by using a series of relatively subjective allocations. As a result, the cost of producing a product is the figure both parties agree to accept rather than some "true" cost. By the same token, the profit figure is as subjective as the cost figure, as several researchers have found.[8] Therefore, a lower price may come in the form of lower profit or lower cost, or both. What we have suggested is that greater <u>price reductions are obtained when industry capacity utilization is low</u>; but we also emphasized that "they (program managers) should resist the natural temptation to take overzealous advantage of lulls in capacity utilization to drive

[8] Hoppe, D. R., "Dual Award and Competition: You Can Have Both," Air Force A-10 System Program Office; Myers, M. G., McClenon, P. R., and Tayloe, H. M., "Price Competition in the DoD," Washington, D. C.: Logistics Management Institute, 1982.

'hard bargains,' and buy goods at very low profit margins."[9]

Amortization of Fixed Cost and Profit Variation

SAI researchers offered a different interpretation of the relationship between the profitability of DoD contracts and capacity utilization. They argued that:[10]

> When capacity utilization is high, contractors may make higher profits as a result of amortizing fixed costs over a large output quantity; whereas when capacity is low, fixed costs must be amortized over a relatively low quantity. Thus, the conclusion that program managers may drive "hard bargains" during times of low capacity is not proven by the analysis.

This interpretation would be valid had we measured the profitability of DoD contracts independent of commercial business. However, in our earlier work, we measured the profitability of DoD contracts in relation to the profitability of commercial business. Thus, the change in profit should be proportional in both sectors when the fixed costs are amortized over more or fewer units and the profitability of DoD contracts relative to commercial business should be stable. Our study showed that this relative profit changes in the same direction as changes in industry capacity utilization. There are two possible interpretations for this phenomenon. First, defense contractors have been able to obtain higher profits from the government when the general business environment was favorable. Second, the government may have been bearing a disproportionate share of contractors' indirect cost, and when their larger share of

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[9]Greer and Liao, op. cit., p. 5.8.

[10]Beltramo and Jordan, "A Detailed Review," op. cit., pp. 13-14.

indirect cost is spread over more units, its impact on profit from defense work is more significant.

Both Willingness and Ability Are Necessary for Competition

SAI's report criticized that we assume the ability to compete is guaranteed by the technology transfer process.[11] This is, of course, to set up a straw man and attack it. Chapter 1 of our earlier report clearly emphasized that both willingness and ability are necessary requirements for competition.[12] As discussed in our report, we found that willingness to compete may be reasonably approximated with a surrogate measure such as industry capacity utilization. Naturally, willingness to compete became the focus of our study, which is quantitative in nature. Ability to compete, on the other hand, is technological in nature. As in most research dealing with weapon systems competition we list it as a necessary requirement, but did not attempt to quantify it.

Cost/Quantity Relationships

There was no direct criticism of our findings in this area. However, in their report, SAI repeatedly maintained that dividing production between two sources causes potential economies of scale that might have been available to a single source producing a larger quantity to be forgone.[13] Explicit and implicit in

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[11]Beltramo and Jordan, "A Review," op. cit., p. 6.

[12]Greer and Liao, op. cit., p. 1.4.

[13]Beltramo and Jordan, "A Review," op. cit., pp. 7-9.

their discussion is that findings not consistent with their hypothesis are illogical. However, various researches have documented increase, decrease, or no change in cost when production quantities were varied. We approached the issue with an open mind and attempted to incorporate the production rate into our model. However, the conclusion is that the statistical significance of a production rate term cannot consistently be substantiated. The explanation for this conclusion was discussed in detail in our earlier report.

The Validity of Using An Approximate Capacity Index

Our use of the Federal Reserve Board's aerospace industry capacity utilization index as a measure of contractors' willingness to compete was criticized. SAI argued that the FRB defines the Aerospace Industry to also include miscellaneous transportation equipment and that the correct industry should be Ordnance.

We obtained the industry capacity utilization data from an FRB printout, and were aware of what detailed information was available and what were included in each industry group. The aerospace industry as defined by the FRB was as specific as could be obtained. The FRB does not have capacity utilization data for the "Ordnance" industry. Therefore we could not verify whether it would or would not be more appropriate (or statistically more significant) than the aerospace data used in our prior work. It should be noted that OSD's Defense Economic Impact Modeling System (DEIMS, 1982) used Standard Industrial Classification (SIC) #3761 for missiles, SIC #3721 for aircrafts, and SIC # 3724 for aircraft engines and parts, all sharing the same prefix of #37. Ordnance and ammunition was classified by DEIMS as a subgroup of fabricated metal product industry, with a SIC # 34 prefix. Further evidence of the appropriateness of using the aerospace industry for our analysis can be seen in _The Statistical Abstract of The United States_, which groups missiles and space vehicles in the same category as aircraft and aircraft engines.

Criticisms such as these, however, really missed the point, and manifest a misunderstanding of our attempt to use a measure of _general business conditions_ to quantify the willingness to compete. For example, SAI argued that "plant utilization and equipment utilization within a plant related specifically to the particular end item in question may be as important or more important." To prove their point, SAI researchers went on at length to calculate the plant utilization rate, but found no correlation between plant utilization and industry capacity utilization. All this can prove is that there is no statistically significant correlation between the end item price and the utilization of the plant in which the item was produced. Why might this be the case? One must realize that plant utilization has a significant bearing on the rate at which factors of production are consumed, but not on the _general business conditions_. We have shown that the production rate is not a significant _price_ determinant under dual-source procurement, therefore, we did not expect SAI's attempt to prove otherwise.

The Ability to Forecast Industry Capacity Utilization

The usefulness of our model depends on the availability of a reliable capacity utilization forecasting model. SAI argued that the decision to establish a second source requires long lead time and any forecast of industry capacity utilization that far in advance may be so speculative as to be meaningless. Dismissing the usefulness of a model before it is polished is premature, of course. Even with a simple time series forecasting technique, we have demonstrated that our model outperforms other currently available models. One of our main focuses in this current study is to explore the possibility of developing a more reliable capacity utilization forecasting model.

The reliability of parameter values

SAI maintained that some of the data supplied by them to us may have been inappropriate for other than case study purposes. They discussed three of the seven cases in which competitive split buys probably did not exist. What were described, however, were symptoms rather than causes. They did not contradict our findings.

SAI researchers also argued that learning curve slopes vary significantly among the cases examined and it makes no sense at all to prescribe a learning curve slope for a model. The reader should note that averaging the slope was done for purpose of testing the performance of our model by assuming that the second sourcing decision was to be made very early in the program when there was no specific information about the learning curve. Nowhere in our report did we suggest that the parameter values were to be used as they are. In fact, it was noted that the parameter values should be altered when more specific information is available.[14]

Time Lag between Negotiated Sales and Deliveries

SAI researchers maintained that the correlation between capacity utilization and price paid by the government remains an unproven hypothesis because of data problems related to the "industry" and the varying lag time between negotiated sales and deliveries.[15] The former was clarified earlier and the latter was mitigated by our use of smoothed data. Our use of the resistant time series smoother followed by a simple Hanning running average[16] was partly designed to handle time lag problems and partly to take into consideration the fact that managerial decisions are not made on the basis of single year data but are more likely to be on the basis of a multi-year perspective. We cannot claim to have eliminated the time lag problem, but its effect was minimized. In fact, we tried both unsmoothed and smoothed data and the latter consistently outperformed the former.

Inappropriate Test of Model Performance

SAI researchers argued that "to properly test whether an industry capacity utilization concept can more reliably estimate

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[14]Greer and Liao, op. cit., p. 5.6.

[15]Beltramo and Jordan, "A Detailed Review," op. cit., p. 13.

[16]See P. Velleman, "Definition and Comparison of Robust Nonlinear Data Smoothers," Journal of the American Statistical Association, September 1980.

dual source competition costs than a production rate model, both models should be of similar form (i.e., either include or exclude the M and N dummy variables from both models)."[17] This is, of course, another example of misunderstanding of the industry capacity utilization concept. M and N (dummy variables used denote split-buy or winner-take-all competition) were as much an integral part of the capacity utilization model as U (capacity utilization rate). In fact, the value of M depends on the value of U. To include M and N in other models would necessarily incorporate the capacity utilization concept in the model.

Although not presented in our earlier report, the following combination of variables were tested:

A. Learning curve (LC)

B. LC plus production rate

C. LC and capacity utilization

D. LC, rate, and capacity utilization

Our attempt was to see if adding the capacity utilization to existing decision models would improve their performance. In theory, adding a significant explanatory variable to a regression model should improve the results. However, we found that (D) did not perform nearly as well as (C). This can easily be explained. As we mentioned earlier, production rate is a highly plant-specific variable. The effect of doubling production can be drastically different between two plants, making the variable unsuitable for a statistical model such as ours. Further,

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[17]Beltramo and Jordan, "A Detailed Review," op, cit., p. 15.

the number of data points for each program tends to be very limited. Adding one more variable means losing a degree of freedom. Therefore, a critical choice in any attempt to develop a statistical model is to select only the dominant variables rather than attempting to include all possible variables.

"80% Rules" Leaves No Margin for Forecasting Error

SAI researchers argued that "the '80% rule' leaves almost no margin for forecasting error as a winner is observed at a capacity utilization of 76.2 and losers are observed at 81.6 and 82.3."[18] They further argue that "if the government used an industry capacity utilization index and capacity level rule (e.g., 80% rule) to assist in the sole source/ dual source determination, contractors could easily game the situation to the government's disadvantage."[19] One must realize that the "80% rule" was based on a preliminary hypothesis check to determine at what point in time the dummy variable M should take on the value "1." The actual sole source/dual source decision still depends on the results of analysis using the equation developed in Chapter 4 of our earlier report. We have not tested the sensitivity of the capacity utilization term. Therefore, the criticism is premature and purely conjectural in nature.

As to the possibility of gaming by the contractor, the criticism is as valid as criticizing the Internal Revenue Service for developing a decision criterion to select tax returns for audit

[18]Ibid., p. 17.

[19]Ibid., pp. 17-18.

on the ground that taxpayers will cheat the government by using the decision criterion to their advantage.

Recalculation of Competition Savings/Losses

SAI researchers pointed out to us that the savings/losses from competition shown in their report[20] include both competitive split buys as well as winner-take-all awards. To examine only the impact of the competitive split buys, they recalculated the savings/losses. The original and recalculated figures, along with the capacity utilization index, are shown below:

Table 1.2

Competition Savings (Loss) and Capacity Utilization

(Original vs. Recalculated)

Procurement Program	Percent Savings (Losses) Due to Competition: Split-buy & Winner-take-all*	Percent Savings (Losses) Due to Competition: Split-buy Only#	Annual Average Capacity Utilization During Dual Source Phase+
Tow	26.0	22.6	63.5
Rockeye Bomb	25.5	3.7	70.9
Bullpup AGM-12	18.7	25.8	76.2
Shillelagh Missile	(4.7)	(6.3)	87.0
Sparrow AIM-7F	(25.0)	(20.5)	81.6
MK-46 Torpedo	(30.7)	(36.0)	91.6
Sidewinder AIM-9D/G	(71.3)	(22.0)	82.3

Source: * Beltramo and Jordan, "A Brief Review," op. cit.

Beltramo and Jordan, "A Detailed Review," op. cit.

+ Federal Reserve Board

[20]Beltramo and Jordan, "A Brief Review," op. cit.

We used these numbers as a preliminary plausibility check of our hypothesis. It is evident that either column of savings (losses) figures would lead to the same logical conclusion.

Summary

In summary, we conclude that the SAI researchers' criticisms of our earlier work stem partly from their misunderstanding of the capacity utilization concept and partly from their using preconceived conclusion to judge a statistical model. The bulk of their criticism may be explained away if one realizes that the capacity utilization concept introduced in our earlier work was a surrogate measure of aerospace contractors' general business environment rather than a specific plant's equipment or capacity utilization. We followed standard statistical methods, and the data used in our analysis were reproduced for ease of replication. Since the findings are statistically significant, the result should not be criticized for failing to support someone else's preconceived hypothesis, unless the methodology is defective.

Chapter 2

ALTERNATIVE MEASURES OF BUSINESS CONDITIONS

In this chapter, we examine to see if the use of other alternative measures of business conditions or firm-specific measures of capacity utilization rather than composite capacity utilization for the aerospace industry would be more reliable for cost estimation purpose.

FIRM-SPECIFIC MEASURES

Virtually everyone who read our first report [Greer and Liao, 1983] suggested that the capacity utilization rate of the specific firm in question would be a better measure of the firm's business condition. This is certainly possible, as a firm with a lot of idle capacity may be hungry for business and may submit a bid price lower than it would have had it been busy. On the other hand, a firm may survey the industry in general and its main competitors in particular and determine that <u>real</u> competition does not exist because other firms in the industry are busy. Under this circumstance, a firm with idle capacity will not necessarily lower its bid price to a significant degree in order to win business because the pressure for business from potential competitors is not high. These are theoretical conjectures, of course. The issue must be examined empirically. In this section, we discuss firm-specific measures used in the empirical test.

In addition to the Federal Reserve Board, which collects capacity and output information from firms on a monthly basis, the Bureau of Census and Bureau of Labor Statistics also collect capacity utilization data at longer intervals. However, all three organizations cited confidentiality as the reason and declined to disclose firm-specific data.

None of the firms contacted by the investigators was willing to disclose the needed information. Therefore, the only feasible source of information is the financial data compiled by investment service organizations.

Relevant data for those firms involved in the seven programs discussed earlier were extracted from Moody's Industrial Survey and Value-Line Investment Survey. Four variables are potentially useful in measuring a firm's capacity utilization: sales, cost of goods sold, gross plant assets, and net plant assets. The cost of goods sold was subsequently eliminated due to its collinearity with sales. The remaining variables were expressed in ratio form to reflect the extent of plant asset utilization: (1) gross plant assets over sales and (2) net plant assets over sales.

A number of contractors are subsidiaries of large conglomerates or privately held. Meaningful data were not publicly accessible, resulting in several cases of missing data.

INDUSTRY SALES, NEW ORDERS, AND BACKLOGS

The Statistical Abstract of the United States reports three categories of business condition measures for the aerospace industry: net new orders, net sales, and backlog. It includes aircraft and parts, aircraft engines and parts, missiles and parts, and other related products and services. Data prior to 1960 were not properly segregated for this study, this accounts for the missing data in the empirical test section.

EMPIRICAL TEST

Data discussed above were compiled and adjusted to constant dollars for testing. To see if the use of above mentioned alternative measures of business conditions would improve the cost estimation in major weapon systems acquisition, we first determine whether or not each of the alternative measures would be a significant explanatory variable in the standard regression equation. The regression model has the following general form:

$$P = kQ^{a}M^{b} \tag{2.1}$$

P, of course, is the unit price for each buy. The Q term is the familiar mid-point quantity associated with each buy, as used in the conventional learning curve model. The M term is the alternative measure of business conditions discussed above. Each of the alternative measures was substituted into the model to see if the t-value associated with the term was significant. The results are shown in Table 2.1.

Table 2.1 T-Ratios for Alternative Measures

	Gross Plant Asset	Net Plant Asset	Net Sales	New Orders	Backlog	Critical Value
			(Original Source)			
Bullpup	*	*	*	*	*	
MK-46	7.79	*	*	*	*	2.92
Sparrow	*	*	*	*	*	
Rockeye	?	?	?	?	?	
Shillelagh	?	?	?	?	?	
Sidewinder	?	?	?	?	?	
Tow	?	?	?	?	?	
			(Second Source)			
Bullpup	*	*	8.95	*	*	6.31
MK-46	*	*	*	*	*	
Sparrow	*	-2.84	*	3.00	*	2.13
Rockeye	?	?	?	?	?	
Shillelagh	?	?	?	?	?	
Sidewinder	-2.39	*	2.91	*	*	2.11
Tow	?	?	?	?	?	

* Statistically insignificant

? Insufficient data

An examination of the t-ratio in table 2.1 shows that the alternative measures were significant in only four of the seven cases with sufficient data for testing. To see if the use of alternative measure in these four cases would be more reliable than the aerospace industry capacity utilization (CU) rate for cost estimation purposes, a comparative analysis was done by examining the coefficient of determination, or R^2 value. This value indicates how well the variables in the regression equation explains the variation in the unit price. The R^2 value, adjusted for the degree of freedom, for each of the four cases are listed in Table 2.2.

Table 2.2 R^2 Values for CU and Alternative Measures

		R^2 Values		
Program	Contractor	CU	Alternative	
MK-46	Aerojet	32.7	47.1	(Gross plant assets/Sales
Bullpup	Maxon	60.7	99.4	(Net industry sales)
Sidewinder	Raytheon	49.2	81.1 76.2	(Net industry sales) (Gross plant assets/Sales
Sparrow	General Dynamics	95.5	97.9	(Net plant assets/Sales) (New orders)

CONCLUSIONS

In this chapter we examined the feasibility and desirability of using alternative measure of business conditions as an explanatory variable in major weapon systems cost estimation models. Two observations may be made from the analysis. First, none of the alternative measures was consistently significant across the programs. Second, for those alternative measures of business conditions which were significant in a specific case, the R^2 values were higher than those obtained using the industry capacity utilization rate.

One way to interpret these findings is that some firms may put more weight on alternative measures of business conditions than on the industry capacity utilization measure for their pricing decisions, but different firms opted to use different measures. It may even be likely that different measures may have been emphasized by the same firm at different times.

Apart from the statistical significance of a variable, one must also judge the usefulness of a variable by the ease of access to the needed data. From the standpoint of timely reporting, industry capacity utilization has a clear advantage over alternative measures, as the Federal Reserve Board release the data on a monthly basis. It may be concluded that, for cost estimation purposes, the aerospace industry capacity utilization is more reliable than other measures of business conditions.

Now that we have concluded that knowledge of the state of capacity utilization in the aerospace industry is an important component of program management, how is one to know prior to the moment of introducing a second source just what capacity utilization situation will be? It is necessary to forecast. The next chapter examines forecasting techniques.

Chapter 3

FORECASTING AEROSPACE INDUSTRY CAPACITY UTILIZATION

It seems clear by now that the aerospace industry capacity utilization rate is a major price determinant of major weapon systems when the procurement is conducted under competition. The explanatory power of our model is evident. Knowledge of the state of capacity utilization in the aerospace industry is essential in the acquisition of major weapon systems under competition.

We formerly attempted to use a Box-Jenkins time series model, or the so-called ARIMA model, to forecast monthly aerospace industry capacity utilization rates with only limited success. In this chapter, we will discuss our current efforts to develop a reliable forecasting technique to predict capacity utilization.

A CLOSER LOOK AT CAPACITY

The capacity utilization rate, as reported by the Federal Reserve Board, is determined by dividing the capacity by the output of the industry. This suggests that, to forecast the capacity utilization rate of an industry, one must consider both output and capacity. This idea may be captured in a simple model:

$$CU_{t+1} = f[CU_t,\ \mathrm{Delta}(OUTPUT_{t+1}),\ \mathrm{Delta}(CAP_{t+1})] \qquad (3.1)$$

The model implies that the current state of capacity utilization

(CU_t), and the expected change in output and capacity (CAP) should jointly determine that status of capacity utilization for next year (t+1). We may hypothesize, however, that some sort of relationship exists between the two unknown variables on the right hand side of the model, changes of output and capacity.

The business community is obviously interested in forecasting output. Indeed, it is logical to assume that output forecasts become a basis for making decisions to alter existing amounts of capacity. If an industry anticipates declines in output, it is likely to allow its capacity to remain static or even to shrink. If firms expect improving business conditions, i.e., if increases in output are anticipated, then they are more likely to expand capacity. Thus, we may further hypothesize that

$$\text{Delta}(CAP_{t+1}) = f[CU_t, \text{Delta}(OUTPUT_{t+1})] \quad (3.2)$$

Eq. 3.2 suggests that when deciding by what amount to change capacity for the next period (t+1), the firm will consider its present (t) state of CU and the anticipated change in output. If this relationship proves to be correct, then Eq. 3.1 may be simplified as follows:

$$CU_{t+1} = f[CU_t, \text{Delta}(OUTPUT_{t+1})] \quad \text{(Eq. 3.3)}$$

This model implies that, given the present state of CU, the expected capacity utilization in the industry may be predicted from the expected change in output in the next period. Thus, a prerequisite for projecting the capacity utilization rate is the determination of the parameters for Eq. 3.2. The next section deals with this issue.

RELATIONSHIP BETWEEN CAPACITY AND OUTPUT CHANGES

To derive the parameter for Eq. 3.2, our intuition tell us to expect positive association for both variables, i.e., positive changes in capacity are relatively more likely to occur when CU is high, and when large increases in output are expected.

It is important to recognize that the usefulness of Eq. 3.2 will ultimately depend on an implicit prerequisite condition that forecasts of changes in output are available. In this sense, this model really constitutes a transposition of existing forecasts. For now, we will assume that accurate output forecasts are available so that we can assess the performance of the model alone. The issue of output forecasts will be discussed later in the chapter.

Data

Table 3.1 shows the data for capacity, output, and capacity utilization for fiscal years 1954 through 1983. The data were compiled from the quarterly figure reported by the Federal Reserve Board and converted to fiscal year averages in conformity with the Federal Government fiscal calendar.

The columns labelled "capacity utilization," "capacity," and "output" were converted from the Federal Reserve Board data as discussed earlier. The fourth column shows the percentage

Table 3.1 Aerospace Industry Capacity and Output

Fiscal Year	Capacity Utilization	Capacity	Change in Capacity from Last Year	Output	Change in Output from Last year
1954	83.23	75.33	8.81	62.70	2.90
1955	71.67	78.00	3.54	55.90	-10.85
1956	74.98	80.93	3.76	60.68	8.55
1957	84.70	84.33	4.20	71.43	17.72
1958	75.07	85.05	0.85	63.85	-10.61
1959	70.12	84.93	-0.14	59.55	-6.73
1960	68.82	85.00	0.08	58.50	-1.76
1961	66.43	84.68	-0.38	56.25	-3.85
1962	72.44	82.90	-2.10	60.05	6.76
1963	81.32	81.10	-2.17	65.95	9.83
1964	82.83	84.03	3.61	69.60	5.53
1965	81.27	87.73	4.40	71.30	2.44
1966	88.26	93.98	7.12	82.95	16.34
1967	92.67	104.38	11.07	96.73	16.61
1968	89.69	113.70	8.93	101.98	5.43
1969	86.99	116.80	2.73	101.60	-0.37
1970	80.22	118.90	1.80	95.38	-6.12
1971	66.69	121.00	1.77	80.70	-15.39
1972	64.88	122.65	1.36	79.58	-1.39
1973	70.57	121.70	-0.77	85.88	7.92
1974	75.30	120.30	-1.15	90.58	5.47
1975	73.15	118.90	-1.16	86.98	-3.97
1976	70.93	117.32	-1.33	83.22	-4.32
1977	73.21	115.90	-1.21	84.85	1.96
1978	79.17	116.75	0.73	92.43	8.93
1979	89.26	122.03	4.52	108.93	17.85
1980	90.49	127.78	4.71	115.63	6.15
1981	83.78	133.78	4.70	112.08	-3.07
1982	73.43	139.38	4.19	102.35	-8.68
1983	68.56	143.65	3.06	98.48	-3.78

change in capacity from the previous year, the variable whose behavior is the focus of our attention, as described in Eq. 3.2. Where negative numbers are reported capacity has shrunk-- presumably from obsolescence or time-related attrition or from disposal.

The last column contains the actual percentage changes in output from the previous years. Since the purpose for now is to determine the parameters for Eq. 3.2, we will presume that this column could also be read as forecasted changes. Later in the chapter we will address the issue of output forecasts.

Analysis

Figure 3.1 graphically depicts the data of Table 3.1. The dotted line on the top represents the level of aerospace industry's capacity. The solid line represents the level of the industry's output. The percentage changes of each variable are captured in the slope of the respective line for the time segment in question. And the distance between the two lines represents the magnitude of idle capacity for a particular time period.

Several observations can be made from a careful examination of the plot. First, an increase in output generally led to expansion of capacity. Second, large amount of idle capacity generally led to shrinkage of capacity. Third, capacity increases tended to lag behind output increases following periods of large amounts of idle capacity, which simply meant that when the industry has a lot of unused capacity, the idle capacity absorbed the increase in output. All these observations are intuitively correct and consistent with the hypothesis discussed earlier.

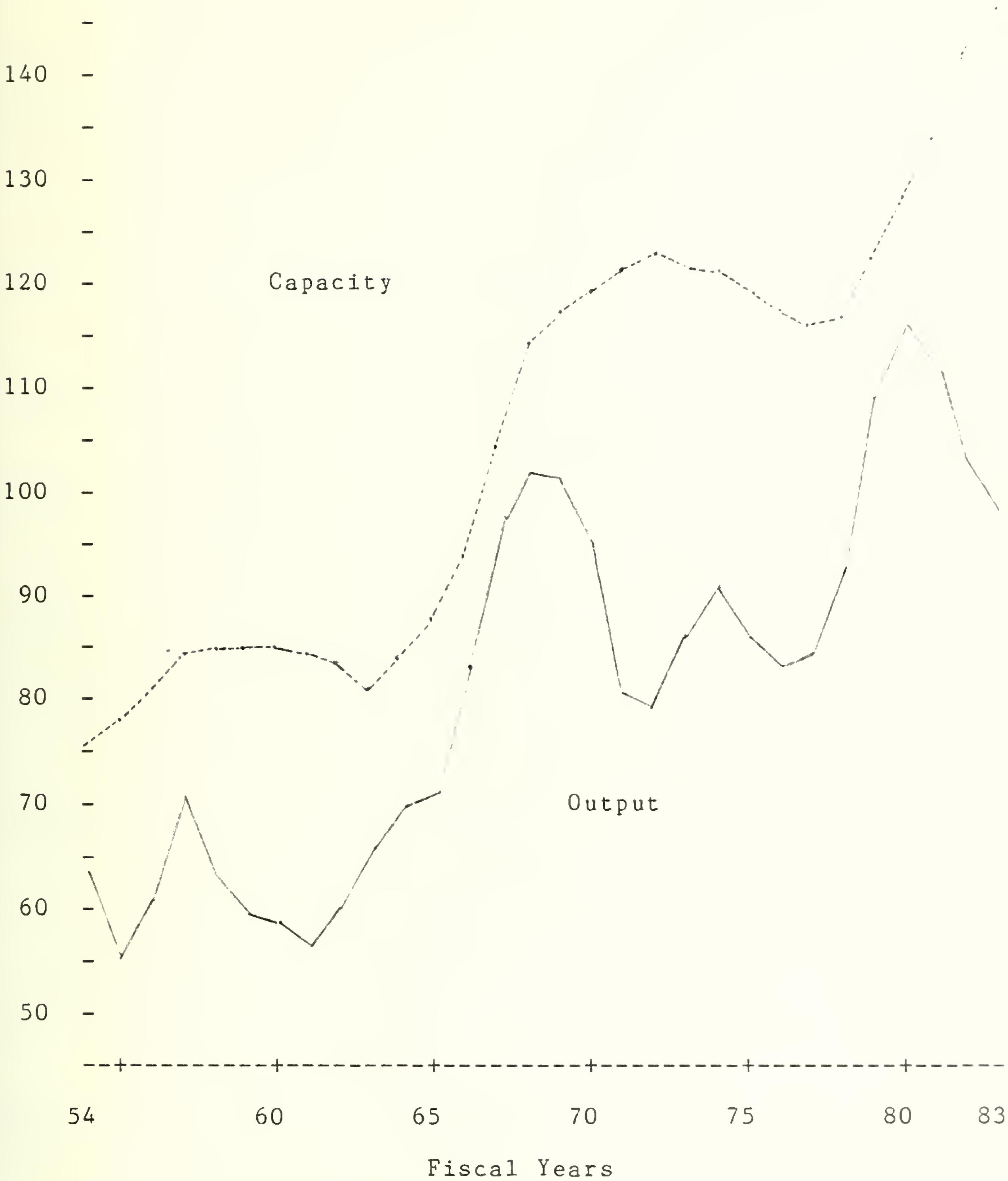

Figure 3.1 Aerospace Industry Capacity and Output, 1954-1983

After several iterations of data exploration, a multiple regression model produced the following result:

$$\text{Delta}(CAP_{t+1}) = -26.89+0.367[(CU_{t-1}+CU_t)/2]+0.217\text{Delta}(OUTPUT_{t+1})$$

The T-ratios for the two independent variables are 8.70 and 6.05 respectively. The adjusted R^2 is 77.0%. With 25 degrees of freedom, all of the above statistics are significant at better than the 1% level. As anticipated, the coefficients for the explanatory variables are positive, depicting the expected positive association.

This equation explains the business community's proclivity to make capacity changes in terms of its present and recent past state of CU, and its own anticipation of changes in output. It gives us a means of preparing moving, dynamic forecasts of changes in capacity, assuming we possess forecasts of output (as well as a history of CU).

To assess the strength of the regression equation, we prepared a CU forecast by using the FRB output as the input for Eq. 3.2. The results are shown in Table 3.2. It should be noted again that this validation method is designed to separate the quality of Eq. 3.2 forecast from that of output forecast, which will be the focus of our test in the next section.

It can be seen from Table 3.2 that, if reliable output forecast is available, the CU forecasting model developed above can predict the state of capacity utilization in the aerospace industry with a high degree of accuracy. We now turn our attention to forecasting aerospace industry output changes.

Table 3.2 Forecast of CU When Output Change Is Available

Fiscal Year	Capacity Utilization Actual	Predicted	Difference
1956	74.99	75.24	-0.25
1957	84.70	85.23	-0.53
1958	75.07	75.99	-0.92
1959	70.12	70.01	0.11
1960	68.82	69.10	-0.28
1961	66.43	67.93	-1.50
1962	72.44	72.72	-0.28
1963	81.32	79.03	2.29
1964	82.83	81.63	1.20
1965	81.27	81.09	0.18
1966	88.26	88.56	-0.30
1967	92.67	95.75	-3.08
1968	89.69	93.37	-3.68
1969	86.99	86.34	0.65
1970	80.22	77.37	2.85
1971	66.69	65.58	1.11
1972	64.88	65.29	-0.41
1973	70.57	71.28	-0.71
1974	75.30	75.66	-0.36
1975	73.15	73.23	-0.08
1976	70.93	70.42	0.51
1977	73.21	71.87	1.34
1978	79.17	77.38	1.79
1979	89.26	87.37	1.89
1980	90.49	88.59	1.90
1981	83.78	81.99	1.79
1982	73.43	73.02	0.41
1983	68.56	69.74	-1.18

FORECASTING OUTPUT CHANGES

It is undeniable that the DOD is a major source of the aerospace industry's business. Government usually accounts for between 40% and 60% of total sales of the heavily defense-oriented industry. Therefore, it is logical to hypothesize that the aerospace industry output may be significantly correlated with DoD's procurement budget. We will proceed to test this hypothesis.

Data

Table 3.3 shows the budgetary procurement data for fiscal years 1961 through 1980. The data were compiled from three sources: (1) Five Year Defense Plan, (2) House Appropriations, and (3) Senate Appropriation Hearing Records. The Five Year Defense Plans cover the years 1962-1980 and the remainder was based on congressional sources.

Table 3.3 Funding Request for Aircraft and Missiles

(In FY72 $1,000,000)

Fiscal Year	Amounts	Fiscal Year	Amounts
1961	5,415	1971	9,107
1962	7,189	1972	9,897
1963	7,270	1973	9,824
1964	7,052	1974	9,956
1965	6,478	1975	10,767
1966	9,148	1976	13,644
1967	9,925	1977	19,167
1968	9,843	1978	24,250
1969	9,694	1979	26,662
1970	8,528	1980	32,036

Analysis

Since the data reported in Table 3.3 are budgetary figures, one would expect that the figure would correlate with the aerospace industry's output in subsequent years. The following regression equation shows the result by using one time lag:

$$OUTPUT_t = 66.431 + 1,834(BUDGET_{t-1})$$

The R2 adjusted for the degree of freedom is 51.4% and the T-ratio for the Five Year Defense Plan budget is 4.47, both are statistically significant at the 5% level. It is interesting to note that the coefficient of determination, which measures the percentage variation in the dependent variable which is explained by the independent variable, falls within the range of government business experienced by the aerospace industry during the past three decades. Therefore the simple regression model performs as well as one can expect. Table 3.4 shows the actual output level, the predicted output level using the regression equation, and the residuals for each period.

It should be noted that the Durbin-Watson statistic for the above regression equation is very low (0.37), indicating a strong autocorrelation among the residuals. This autocorrelation may be attributed to the cyclical variation in the commercial market.

Using the Box-Jenkins method of time series analysis, the residuals were analyzed with an autoregressive model with the order of two, or ARIMA(2,0,0). Let us assume that the residuals

Table 3.4 Predicted Output Using Regression Equation

Fiscal Year	Actual Output	Predicted Output	Residual
1962	60.05	76.36	-16.31
1963	65.95	79.62	-13.67
1964	69.60	79.76	-10.16
1965	71.30	79.36	-8.06
1966	82.95	78.31	4.64
1967	96.73	83.21	13.52
1968	101.98	84.63	17.35
1969	101.60	84.48	17.12
1970	95.38	84.21	11.17
1971	80.70	82.07	-1.37
1972	79.58	83.13	-3.55
1973	85.88	84.58	1.30
1974	90.58	84.45	6.13
1975	86.98	84.69	2.29
1976	83.22	86.18	-2.96
1977	84.85	91.45	-6.60
1978	92.43	101.58	-9.15
1979	108.93	110.90	-1.97
1980	115.63	115.33	0.30

from the regression equation is designated by E, or error, the resulting equation is as follows:

$$E_t = 0.0593 + 1.4145(E_{t-1}) - 0.7505(E_{t-2})$$

The coefficients for E_{t-1} and E_{t-2} are statistically significant at the 5% level. Combining the simple regression equation and the autoregressive equation, we obtain an output estimation model as follows:

$$OUTPUT_t = 66.4803 + 1834(BUDGET_{t-1}) + 1.4145(E_{t-1}) - 0.7505(E_{t-2})$$

Table 3.5 shows the strength of the output prediction model, using the Five Year Defense Plan budgetary data as the only input. Predicted capacity utilization of the aerospace industry shown in Table 3.5 was based on the coefficients for Eq. 3.3 discussed in the preceding section. Figure 3.2 graphically depicts the high degree of reliability of the capacity utilization method discussed in this chapter. The solid line represents actual capacity utilization rate reported by the Federal Reserve

Table 3.5 Result of Output Prediction Model

		Based on Output Prediction Model				
Fiscal Year	Actual Output	Predicted Output	Error	Output Change	Capacity	Capacity Utilization
1962	60.05	62.69	-2.64	11.43	84.79	73.94
1963	65.95	66.18	-0.23	5.58	86.18	76.79
1964	69.60	72.74	-3.14	9.90	88.96	81.77
1965	71.30	75.30	-4.00	3.53	92.37	81.52
1966	82.95	74.59	8.36	-0.94	95.21	78.34
1967	96.73	95.88	0.85	28.54	101.49	94.47
1968	101.98	100.34	1.64	4.65	109.70	91.47
1969	101.60	98.93	2.67	-1.40	116.49	84.93
1970	95.38	95.46	-0.08	-3.51	120.88	78.97
1971	80.70	85.09	-4.39	-10.87	121.76	69.88
1972	79.58	72.87	6.71	-14.36	118.43	61.53
1973	85.88	80.64	5.24	10.67	116.59	69.17
1974	90.58	89.01	1.57	10.36	117.58	75.70
1975	86.98	92.45	-5.47	3.88	119.86	77.13
1976	83.22	84.87	-1.65	-8.20	120.51	70.43
1977	84.85	85.61	-0.76	0.88	120.26	71.19
1978	92.43	94.52	-2.09	10.40	122.07	77.43
1979	108.93	102.97	5.96	8.94	126.07	81.68
1980	115.63	119.47	-3.84	16.02	133.30	89.62

Board. The dotted line represents our prediction described above.

LONG-TERM FORECAST OF CAPACITY UTILIZATION

Although using the Five Year Defense Plan budgetary data as the basis to forecast aerospace industry output and capacity utilization has been shown to be highly accurate, the period for which forecasts can be made is only one period ahead of the release of the Five Year Defense Plan. For second sourcing decision, we must look ahead at least five years into the future. Therefore, the use of a long term output forecast is necessary if Eq. 3.3 is to be useful.

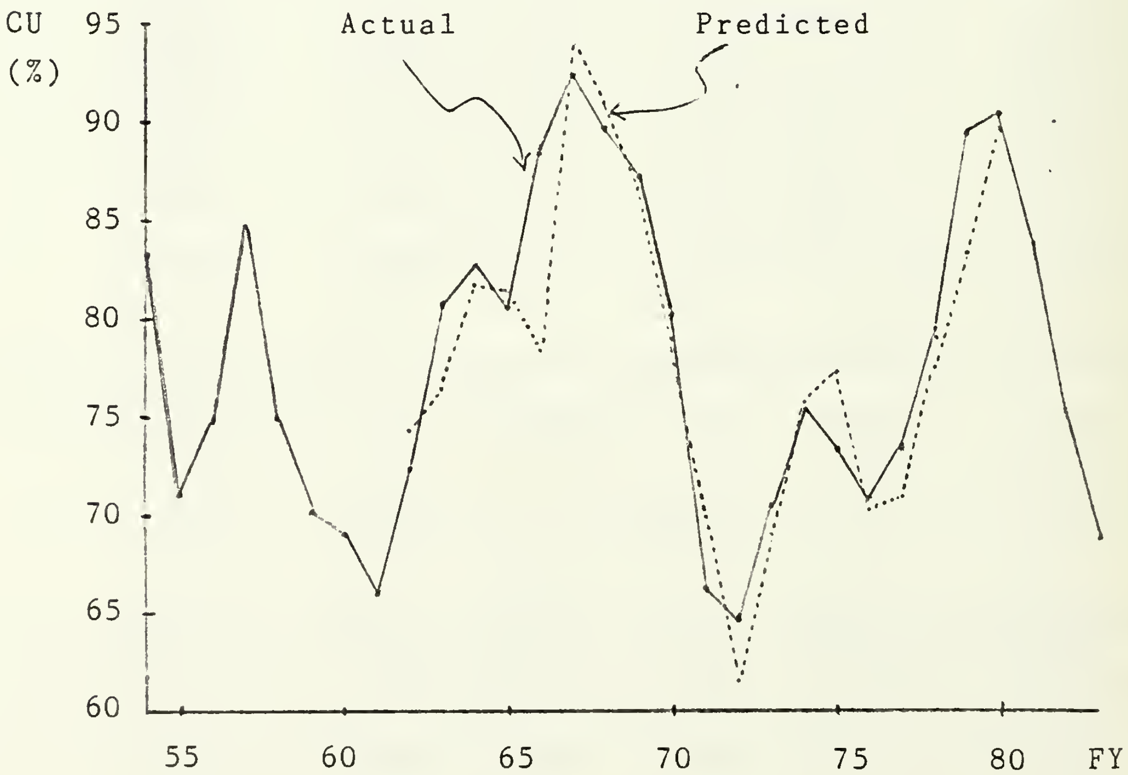

Figure 3.2 Actual vs Predicted Capacity Utilization

The Electronic Industries Association (EIA) sponsors the preparation of ten-year forecasts of DoD procurements. The figures shown in Table 3.6 cover FY83-93 for aircraft, missiles and space (which essentially defines the non-commercial segments of the aerospace market).[1]

Table 3.6 EIA Forecast of DoD Aerospace Market

FY	Forecast Output (Bil FY84$)	Forecast Change in Output
83	42.7	-
84	49.5	15.93%
85	52.4	5.86
86	55.2	5.34
87	57.0	3.26
88	58.2	2.11
89	57.5	-1.20
90	55.9	-2.78
91	54.2	-3.04
92	52.5	-3.14
93	50.7	-3.43

The Value Line Investment Survey is another source of reliable (but shorter-term) forecasts for the performance of the aerospace

[1]This information was abstracted from a conference manual, White, L.B., Analyzing & Forecasting Aerospace Markets, The Technical Marketing Society of America, (undated), p. 90.

industry.[2] The prognosis reported in its industry analysis dated April 20, 1984, lends creditability to the EIA forecast:

> . . . we expect defense spending to grow throughout the 1980s, although the annual percentage increase will slow as the budget gets bigger and immediate needs are met.

Value Line expects the <u>total</u> aerospace market to grow at only a 5.33% rate from (CY) 1983 to 1984, but then at an average rate of about 8.34% from 1984 until 1988. This is attributable to a currently weak commercial market which they expect to improve dramatically by the mid-eighties. These different shorter-term outlooks will provide an opportunity for sensitivity analysis.

Table 3.7 Forecasts of Aerospace Industry CU

	Forecast of CU based on	
FY	EIA Forecast	Value Line Forecast
84	77.44%	71.97%
85	81.02	77.42
86	82.58	81.96
87	82.11	85.24
88	80.78	87.44
89	77.67	82.64
90	74.33	77.45
91	71.82	73.75
92	70.09	71.30
93	68.78	69.56

[2]Value Line, Inc., New York.

THE PROGNOSIS

Based on the forecasts shown in Table 3.7, it appears that conditions will be relatively favorable for dual sourcing during most of the next decade. However, there will be a brief period during the mid-to-late eighties during which especially alert management of the procurement process will be necessary if net financial benefits are to be expected. Figure 3.3 summarizes our findings.

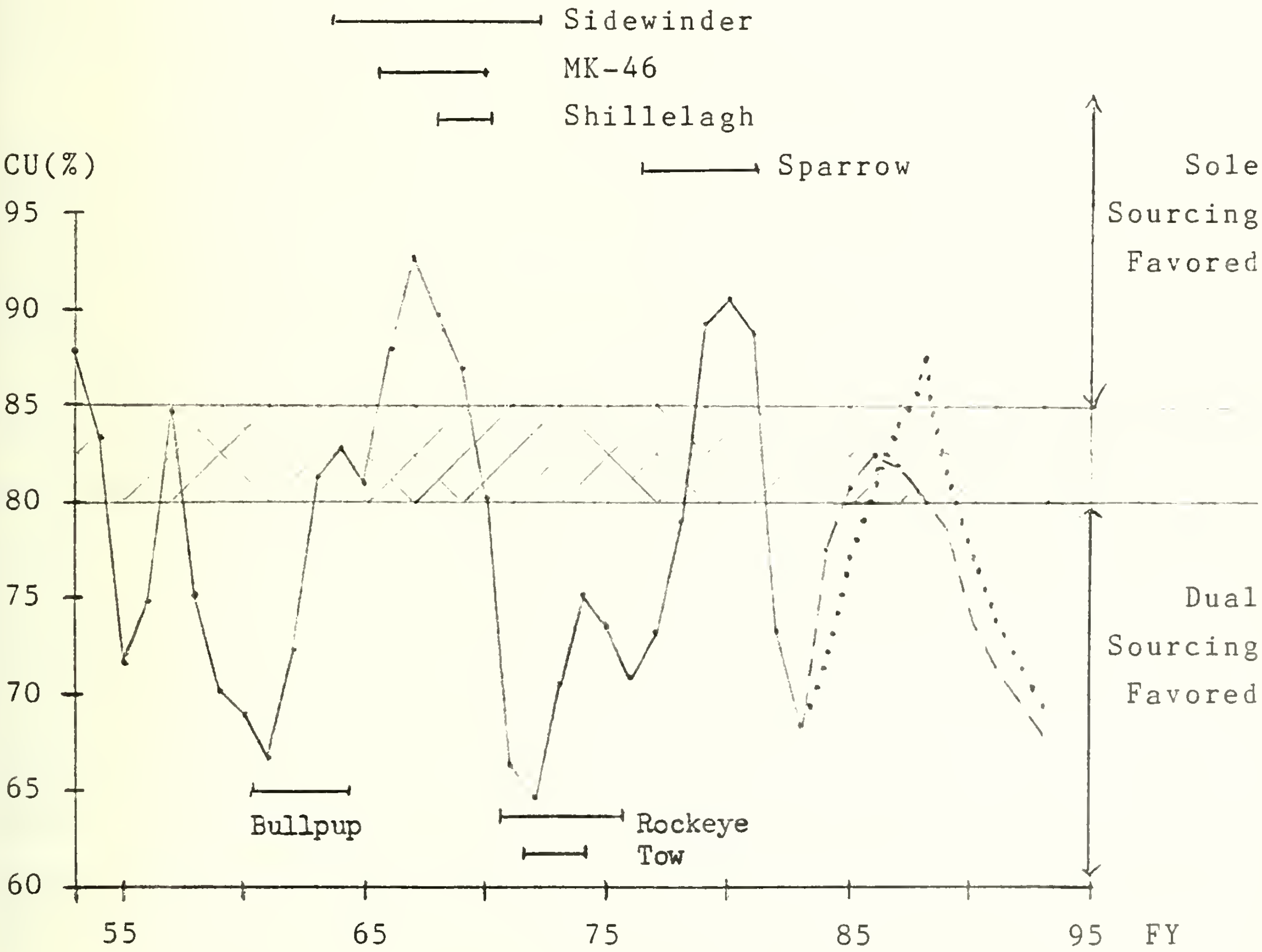

Figure 3.3 CU Through Time--History and Forecasts

The solid line in Figure 3.3 traces actual CU from FY53 through FY83. Two forecasts are shown as extensions of that line. The dotted line is an outlook constructed from Value Line's expectations of aerospace industry growth. The dashed line represents a forecast on the basis of the EIA prognosis for DoD procurements.

Prior experience with major weapon systems has shown that positive savings can be expected from dual sourcing when CU lies below 80%. The zone lying below the shaded bar can therefore be thought of as identifying time periods during which dual sourcing is the logical choice.

Since dual sourcing should not be expected to produce savings when CU is above about 85%, the area <u>above</u> the shaded bar identifies times when sole-source procurement would be favored. These conditions are not expected to prevail during the next decade.

The shaded bar itself can be thought of as a "caution zone." Careful management of a procurement is necessary if positive savings are to be experienced when CU lies within this range. For example, if a program's capacity constraints or other factors prevent what appears to be an optimal division of procurements between the original supplier and the second source, it might be preferable to plan on using sole sourcing from about FY86 through, say, FY89. Since this may be a difficult time during which to use dual sourcing as a cost-reducing apparatus, the best policy might be to remain very flexible.

EQUILIBRIA

Since the CU forecasting model discussed in the chapter expresses the rate at which capacity is growing as a function of recent CU and the growth rate anticipated for output, a constant rate of output growth should lead to a CU equilibrium point. This equilibrium can be determined either iteratively or analytically.

Table 3.8 contains an array of possible growth rates and the CU equilibrium which would be associated with each.

Table 3.8 Output Growth Rates and CU Equilibria

If Output Growth Rate Is	Equilibrium CU Will Be
-2%	69.0%
0	73.2
2	77.5
4	81.8
6	86.0
8	90.3

It is intuitively appealing to note both that the economy is more efficient in terms of CU when it is growing at a fairly rapid clip and that competition would be more effective as a price reducer during slow-downs.

However, we might make additional observations which are more relevant to the procurement process. Dual sourcing would not normally be useful as a cost-reducing apparatus unless the sustained rate of output growth was less than about three or three-and-a-half percent. Even with exceptionally good management it would be difficult to achieve net financial benefits when the growth rate exceeded roughly five percent.

Value Line anticipates (real) output growth in the aerospace industry will average 7.7% between now and the end of 1988. The EIA expects the rate of growth in the DoD portion of the market to decline to less than three percent by FY88, and to continue declining through FY93.

These growth rates should not be interpreted as <u>sustained</u>, so equilibrium conditions will not actually be achieved, but the anticipated <u>trends</u> do lend credence to the principal conclusion reached in the chapter. During the mid-to-late eighties especially careful management of the procurement process will be necessary if we are to reap net financial benefits from dual sourcing. The <u>best</u> opportunities for using dual-source procurement during the next decade will occur after FY88.

Chapter 4

ANOTHER LOOK AT DUAL SOURCING EXPERIENCE

There have been many studies identifying and quantifying the procurement cost consequences of dual sourcing. The theoretical roots of much of this work go no more deeply than learning curve theory. Much has been made of the "shift" and "rotation" which seem to be apparent in the learning curve when a second source is introduced.[1]

Increasingly, production rates are being recognized as also having an important influence on procurement costs.[2] Indeed, production rate effects are often used as an argument <u>against</u> dual sourcing.[3]

Second-source start-up costs, including the costs of (1) technology transfer, (2) special tooling, test and production equipment, (3) educational buys and (4) administrative costs to the Government, have also been recognized as affecting the outcome of a dual-source procurement.[4] These must be offset

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[1]For example, see Cox, L.W. and J.S. Gansler, "Evaluating the Impact of Quantity, Rate, and Competition," <u>Concepts</u> (Autumn 1981).

[2]Bemis, J.C., "A Model for Examining the Cost Implications of Production Rate," Department of Defense, Product Engineering Services Office, Defense Logistics Agency, Cameron Station, Alexandria (undated).

[3]Bemis, J.C., and J.S.W. Fargher, Jr., "Model for Determining the Effects of Production Rate Change and Dual/Second Sourcing Decisions," (unpublished draft).

[4]For some interesting insights, see Myers, M.G., P.R. McClenon, and H.M. Tayloe, "Price Competition in the DOD," Logistics Managment Institute, September 1982.

against price savings to determine the net financial benefit derived.

It is also recognized that procurement cost savings must be discounted to present value using an appropriate time value of money. Failure to do so will overstate the economic advantage available from dual sourcing.[5]

Finally, we wish to cite our earlier work done for NAVAIR demonstrating that capacity utilization in the relevant industry is an important determinant of the savings obtainable under dual sourcing.[6] It is this work upon which we seek to build.

CAPACITY UTILIZATION AND EFFECTS OF QUANTITY SPLIT

In the above-cited NAVAIR work, capacity utilization (hereafter referred to as CU) was found to be positively correlated with the price paid to an original-source contractor under dual-source competition for major weapon systems.[7] That is, when CU is high--when there is very little idle capacity in the industry--neither the threat nor the fact of competition is sufficiently onerous to induce much in the way of price concessions. However,

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[5]Archibald, K.A., et al., "Factors affecting the Use of Competition in Weapon System Acquisition," Rand Corp., R-2706-DR&E, February 1981.

[6]Greer, W.R., Jr., and S.S. Liao, "Cost Analysis for Dual Source Weapon Procurement," Naval Postgraduate School technical report No. 54-83-011, October 1983.

[7]Much of the data upon which this work was based were collected by and for Beltramo, M.N. and D.W. Jordan, "Issues to be Considered in Establishing Dual Source Competition," (second report) Division of Cost Analysis (MAT-01F4) Headquarters, Naval Material Command, 24 September 1982.

if CU is low (implying larger amounts of idle capacity in the industry) competition can be valuable as a price-reducer.

We will model the price paid to the original source, P_1, as a general-form function of CU and all other factors, OF:

$$P_1 = f(CU, OF). \tag{4.1}$$

Again, the direction of the relationship between P_1 and CU has been found to be positive.

The same relationship between CU and the price paid to the second source can be expected if both are in the same market.[8] Therefore the same general model will be sufficient to describe the factors influencing P_2:

$$P_2 = f(CU, OF). \tag{4.2}$$

Next consider the division, or splitting, of the procurement between the original source and the second source. There are many possible ways to measure this division.[9] For example, either quantities or dollars could be used. Also, one could measure the split during only the competitive phase of a program

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[8]Our earlier study (see footnote 6) confirmed this positive relationship. However, the numerical values of the coefficients are different for the original and the second source suppliers.

[9]The interested reader might like to study Bell, J.P., "Competition as an Acquisition Strategy: Impact of Competitive Research and Development on Procurement Costs," Institute for Defense Analysis paper No. P-1744, November 1983.

or during the _entire_ program. For simplicity, we will measure the division in terms of _total_ (real) dollars spent with each respective source over the entire life of the procurement. D_1 will represent the _percentage_ of the total procurement dollars captured by the original source. D_2 is the percentage the second source receives. (Please note that $D_2 = 100\% - D_1$.)

Next, we can define a weighted average procurement price paid under dual sourcing, P_d:

$$P_d = (D_1 \times P_1) + (D_2 \times P_2). \tag{4.3}$$

By substitution,

$$P_d = [D_1 \times f(CU, OF)] + [(100\% - D_1) \times f(CU, OF)]. \tag{4.4}$$

If other factors (OF) are held constant, Eq. 4.4 implies that the weighted average price paid under dual sourcing is a function of D_1 and CU.

QUANTIFYING THE SAVINGS

The procurement price savings generated by dual sourcing are conventionally determined by comparing the actual prices paid with the prices which _would have been paid_ under sole sourcing. More will be said later about sole-source prices, but, for now, simply let the sole-source price (which is assumed to be greater than the dual-source price) be P_s, so the price reduction achieved by dual sourcing is $P_s - P_d$.

Earlier it was pointed out that establishing a second source (after some period of procuring from only the original source) requires the incurrence of start-up costs. Some start-up costs undoubtedly increase with the proportion of the total quantity to be procured from the second source. These might include (but are not necessarily limited to) the costs of special tooling, test and production equipment, educational buys, and perhaps some of the administrative costs borne by the Government.

Start-up costs (SC) must be offset against the discounted present value of the savings in procurement price to determine the net financial benefit (NFB) from dual sourcing. In simple equation form,

$$NFB = pv(P_s - P_d) - SC. \tag{4.5}$$

To review the direction of the impact of changes in the critical variables on NFB, first consider CU. From Eq. 4.4 we know P_d rises when CU rises. Therefore, Eq. 4.5 tells us that NFB (which we seek to maximize) <u>declines</u> as CU rises. We save less when CU is high.

The other variable of interest is D_1, percent of procurement dollars captured by the original source. Here the relationship is more complex. In theory, savings result when the original source is pressed by a second source under conditions of low capacity utilization. This might imply that as D_1 declines NFB rises, because the pressure placed upon the original source to reduce P_1 would be even greater: but diminishing returns must be reached at some point.[10] And raising D_2 causes SC to rise, thereby reducing NFB.

The final determination of the relationship's shape, as well as the most likely optimum point (if there is one) is therefore complex and must be studied through empiricism. It is to this task that we now turn.

AN EMPIRICAL EXAMINATION

Data

The data examined in this study include weapon systems acquisition histories and industry capacity utilization data. These data have been used and described in our earlier study, but we will briefly describe each here.

The weapon systems data describe the economic outcomes of seven major weapon acquisition programs which were dual sourced after an introductory period of sole-source procurement. The savings (loss) percentages listed in Table 4.1 are those previously reported for these programs.[11]

The CU data came from the Federal Reserve Board in quarterly form. They were converted to a fiscal year basis before use. The CU figures reported in Table 4.1 are averages for the fiscal years during which each of the programs was dual sourced and

[10] Note that if this is taken to either extreme (D_1 = 100% or D_2 = 100%) you are in a sole-sourcing situation again.

[11] See footnotes 6 and 7. Other analyses have produced similar results. See Sherbrooke and Associates, "Quantitative Acquisition Strategy Models," Potomac, March 1983.

(when applicable) the first year in which a winner-take-all, "buy-out" competition was held.[12]

Table 4.1 Summary Data of Weapon Systems Examined

Procurement Program	Savings or (Loss) Due to Competition (NFB)	Average CU During Competition	D_1 for Program
TOW	26.0%	65.8%	85.9%
Rockeye Bomb	25.5	67.7	88.0
Bullpup AGM-12B	18.7	75.7	88.3
Shillelagh Missile	(4.7)	88.8	86.9
Sparrow AIM-7F	(25.0)	83.0	70.0
MK-46 Torpedo	(30.9)	89.4	46.2
Sidewinder AIM-9D/G	(71.3)	83.4	10.8
Average	(8.8%)	79.1%	68.0%

The data from which D_1 was derived came from the same source as the savings (loss) data. Constant dollar costs were used to avoid any distortions which might have been introduced by inflation.

Analysis

By examining Table 4.1, the reader can confirm that of the seven programs studied, only three generated price savings ($P_s - P_d$)

[12]This is the only year in which a buy-out competition has been found to have a siginficant impact on price. See Greer and Liao, op. cit.

with present values which were high enough to more than offset the start-up costs (SC) required to obtain them. In other words, in only three cases was NFB from Eq. 4.5 positive. Indeed, the average of the savings (loss) column shows an overall average <u>loss</u> of 8.8%! In each of the three "savings" cases, CU averaged less than 80% during the competitive phase of the program. The D_1 values for most of the programs with positive NFBs fell within a range of about 85-90%.

Further analysis can provide even richer insight. A regression can be run on the data contained in Table 4.1. If we regress NFB using CU and D_1 as predictors, the result is:

$$NFB = 27.38 - 1.267\ CU + .942\ D_1. \qquad (4.6)$$

The T-ratio statistics from the regression were -2.86 for CU and 6.54 for D_1. This yields significance at better than the .05 level for both predictors. The R^2 adjusted for degrees of freedom is 93.6%--a very good "fit."

Again, we see that as CU rises NFB declines. In addition, it is clear that, <u>within the range of values for the quantity-split shown in the table</u>, tilting the division of the procurement toward the original source produces greater savings. However, this conclusion should be qualified due to serial correlation of residuals.

The residuals from the regression model shows a moderate degree of first order autocorrelation. Rearranging the data in an ascending order according to the quantity-split, D_1, for the regression analysis results in even stronger first order autocorrelation among residuals. Further analysis of the residual shows that this phenomenon is caused by the nonlinearity of the relationship between NFB and D_1. As discussed earlier, when D_1 declines, NFB rises, because the pressure placed upon the original source to reduce P_1 would be even greater: but diminishing returns must be reached at some point. And reducing D_1 beyond certain point causes SC to rise, thereby reducing NFB. On the other hand, if the second source receives only a nominal amount of quantity, i.e., D_1 approaches 100%, it would not pose as much of a threat to the original source. Therefore, NFB would decrease as D_1 approaches the extreme points at both ends. Unfortunately, for the limited number of observations available for analysis, the values for D_1 cluster in the 70% to 90% range. We were unable to determine with sufficient confidence the shape of the curvilinear relationship and its turning point.

With this limitation in mind, let us assess the quality of the regression model by examining the values of NFB it would predict, and comparing these with the actual values. This is done in Table 4.2. While the predictions are not perfect (other factors are never precisely equal), a gain would always have been predicted when in fact there was a gain, and a loss would have been forecast when a loss actually occurred--and the magnitudes are ordinally correct.

Table 4.2 Quality of Regression for NFB = f(CU, D_1)

Procurement Program	Actual Savings or (Loss) Due to Competition (NFB)	Predicted Value Using the Regression
TOW	26.0%	24.9%
Rockeye Bomb	25.5	24.5
Bullpup AGM-12B	18.7	14.6
Shillelagh Missile	(4.7)	(3.3)
Sparrow AIM-7F	(25.0)	(11.9)
MK-46 Torpedo	(30.9)	(42.4)
Sidewinder AIM-9D/G	(71.3)	(68.1)
Average	(8.8%)	(8.8%)

DISCUSSION

So far, the analysis has verified that dual-source competition produces greater NFBs for the Government when there is substantial idle capacity in the relevant industry. At the average value of D_1, 68%, a "break-even point" would occur at about CU = 72%.

It appears that, in many of the cases studied, the second source has been called upon to play a larger-than-optimal role. Greater net financial benefits have been experienced when the second source was allotted about 10-15% of the procurement. It seems plausible that this amount of business is sufficient to induce the desired original-source price reductions during periods of low CU, but not so large as to require outsized amounts of start-up cost. In fact, the data contained in Table 4.1 combine with Eq. 4.6 to suggest that with close control of D_1 it would be possible to generate savings with CU as high as about 85%. Unfortunately, limited observations and the distribution of D_1 do not allow us to determine the exact shape of the curvilinear relationship and pinpoint the point of diminishing return for the quantity-split. Further study is needed to tackle this neglected issue.

Chapter 5

CAPACITY UTILIZATION AND SOLE SOURCE ACQUISITION

Thus far the development of the literature has implicitly assumed there to be no association between capacity utilization (CU) and the price paid under sole source acquisition, P_s. While this in fact may be true, the issue bears examination inasmuch as an accurate statement of net financial benefit (NFB) would require knowledge of any functional relationship between P_s and CU.

SOLE SOURCED PROGRAMS

In examining procurements that were sole sourced, we used data for missile, fixed-wing aircraft and helicopter programs.[1] One may question the reliability of these data, which were compiled from congressional records, as a true representation of actual acquisition cost to the Government. For lack of better source to collect sufficient data from a cross-section of major weapon systems, we used them to see if a clear correlation exists between the price paid by the Government and the CU of the aerospace industry. One may reject the reliability of the magnitude of a specific coefficient, but the pattern of the relationship between the variables examined should not be denied if a consistent and logical pattern is found.

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[1]These data were taken from Nicholas, T.G., U.S Military Aircraft Data Book, 6th ed., and U.S. Missile Data Book, 8th ed., both by Data Search Associates, 1984.

With this data caveat in mind let us discussed the programs to be analyzed. A number of sole-sourced programs were selected for scrutiny. Those showing no statistical significance were eliminated from further analysis. Table 5.1 lists those that survived this initial screening.

Table 5.1 Sole-Sourced Programs Studied

Fixed-Wing Aircraft	Helicopters	Missiles
EA-6B	AH-1S	ALCM (86B)
A-6E	CH-53E	HARPOON (84A)
A-7E	UH-60A	IMPROVED HAWK (23B)
A-10A		PHOENIX (54A)
C-9B		
C-130H		
E-2C		
F-14A		
F-15A		
F/A-18A		

ANALYSIS

The following model was run for each program:

$$P = kQ^a R^b CU^c. \tag{5.1}$$

The dependent variable, P, is the average unit price for each lot. The constant, k, is the intercept in the conventional learning curve model. The first term of this model, Q^a, will be recognized as the conventional learning curve. The independent variable, Q, is the mid-point unit number.[2] The second term, R^b, is the now-familiar Bemis alteration of the learning curve model, which includes a production rate term.[3] Following convention, we used the annual procurement quantity as a surrogate for rate. The final term, CU^c, adds our capacity utilization term. CU is defined as being for the aerospace industry as a whole.

Linear regression was used to derive parameter values for each program (from the log form of the model), and the statistically significant values were then averaged by category. The results are shown in Table 5.2:

Table 5.2 Parameter Values for Sole Source Program Cost Model

Parameters	a	b	c
Fixed Wing (R^2 = 72.8%)	-.160	-.389	-1.062
Helicopters (R^2 = 91.7%)	ns	-.293	-1.265
Missiles (R^2 = 89.8%)	-.327	-.339	-1.205

The a- and b-parameter values reported in Table 5.2 are typical. Fixed wing aircraft show a 90% learning curve (a = -.160) and missiles show 80% (a = -.327). Helicopters, with their small-quantity, short run production, display no statistically

[2]The conventional formula, ((Q + 1)/3) + 0.5, was used to determine the lot "mid-point" for the first lot. See Greer and Liao, op. cit.

[3]Op. cit.

significant learning curve parameter. The rate term (b-parameter) values found are in line with those found by Bemis.[4] The c-parameter holds greater interest.

It is clear from examining the "c" values in Table 5.2 that CU (as well as the more conventional terms) offers insight which could be useful in both cost estimation and procurement policy-making settings. That is, advance knowledge of CU would enable procurement costs to more accurately be estimated--whether the mode is sole <u>or</u> dual source.

IMPLICATION FOR SOLE SOURCE ACQUISITION

The exponent values shown in Table 5.2 indicate there is a tendency for procurement costs to <u>fall</u> as the aerospace industry CU <u>rises</u> if a procurement is conducted in a sole-source mode. (Note the <u>negative</u> exponents for the CU terms.) This tendency probably derives from the practice of allowing a contractor to spread his fixed costs over the smaller number of units produced when the market is slackens and overall corporate CU is low--thus "cost-justifying" a higher price.

There is some cause-effect similarity between price changes induced by changes in CU and changes in production rate, R, under sole source environment. In either case, fixed costs attach to different quantities of output. However, in the case of CU the quantity change is a change in <u>overall</u> corporate output (as it relates to corporate overhead). A rate change (R) <u>by</u>

[4]Op. cit.

itself causes only a change in the allocation of those fixed costs which originate in the facility (or segment) which is used for the program in question. Either of these changes can occur independently of the other, depending on what is taking place in the rest of the firm. The two will be identical only if the program of interest is the only business the firm has. However, a notable feature in Table 5.2 should be mentioned. Note that the negative exponents for c are all much steeper than those for b, indicating that a change in CU has a much more profound effect on the price than the same percentage change of R. This is probably the result of the corporate structure in the aerospace industry, i.e., the plant in charge of a specific weapon program is only a small segment of the whole firm. This observation also helps explain why CU is such a strong determinant of weapon system price, as we have discussed earlier.

Table 5.3 helps to summarize the findings thus far. Over the last 30 years CU has in fact varied over a range of 66% to 93%. The 30-year average has been 78%. The first column in Table 5.3 shows various different levels of CU over this range. The next two columns show the savings (loss) we might expect to result from dual sourcing those missile programs examined above (no generalization can be made to aircrafts as no historical dual source data can be analyzed) at those levels of CU for two different values of D_1; 68% and 85%. Note again that savings result from dual sourcing when CU is low; losses are experienced when CU is high. Much better results can be expected when D_1 = 85% than when D_1 = 68%.

Table 5.3 Predicted Savings (Loss) at Various Levels of CU (Missiles)

CU	Savings from Dual Sourcing $D_1 = 68\%$	Savings from Dual Sourcing $D_1 = 85\%$	Savings from Sole Sourcing
95%	(28.9%)	(12.9%)	21.1%
90	(22.6)	(6.6)	15.8
85	(16.3)	(0.2)	9.8
80	(9.9)	6.1	3.0
78 (average)	(7.4)	8.6	0.0
75	(3.6)	12.4	(4.8)
70	2.8	18.8	(13.9)
65	9.1	25.1	(24.6)

The final column in Table 5.3 requires elaboration. Let's conceptualize a <u>standard</u> (or "normal") sole-source price as one which could be expected at CU = 78%--the average for the last 30 years. The figures in this column show the percentage change in price we could expect if CU were to rise or fall to the indicated level. For example, an increase in CU from 78% to 85% would be expected to produce about a 10% price <u>savings</u> when we refrain from dual sourcing. If CU were to fall from 78% to 70%, we could expect the price to <u>rise</u> by about 14% if we continue the sole source mode. The entry in the CU = 78% row is, obviously, zero.

DISCUSSION

To summarize, if "standard" or "average" conditions prevail (CU = 78%), a well-managed dual-source program could be expected to produce small NFBs for the Government. But dual sourcing has an unambiguous edge over sole-source procurement when CU is very low--say 65-70%. Sole sourcing appears to be financially preferable when CU is high--particularly above about 85%.

Chapter 6

IMPLEMENTATION, RECOMMENDATIONS, AND CONCLUSIONS

Our analysis has shown that advance knowledge of aerospace industry capacity utilization (CU) can improve the Government's ability to plan for economical procurements of major weapon systems. This ability is useful in both cost estimation and procurement policy-setting. In this chapter, we will discuss the implementation of our findings and suggest future plans to further the understanding of weapon cost determinants.

IMPLEMENTATION OF FINDINGS

Price Changes and CU

The methodology developed in this paper points to ways of improving the cost-estimation process for major weapon systems. It is now possible to calculate the percentage change in price that can be expected to result from forecast changes in the state of CU once the procurement mode is known. For example, if we know a fixed-wing aircraft is to be procured sole source, and if CU is, say, 80% at the onset of procurement but is expected to decline to 70%, we could expect the price to rise above what it would otherwise be by,

$$\frac{70^{-1.062} - 80^{-1.062}}{80^{-1.062}} = 15.2\%.$$

Parameter values shown in Table 5.1 may be used to estimate sole source price changes for other categories of weapon systems.

Cost estimation under dual sourcing is more complex in that it requires advance knowledge of more of the conditions surrounding the procurement.[1] In its simplest form we may use the price prediction models developed in our earlier study.[2] For convenience, the equations are reproduced here.

For the Original Source:

With median values: $$P = kQ^{-0.278}\, CU^{1.25}\, e^{-0.201M}\, e^{-0.854N} \qquad (6.1)$$

With mean values: $$P = kQ^{-0.26}\, CU^{1.765}\, e^{-0.201M}\, e^{-0.854N} \qquad (6.2)$$

For the Second Source:

With median values: $$P = kQ^{-0.174}\, e^{-0.520N} \qquad (6.3)$$

With mean values: $$P = kQ^{-0.214}\, e^{-0.520N} \qquad (6.4)$$

"P", of course, is the average price for the buy. "k" and "Q" are the intercept and midpoint cumulative quantity found in the learning curve model. "CU" represents capacity utilization while "M" and "N" are dummy variable, with M=1 if the buy is under dual sourcing and N=1 if the competition is winner-take-all.

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[1]W. R. Greer, Jr., and S. S. Liao, "Cost Analysis for Dual Source Weapon Procurement," Naval Postgraduate School Technical Report, NPS54-83-011, October 1983. (A135351)

[2]Ibid., p. 4.9.

Our current analysis found additional evidence that the division of procurement dollars is another determinant of the magnitude of competitive savings. But the most important result is the development of a reliable CU forecasting method to allow operationalizing the concept of fitting the procurement <u>mode</u> (dual source versus sole source) to the CU conditions which are expected to prevail during the competitive phase of the procurement.

<u>Timing of Procurement and CU</u>

Tailoring the procurement <u>mode</u> to the CU conditions may be as simple a matter as better timing. We have shown that it is virtually impossible to generate any kind of savings by introducing a second source supplier when the industry capacity utilization rate is 85% or higher. On the other hand, when CU is lower than 80%, dual sourcing presents an opportunity for savings, and it should actively be considered.

<u>Quantity Split and Savings</u>

We found that the magnitude of competitive savings to be closely related to the split of procurement dollars between the two suppliers under dual sourcing. Two different factors may be involved in this relationship. First, much as the CU reflects whether there is competitive pressure in the market, the division of procurement has an impact on the degree of competitive pressure. The more of the procurement is allocated to the new source, the more creditable the competitive threat is. On the other hand, tilting the quantity split to the new source also increases the second sourcing start up cost. Therefore, diminishing returns must be reached at some point. Unfortunately, we have not been able to determine the exact shape in the relationship.

An Example

To illustrate how our findings might be implemented, let's see how they could be used to assist in the procurement planning for AIAAM.

An SAI report was couched in terms of a 60/40 or 70/30 division for the AIAAM, with full scale development beginning in FY85, original source production starting late in FY89, and the onset of competitive buys in FY94.[3] Based on our analysis, the policy planners might like to consider two alterations which could improve the financial outcome of the program.

First, it appears the plans for the division might profitably be revised toward keeping more of the procurement dollars with the original source--say to 85/15 or even 90/10. Eq. 4.6 tells us this change alone could easily make the difference between experiencing a financial loss or a gain from dual sourcing the program.

Second, the anticipated state of CU should certainly be considered in the planning process. Table 3.7 shows CU is expected

[3]Beltramo, M.N. and D.W. Jordan, "Analysis of the Cost Implications of Dual Source Competition for the AIAAM," Science Applications, Inc., 2 March 1983.

to be relatively high during FY86-FY89. These years are likely to offer conditions which favor sole sourcing. Therefore, the sole-source phase of the program, which SAI envisions starting late in FY89, might profitably be moved up (providing technological factors do not diminish the desirability of such an action). This would enable the Government to take full advantage of an industry which will be in a position to spread its fixed costs over large quantities of output.

On the other hand, excellent conditions for dual sourcing will be present after FY89. We would expect sole sourcing during this period to be relatively expensive, but that significant financial savings could be generated by using dual-source competition. SAI assumes competition would not be introduced until FY94. Policy makers might attempt to move this date up as well--to use the slack conditions to full advantage.

SAI anticipates the total cost of AIAAM to exceed $350 million (FY83$), and that, "competition for the AIAAM would be unlikely to result in overall cost savings . . ." However, we find that if the division of procurement dollars could be revised to an optimal level, and the dual-source procurement mode timed to fit the CU conditions anticipated for FY90-93 (about 73%), it would be possible to expect savings on the order of 15%. This would amount to $50,000,000.

SUGGESTIONS FOR FUTURE RESEARCH PLANS

The validity of our net financial benefit forecasting model, Eq. 4.6, is self-evident, as can be seen from Table 4.2. Such a simple model, however, is likely to be disturbing to those acquisition analysts who might argue that the effect of dual source competition is much too complicated to be reduced to a simple model. No doubt the issue of competitive savings <u>is</u> a complicated one and there <u>are</u> numerous factors which may affect the production cost of weapon systems, as mentioned in most prior studies. One should bear in mind, however, that what the Government pays is the price charged by the contractor(s), which consists of two elements: cost and profit. The plethora of government regulations on contract management, the extensive audit by DCAA, and the explicit rule on allowable profit give us an unjustified aura of the precision with which cost and profit can be measured. In reality, "true" cost is an elusive concept--one which is virtually impossible to define, let alone determine, even after the fact.

As shown in Figure 1.2, a contractor submits a bid bearing in mind the risk level acceptable to the firm to achieve a given amount of profit. A lower risk level simply means the firm's chance of making or bettering its profit goal is improved. No doubt there are many factors influencing production costs, but most if not all of these factors are elements of <u>risk</u> analysis. Changes in these factors are simply internalized by the contractor and are not individually accounted for in an accounting system. The only exception is perhaps the learning curve, which is why a learning curve term remains in our model.

In summary, an attempt to determine the "true" production cost by identifying many relevant factors is unlikely if not impossible to succeed, as we can see from prior comprehensive studies. But if one understands the risk analysis involved in a contractor's price determination decisions, then it is easily realized that the major factors we identified, CU and quantity split, actually capture most of the elements other researchers have mentioned but have been unable to quantify. Estimated costs probably have never been right on the mark. Many factors can contribute to changes in production cost. Therefore, cost estimation inevitably involves risk analysis to a certain extent. How much risk the contractor is willing to take depends on his assessment of the market environment. We found that CU is an effective measure of the market environment, albeit only as a surrogate measure. Thus, CU indirectly captures the influence of many relevant factors.

By the same token, procurement split is a variable that captures the effect of many factors. It is a variable that measures whether the second source can pose as a genuine threat to the original source. Together with CU, it reflects whether competition exists in the market. It also reflects, to some extent, how much start-up cost must be incurred to establish a second source.

In view of the fact there are only a limited number of major weapon systems that have been second sourced, we feel our approach is probably the only feasible one with which to proceed. With this in mind, we will offer suggestions for future research plans.

Quantity Split

Optimal splitting of quantity under dual source procurement has been the subject of several prior studies.[4] However, the implication of quantity split for our model is broader than in prior studies. In addition to the issue of optimal split, it also affects the decision on the production level for which the second source should be facilitized. Future studies on quantity split should consider the question of front-end investment as well as price.

It should be noted that further attempt to determine the exact shape of the curvilinear relationship between quantity split and net financial benefit will prove to be unproductive until many more data points are available. Until then, inference can only be made within the relevant range of the data.

Different Forms of Second Sourcing

A second source supplier may be introduced in several different ways: Form-fit-function (F^3), technical data package, direct licensing, leader-follower, and contractor teaming.[5] While

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[4]See, for example, J. C. Pelzer, "Proposed Allocation Technique for a Two-contractor Procurement," Master's thesis, Air Force Institute of Technology, May 1979.

[5]See B. R. Sellers, "Second Sourcing: A Way to Enhance Production Competition," National contract Management Journal, Vol. 15, Issue 1, 1981.

arguments have been advanced to support different ways of introducing a second source under different conditions, no attempt has been made to determine the financial consequence of these forms.

There are several issues involved in considering the different forms of second sourcing. First of all, different ways of introducing a second source will have different start-up costs. Furthermore, the willingness of the original source to assist the new source, and the compensation required for such assistance, conceivably may be related to the market environment. Last but not least, the effectiveness of each of these forms as a device for bringing price reduction pressure to bear on contractor must be analyzed.

The last three forms mentioned above, direct licensing, leader-follower and contractor teaming, all have a relative short history. Comprehensive quantitative study probably will not be feasible for several years. To establish the foundation for future quantitative study, an analysis of the basis in economic theory may be appropriate. Appendix B contains such a study by P. M. Carrick on competitive contractor teaming.

<u>Multi-Year Contracting and Market Environment</u>

Although multi-year contracting has been in existence for a long time, the multi-year contract as it is structured now is significantly different from the level price, multi-year option contract of the past. A significant number of major systems have been approved in recent years and an increasing number of systems have been proposed.[6]

It is apparent that economic conditions in the market is the overriding factor in a multi-year contract.[7] Multi-year contracting has a characteristics similar to winner-take-all competition in that it narrows the supply source to a single contractor. A significant number of multi-year contracts are available for analysis. It should be beneficial to the Government to analyze whether the estimated savings from such a contract are related to the market environment in the aerospace industry, and whether there is a similar pattern between winner-take-all competition and multi-year contracting.

Degree of Subcontracting and Competitive Savings

Prior work on the costs and benefits of introducing competition has not looked beyond the prime contractor level. For major weapon systems, the prime contractor is often more a system integrator than an actual manufacturer. An extensive subcontractor network is needed to support the prime contractor.

Acquisition researchers have noted that the degree of subcontracting may have an impact on potential savings when competition is introduced. Some have argued that the lack of competition for certain major components may reduce the savings potential

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[6]See Chief of Naval Material memo on "Multiyear Contracting Policy", 17 January 1983.
[7]Harvey Fromer, "Multi-year Contracting," seminar manual , Technical Marketing Society of America, March 1984.

if a second prime contractor is introduced. On the other hand, we can argue that CU reflects the economic condition of the industry as a whole, and it should not make any difference whether the procurement dollar stays with the prime or flows down to the subcontractors. With the factor of quantity split in the model, however, the picture is less clear. Further analysis of this issue is necessary in order to see whether the impact of subcontracting on competitive savings is captured in CU.

Cost Growth and Economic Environment

The widely recognized "buy-in" practice by contractors inevitably results in cost growth or in a reduction in the rate of cost decrease.[8] The relationship between the size of investment by the firm to "buy" into a development contract and the magnitude of subsequent cost growth has been neglected by acquisition researchers. For acquisition planners, a more important issue is the identification of factors that may be used to predict future cost growth. It is conceivable that the economic condition of the industry plays an important role in the "buy-in" and cost growth behavior. If this is the case, then CU may well be an effective variable for forecasting purposes.

CONCLUSIONS

Our analysis has shown that advance knowledge of the aerospace

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[8]E. Dews, G. K. Smith, A. Barbour, E. Harris, and M. Hesse, "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s," The Rand Corporation, R-2516-DR&E, October 1979.

industry's capacity utilization can improve the Government's ability to plan for economical procurements of major weapon systems. This ability is useful in both cost estimation and procurement policy-setting.

The cost savings which result from dual sourcing are a function of CU and the division of the procurement between the original supplier and the second source. As CU rises the amount of the savings declines.

The best results have been achieved when the division is such that the second source is called upon to supply no more than about 10-15% of the procurement: that is, when the division of dollars to the original source, D_1, is in a range of 85-90%. The percentage net financial benefit (NFB) from dual sourcing can be predicted with the following equation:

$$NFB = 27.38 - 1.267\ CU + .942\ D_1.$$

Historically, dual sourcing has generated positive NFBs only when CU has been below about 80%. But savings should be obtainable when CU is as high as 85% with proper control of D_1.

When procurements are conducted under sole sourcing the direction of the impact of CU movement on prices is just the opposite. A parametric pricing model for missiles which includes a CU term in addition to the conventional quantity (Q) and production rate (R) terms was derived:

$$P = k\ Q^{-.327}\ R^{-.339}\ CU^{-1.205}$$

This model should enable the use of CU forecasts to assist in the refinement of cost estimates when a procurement is to be conducted using sole sourcing.

Finally, we turned to the task of building a model for projecting aerospace industry CU as a function of the recent state of capacity utilization and expected changes in output. The model is:

$$\text{Delta}(\text{CAP}_{t+1}) = -26.89+0.367[(\text{CU}_{t-1}+\text{CU}_t)/2]+0.217\text{Delta}(\text{OUTPUT}_{t+1})$$

This is a dynamic model which expresses the percentage change in capacity (CAP) for the next FY (t+1) as a function of the present and recent past state of CU and the percentage change in output (OUT) expected for next year. This model proves to be a reliable, accurate forecasting model.

Actual forecasts for the aerospace industry's CU for the next decade were given in Table 3.7. The two columns contain forecasts based on output change projections for (1) DoD procurements (source, EIA), and (2) total output (Value Line projections through 1988, then EIA).

Based on the forecasts shown in Table 3.7, it appears that conditions will be relatively favorable for dual sourcing during most of the next decade. However, there will be a brief period during the mid-to-late eighties during which especially alert management of the procurement process will be necessary if net financial benefits are to be expected.

APPENDIX A

ADDITIONAL DUAL-SOURCE COMPETITION DATA

The seven programs examined in our studies represent 87 buys, of which 39 were awarded competitively. However, the limited number of programs available for empirical study obviously led some people to have doubts about the precision and reliability of the dual-source savings models. In this section, we examine additional programs for suitability for inclusion in future studies dealing with dual-source competition.

OVERVIEW OF POTENTIAL PROGRAMS

There are approximately 30 competitively procured systems that were studied in the 1970's. However, the majority of these systems were low complexity items competed under open advertising or did not in fact end up in a competitive environment. A short discussion of a few typical examples will show why most of these programs are unsuitable for further study.[1]

FAAR

The Forward Area Alerting Radar System (FAAR) was developed by Sanders Associates, Inc. The developer was awarded the sole source production contract until an open competition was held.

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[1]For program histories and cost data see E. T. Lovett and M. G. Norton, "Determining and Forecasting Savings from Competing Previously Sole Source/Noncompetitive Contracts," Army Procurement Research Office, APRO 709-3, October 1978.

At that time offers were received from four bidders and the Sperry Rand Corporation was awarded the contract. One can easily see that this was not a typical dual source competition.

AN/PRC-77 Radio Set

This system has a long and complicated production history. RCA Corporation, the developer, was awarded two sole source production contracts. An invitation for bids resulted in Electrospace Corporation receiving the next contract, which was multi-year. Lengthy delays in delivery resulted in an additional contract to Hamilton Watch Company two years later. Hamilton, however, failed to deliver a single item. E-Systems, Inc., was substituted as the contractor. Subsequent contracts were no less complicated and a complete run-down of the history is unnecessary. Suffice it to say that no dual source competition environment has ever existed during the long history of the program.

AN/ARC-131 Radio Set

Magnavox developed the system at their own expense and was awarded three sole-source production contracts. DEI Industries won the next contract on a competitive bid, but failed to deliver a single item. The default dictated a return to sole source procurement with Magnavox. Therefore, no actual competition ever took place.

AN/UPM-98 Radar Test Set

This system has a production history somewhat similar to that of the AN/ARC-131 Radio Set. Admiral Corporation, the developer, was awarded the first production contract on a sole source basis. A second contractor won the next contract on a competitive bid, but failed to deliver any item. A third contractor won the next contract, but again failed to deliver. The last contract was awarded competitively to the original developer.

PP-4763/GRC Power Supply

The production history, again, was virtually identical to that of the AN/ARC-131 Radio Set. Christie Corporation was awarded the first production contract on a sole source basis. DEI Industries won the next contract on a competitive bid but failed to deliver a single item. A third contractor was awarded the next contract under invitation for bid, again there was a failure to deliver a single item. Urgent requirements necessitated a return to sole source procurement from Christie.

Summary Remarks

The programs discussed above are just a few examples of failed attempts to develop a second source. Undoubtedly there must be an unknown amount of investment associated with each failed attempt. These investments are similar in nature to the cost of hitting a "dry hole" in the oil drilling industry. Although the odds of successful attempt are probably better in second sourcing decisions, the costs of "dry holes" are nevertheless unavoidable and must be spread among the successful ones. From the standpoint of acquisition policy, most studies have probably overstated the benefit of competition in major systems acquisition for failing to consider these costs.

SUITABLE ADDITIONAL PROGRAMS

We were however, able to identify several additional programs that do appear to be suitable for inclusion in future studies of dual source competition procurement. A validation check was performed for each of the additional programs. None of result would contradicts our basic conclusion that the aerospace industry capacity utilization (CU) is a strong determinant of dual-source competition savings.

Walleye Missiles

While not strictly an example of dual sourcing (there was never a period during which actual competitive split buys were conducted),[2] the Walleye Missile does tend to confirm the reliability of Eq. 4.6. Disregard the small quantity of Walleyes produced by NAFI. Treat Martin (the second producer) as the "original source" and Hughes as the "second source." There was a "transition" during, FY67-68. Treat this as "competition."

CU was 91.2% during the transition; D_1 was 84.8%. Eq. 4.6 predicts NFB = (8.3%). Tecolote places the actual NFB for the program at (21.4%).[3] The unusually large loss is probably attri-

[2] A report by A.J. Kluge and R.R. Liebermann, "Analysis of Competitive Procurements," TM-93, Tecolote Research, Inc., August 1978, was the source of our information on this program. In their comments the authors note that, "some suggest that it [the Walleye I] was not a competitive award [program] in the normal sense."

[3] Ibid., p.2.

butable to the brevity of the "competition," or the lack of it, as some observers have suggested. Table A.1 presents the cost summary.

Table A.1 Walleye Missile Cost Summary

FY	Contractor	Quantity	Unit Price (FY72 $)
64	NAFI	30	51,597
65	NAFI	134	44,194
66	Martin	50	28,814
66	Martin	766	15,872
66	Martin	1,413	9,073
67	Martin	6,000	7,000
68	Hughes	20	24,830
69	Hughes	57	21,246
70	Hughes	148	20,789
70	Hughes	159	22,942
71	Hughes	561	22,035

Dragon Missile

McDonnell Douglas, the system developer, was awarded the first production contract on a sole source basis. The system was then divided into two parts for separate competitions. Raytheon was selected as the second source for Dragon Round and was awarded an education buy in FY72. Kollsman Instrument was the second source for Dragon Tracker and was awarded a small educational quantity in FY73. 60/40 split competition was conducted in FY75 (with option for FY76) and McDonnell won both competitions.

However, both second sources won the subsequent buy-out competitions in FY7T and FY77.

Part of our data for Dragon Missile is from classified sources, therefore, no cost summary will be provided here. CU for FY75-77 averages 72.43%. D_1 is 48.8% for Dragon round and 44.2% for tracker. Eq. 4.6 predicts net losses from dual sourcing to be (18.4%) for the round and (22.73%) for the tracker. The Army researchers estimated that dual sourcing resulted in a 2.7% savings (assuming 85% learning curve) for the round and 12% savings (assuming 85% curve) or (8.5%) losses (assuming 83% curve). However, examining the original data would show that Eq. 4.6 estimates should be closer to reality. The Army researchers used the first 0.5% of the procurement quantity to estimate what the remaining 99.5% of quantity would have cost under sole source. In reality, well over 10% of total quantity was procured during the sole source phase, and the learning curve for the 14 lots of round and 4 lots of tracker clearly reflect an 80% curve for the round and better than 80% curve for the tracker. If one revises the assumed learning curves to reflect the actual contract prices, Eq. 4.6 estimates would have been very close to the mark.

Standard Missile

The Standard Missile is not exactly suitable for inclusion in a dual source study because no dual source characteristics are present in the program. General Dynamics developed the system and was was awarded a sole source contract. GD subsequently won a competitive buy contract and also supplied the system on an option contract. Therefore, the system was never actually produced by anyone other than GD. Since the data were relatively clean and the program did have one actual competitive contract, relevant data are shown here to facilitate future research.

Table A.2 Standard Missile Cost Summary

FY	Contract Type	Quantity	Unit Price (FY72 $)
65	Directed buy	100	173,439
67	Directed buy	860	75,230
67	Competitive	1,087	63,522
67	Add-on	900	53,559
67	Add-on	900	50,652
67	Add-on	479	46,481
67	Add-on	900	46,290
67	Add-on	701	32,205

Note that the Eq. 4.6 estimation model would not be appropriate for the Standard Missile because D_1 is 100%, and lies outside the relevant range. As discussed in Chapter 4, we could not confidently determine the exact shape of the curvilinear relationship between NFB and D_1. Using Eq. 4.6 to estimate Standard Missile's competitive savings would have overstated the amount. (CU = 92.7%, D_1 = 100%, NFB = 4.1%; Tecolote places the actual NFB for the program at -3.9%)[4]

[4]Ibid, p. 14.

Sidewinder AIM-9B

Table A.3 shows the quantities and prices of Sidewinder AIM-9B for the two contractors. Although the production history is long, there were only two competitive buys, probably because Philco-Ford was involved in the development of 9D/G configuration, which left General Electric as the sole producer of the 9B for several years.

Table A.3 Sidewinder AIM-9B Cost Summary

(FY72 Dollars)

	Philco-Ford		General Electric	
FY	Quantity	Unit Price	Quantity	Unit Price
55	272	12,158	-	-
56	3,267	5,168	200	5,555
57	5,720	4,172	7,500	3,966
58	9,532	2,448	3,585	2,884
59	-	-	3,600	2,488
	-	-	2,302	2,111
60	-	-	4,407	1,831
61	-	-	5,256	1,474
62	-	-	8,988	1,652
	-	-	4,200	1,591
63	5,806	1,413	-	-
	1,264	1,360	-	-
64	-	-	1,155	1,220

CU averages 79.9% during the split-buy periods and D_1 was

45.2%. Eq. 4.6 predicts NFB = -31.3%. Tecolote places the actual NFB for the program at -4.1%.[5]

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[5] Ibid., p. 36.

APPENDIX B

ASSESSMENT OF THE ASPJ COMPETITIVE CONTRACTOR TEAMING ACQUISITION STRATEGY

by

Paul M. Carrick

SUMMARY

The Airborne Self-Protection Jammer (ASPJ) is a half-million dollar electronic countermeasures (ECM) package that will be installed on the F-16, F-18, A-6, AV-8B, F-14, and F-111 aircrafts. Its purpose is to counter enemy missiles' terminal guidance by either deception or noise jamming. The ASPJ program was initiated in 1975. A distinctive acquisition strategy, competitive contractor teaming, was adopted with the award of concept definition contracts to three industrial teams in 1979. An $81 million full-scale development FPI contract was awarded to the Westinghouse-ITT team in late 1981. Delivery of the first production article is still scheduled for 1986, even though a significant over-run and schedule revision has had to be made.

This paper considers two questions: Does the acquisition strategy fit the product? Secondly, is the acquisition strategy an efficient one? It is concluded that the competitive contractor teaming acquisition strategy is not consonant with the technical characteristics of the product and that it is inefficient to maintain two contractors through the production phase. Moreover, significant savings may be attainable by having a buy-out competition for the entire production run.

The discussion will begin with a history of the ASPJ acquisition program. This will be relatively brief since an extensive history of the reasons for the choice of the ASPJ acquisition strategy already exists.[1] There are also ample summaries of the program's history in the trade press.[2]

THE ASPJ ACQUISITION STRATEGY

The standard DoD acquisition plan is structured around the review milestones called for in DoDD5000.1 and DoDD5000.2. The early phases consist of an initial concept definition phase followed by advanced development. These phases are usually conducted at very low cost to DoD, although the decisions made at this time can result in the commitment of billions of future expenditures. They are followed by full-scale development and, finally, a production phase. Both of these phases, and especially the latter, are usually quite costly.

The standard DoD acquisition strategy is to encourage extensive competition in the early program phases and to then rapidly narrow down the number of competitors for full-scale development and production to a single firm. A second source may be brought in subsequently in the production phase but this is not typical. Defense contractors respond to this buying strategy by forming

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[1]J. Ruppert and S. Starrett, "An Evaluation of the Competitive Contractor Teaming Strategy," Master's thesis, Naval Postgraduate School, december 1983.

[2]Electronic News, November 2, 1981; Defense Electronics, November 1983; and January 1984; Jane's Weapon Systems, 1983-84, Janes Publishing Co., 1984; Aviation Week, April 2, 1984; Armed Forces International, March 1984, p. 52.

teams of independent contractors. The capability of each team's members are complementary in nature so that the teams' strengths must be assessed collectively. A team's members expect to be participants throughout the rest of the acquisition process. For example, the USAF has recently initiated a concept definition competition for a next generation tactical fighter aircraft ECM system, the Integrated Electronic Warfare System (INEWS). Six teams have entered bids. Three teams will be selected for the advanced development phase. Only one team will be selected for the later phases.[3]

The ASPJ program had its origin in the early 70's. Both the Air Force and the Navy had been encouraging the development of radar warning receivers and radar and IR jamming equipment for their aircraft. The ASPJ is not the first, but is the most advanced, ECM equipment to integrate the radar warning receiver and the jamming equipment into a single unit. Similar ECM equipment is produced by the Loral Corporation and Sanders Associates, Inc.

In 1975 OSD directed the Navy and Air Force to combine their tactical fighter ECM development programs. A joint service program office was established in 1977 with lead responsibility given to the Navy. The program office formulated a distinctive acquisition strategy: the use of competitive (as opposed to complementary) contractor teams. Each member of a team was

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[3] Armed Forces International, March 1984, p. 52; Aviation Week, April 16, 1984, p. 120.

to be capable of coordinating the design and producing the ASPJ.[4] By february 1979 three teams were selected for an abbreviated concept definition competition. The three teams consisted of Westinghouse/ITT; Sanders Associates/Northrup; and Loral/Eaton-AIL. In August 1979 the first two teams were selected to compete further in the advanced development phase. A winning team was selected in August 1981 when a full-scale development contract was awarded to the Westinghouse/ITT team.

ITT and Westinghouse took a legal step of forming a joint venture contract. A building was set aside at ITT's Nutley, New Jersey, facility for the use of the two contractors' ASPJ design team. The two design groups arrived at a rough initial allocation of the total design effort after first mutually laying out the design goals for important system performance parameters. Essentially, each company assumed sole responsibility for a receiver and transmitter and shared the design of a common central processor. Some reallocations of design responsibilities were made subsequently.[5]

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[4]One reason given for the adoption of this acquisition strategy was that excess capacity existed among ECM suppliers. To be sure, it is desirable for the government as the sole buyer of a specialized service to stabilize its purchases and not induce excessive perturbations in suppliers' employment and facility utilization, modernization and expansion. But by hindsignt, at least, this was a poor reason for adoption of the acquisition strategy. The ECM business area has been expanding at an 43% annual rate since 1975 (<u>Aviation Week</u>, March 12, 1984, p. 215). It is difficult to believe that sufficient industrial capacity currently exists to handle efficiently such a large expansion of demand.

[5]The companies' allocation of design responsibilities is discussed in <u>Aviation Week</u>, April 2, 1984.

One of the major constraints on the ASPJ design has been to comply with the form and the 2.3 feet space constraints imposed by the internal rack space allotted on the F-18 aircraft. The F-18, in common with the F-16, had space allotted for ECM equipment based upon the requirements of the AN/ALQ-126 ECM equipment designed by Sanders Associates. The team's initial design did not satisfy this constraint. Although the achieved space and form configuration exceeded the required value by less than 3%, this resulted in excessive heat built-up and power requirement, necessitating a redesign and repackaging effort. The effect has been to delay completion of full-scale development and cause a contract over-run. Instead of an $80 million FSD effort it is now an estimated $138 million. Because the contractor team agreed to a fixed price incentive (FPI) contract for performance of the FSD, the contractors will receive a "negative fee", i.e., they will invest company funds of around $18 million.

By means of a reduction in the number of contractually deliverable prototypes and an abbreviation of the test program, schedule slippage has been minimized. The initial design-to-unit production cost (DTUPC) target remains at $400,000 per unit (in '79 dollars). Surprisingly, the DTUPC has not been reported to be a significant constraint on the ASPJ's design. The DTUPC for the ECM equipment for the B1-B bomber is $20 million.[6]

DOES THE ACQUISITION STRATEGY FIT THE PROJECT?

The unique feature of the ASPJ's acquisition strategy is

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[6]Aviation week, March 12, 1984, p. 215.

the use of competitive contractor teaming. The additional cost, if any, of supporting a cooperative full-scale development effort by ITT and Westinghouse has been incurred by DoD to assure the existence of two qualified producers at the time of the initial production order. This is in sharp contrast to any alternative strategy for assuring a second production source. Compared to a leader-follower or competition via technical data package, competitive contractor teaming eliminates reliance upon a sole production source for about a three-year period -- the time needed from the initiation of a sole source's production to complete operational testing, validate a technical data package (or train a second source's personnel), select and facilitate the second source and qualify its output.

Other things being equal, competitive contractor teaming seems to constitute the superior method of introducing a second source. A qualified second source is available for the entire production run, avoiding about three years of sole source production, for what must be a comparatively nominal cost of supporting two design production planning groups during full scale development. However, in the case of the ASPJ, one of the alternative methods for introducing a second source would have been preferable. In fact, the ASPJ acquisition should probably have been conducted as a sole source program. The reasons for these conclusions have to do with the technical characteristics of an airborne ECM system. In essence, it will be argued that competitive contractor teaming is a superior acquisition strategy, but for some more technically stable product.

It is desirable to first recall some of the elementary technical considerations involved in designing an airborne ECM system. Since an airborne ECM system is designed to interfere with the terminal guidance of an enemy's missiles, it is necessary to first consider how a missile is guided to a target. It is apparent, though often overlooked, that all modern anti-aircraft or anti-missile systems utilize the search and tracking capabilities of radar. This has heavily influenced the design of virtually all pertinent weapon systems. Target location information acquired by radar is a necessary component for any target destruct system that is intended to intercept the target at a range longer than 1 miles. Target tracking is very much enhanced if the tracking radar during the terminal phase of flight operates at very high frequencies. But high frequency radars are intrinsically restricted to short ranges. The development of infra-red imaging passive receptors and very high frequency radars, plus the micro-mini-aturarization of electronic circuitry have allowed designers to incorporate two or more guidance systems into a missile. The missile is quided from its launch point by a command guidance radar located at the launch point. Then at some point in the missile's trajectory, guidance is handed-off to a self-contained terminal guidance system aboard the missile.

A good example of how a missile may be guided to a target is the guidance doctrine for the new advanced medium range air-to-air missile (AMRAAM), the AIR-120.[7] It will replace the

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[7]The information regarding the AMRAAM was obtained from <u>NATO's 16 Nations</u>, 28, December 1983-January 1984, pp. 68-70.

Sparrow missile, in use by both the Air Force and the Navy. First, the aircraft radar detects a target. An on-board computer calculates a minimum energy intercept missile flight trajectory. This is translated into flight instructions and fed into the missile's computer memory. After launch, the missile's flight path is controlled by its guidance package. However, the aircraft's pilot can update the target's coordinates via a data link with the missile. In other words, the aircraft need not continue to illuminate the target with its radar after launching the missile. At some point in the missile's flight path there is a shift over to the missile's guidance system. A so-called semi-active radar aboard the missile provides the necessary information for the terminal guidance to the target. A number of choices are possible at this point. The missile's radar seeker can use either a high pulse repetition frequency or a medium pulse repetition rate. The missile may also turn off its radar and home on a jamming radar signal from the target. The missile can also be launched from an aircraft by visual information only. In total, there are some 27 operating modes available from which the pilot may select.

The AIRM-120's radar, in common with most tracking radars, can operate over a fairly wide range of frequencies, at different power levels and may use differing pulse frequencies and pulse widths. An airborne radar will use both pulse and doppler signals so the resulting wave form may be exceedingly complex. For example, the missile may use a monopulse semi-active radar seeker with a digital signal processor, as is the case with the newest

Sparrow missile (AIM/RIM-7M).8

The point of this very brief discourse on missile guidance and the role of varying radar transmission frequencies is to pose the problem that an ECM designer confronts. Given some appreciation of these complexities it is then possible to establish bounds on the manner in which the enemy chooses to employ radar in locating an airborne target and establishing and maintaining a target intercept trajectory. The ECM designer has a large number of options open to him, none of which can be a perfect counter or can be used in isolation. The ease with which a search radar acquires information can be reduced by mechanically reducing the reflectivity of the target. The designer can attempt to mask the target by emitting sufficiently powerful electromagnetic energy from the vicinity of the target to obliterate a reflected signal. But such noise jamming requires a source of sufficient power plus a transmitter and waveguide that will have to be comparatively large to be capable of jamming most enemy radar equipments. Alternatively, the designer may choose to resort to deception jamming; upon discovering that an enemy radar is illuminating the aircraft, the character of the transmission is determined and the reflected signal is modified by transmitting a distorted wave form. But this requires a very sensitive receiver, a means of identifying the location and type of radar transmitter as well as the wave form and signal coding system, a means of computing the efficient means of distorting the reflected signal

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[8]This information is contained in a Raytheon advertisement in Armed Forces International, March 1984, p. 20.

and, of course, a transmitter capable of emitting the required wave form.

There obviously exists quite complex interdependencies between a radar system's design and an ECM system's design. From the radar designer's standpoint, he should want to choose the radar's carrier frequencies and signal forms so as to reduce vulnerability to ECM. But the ECM designer, given enough information about an opponent's radar and missile guidance doctrine, should be able to design an ECM system that can substantially reduce an elaborate system of coding pulses, so that he can detect and reject deception jamming attempts. The ECM designer must develop sufficiently elaborate computer software to discover the coding system.[9]

Several conclusions can be drawn from this discussion. First, since the ECM equipment requires an appreciation of the design of the opponent's radar, the same kind of technical skills are required for both equipments. a company might specialize in designing and manufacturing only ECM equipment but it probably would not be fully utilizing the capabilities of its skilled engineers to do so. The same kinds of technical skills are required to design a radar's components. Thus, the more viable competitors for ECM systems should also be in the business of designing and manufacturing radars. This inference is consistent with the business practices of Westinghouse, Hughes Aircraft,

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[9]The technical possibilities that the two designers face are more complicated than stated. Two excellent sources of pertinent information are: Robert J. Schlesinger, Principles of Electronic Warfare, Peninsula Publishers, 1961; J. A. Boyd, et al., Electronic Countermeasures, University of MIchigan, 1961.

ITT, and Raytheon. However, the inference is not consistent, for example, with the business base of the Loral Corporation, for which 90% of its business is ECM systems or components,[10] or Sanders Associates, which also specializes predominantly in ECM systems. Of course, there are companies that design and manufacture radars that are not active participants in the ECM military market. These companies include General Electric, RCA, Bell Labs, and Ford Aerospace.

The important point is that the size of the industry for supplying ECM equipment is as large as the number of suppliers of radars. Engineering talent should be able to move from a radar design to an ECM design quite easily. In fact, this is precisely the assumption underlying the engineering organization of both Westinghouse and ITT. Both companies maintain a matrix organization in which engineers specialize by component - receivers, transmitters, traveling wave tubes, etc. Personnel are drawn from each group for whatever business happens to be in-house. This points out the significance of a multi-product business base, or the economies of scope, in defining the relevant members of an industry.[11]

A second conclusion from the technical considerations is that an ECM design should never be considered finished. On the one hand, ECM receivers and transmitters must necessarily

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[10] Ecectronic News, January 30, 1984.

[11] The economies of scope is a term that has recently been coined to explain the economic basis for multi-product firms. See W. J. Baumol, J. Panzar and R. Willig, Contestable Market and the Theory of Industry Structure, Harcourt Brace Jovanovich, Inc., 1982, pp. 248-56.

be extraordinarily sensitive over a wide frequency range. The received signal must be processed for identification and then followed by the selection of a correct response to be transmitted, i.e., a deception or jamming transmission. But once the designer of the radar knows his systems is vulnerable to jamming he can make a number of possible fixes. For example, he can change the signal coding system without excessive component redesign. But this means that the ECM signal processor will have to be programmed to recognize a different coding system. Thus, at least some of the original ECM equipment designers should be retained over the operating life of the ECM system for possible redesign contingencies. Of course, it is to be expected that a radar designer will not wait for the ECM designers to catch up, but will develop a reservoir of anti-ECM design modifications for future use.[12]

The ECM equipment designer confronts much more severe technical demands than does the typical radar designer. Space and power restrictions may negate an effective solution. The ECM receiver's performance must be much more sensitive and cover a much wider frequency range than a radar receiver. The ECM transmitter must be tunable to an assortment of wave forms while a radar transmitter can be designed for single operating mode. The ECM equipment requires far greater computational capability

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[12]For a portrayal of just how effective ECM strategies can be, see "Syrian-Israeli C3I: The Wests' Third Front?", Armed Forces International, March 1984. The author also makes the point that the Israeli's disclosure of their ECM capability has induced changes to all Warsaw Pact radars, thus forcing the United States to develop a new generation of ECM tactics.

and programmable memory than a radar must have. As with any equipment that reflects such severe technical demands many components or assemblies will have to incorporate unproven state of the art advances. As in designing calibration equipment for use with test equipments, measurement accuracy requirements dictate the use of equipment that will function acceptably only in the controlled conditions of a test laboratory and will perform poorly in the field until they have undergone extensive redesign.[13]

Two inferences can be drawn from these technical considerations. First, an initial ECM design may work acceptably and even pass its operational tests, but the equipment will require a long sequence of engineering changes and modifications as field experience accrues. It is to be expected that production will be subjected to frequent interruptions and costly retrofits, especially during the first few years. But even if the equipment performs reliably in the field, performance deficiencies or technical improvements developed elsewhere will impose demands for periodic redesign and modifications. This means that a permanent continuous relationship must be established with the equipment's original design team.

Thus, dual sourcing for the production of ECM equipment appear to present some cumbersome management problems. Engineering change proposals and orders will very likely be at a high level. Field reliability, equipment servicing and availability will probable pose severe problems, at least during the first few

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[13]A good example of this extreme measuring accuracy is the Bragg Cell device for determining the frequency of received signals, which is under development by the Teledyne-Mec company. See the Teledyne Annual Report for 1983 for a lucid discussion of the design and fabrication difficulties.

years the ASPJ is operational. It will be difficult to define a configuration on which the two firms can compete effectively. It is likely there will be an acute contractor incentive problem resented by ECPs. It is desirable to encourage redesign and circuit or component modifications as operational experience with the ASPJ is gained. If the two suppliers are in competition it will be difficult to coordinate their engineering efforts, not to mention the issues of resolving conflicting redesign solutions or establishing and pricing out a common configuration which the competitors will then produce.

To be sure, all weapon systems undergo extensive design changes as a result of production and field experience. These continue for an extraordinarily long time. For example, the writer found in an earlier study that even in the 18th year of production of the Army's M113 (Armored Personnel carrier, built by FMC Corporation), there were still 15 ECPs scheduled for adoption in that year. Competition is most appropriate when the product can be procured by form-fit-function performance specifications. Then, the competing suppliers' product can be allowed to differ physically and become another attribute of the competition. It is very unlikely that ECPs for the ASPJ cab ever be handled so cavalierly.

IS A COMPETITIVE CONTRACTOR TEAMING ACQUISITION STRATEGY EFFICIENT?

The argument to be developed in this section is independent of the concerns in the previous section. for purposes of discussion, it will be assumed that any acquisition strategy is appropriate for the procurement of any product. This section will compare the efficiency obtainable from a competitive contractor teaming acquisition strategy to that obtainable from more traditional practices. It will be shown that not only is the traditional sole production source acquisition strategy just as efficient, conceptually, as the competitive contractor teaming strategy but it may usually be more efficient.

What is the traditional acquisition strategy? It can be defined by a process of elimination. There are countlessly some major defense acquisition programs that have been sole sourced from their conception. The aircraft projects at Lockheed's "Skunk Works" probably fall into this category. Then again, there are some in-house product developments, such as the Army's M198 155mm howitzer, which are conceived, designed and produced entirely in-house: There are also numerous alleged cases where it is believed that a competition is "wired" for a specific firm, so that the routine of soliciting competitive bids is only a formality. Of course, every defense supplier endeavors, or should at lest establish this kind of relationship with the defense buying agency.[14] But all these instances of defense acquisition strategies are the exception. The preponderance of acquisition involve the use of competitive procurement at least once in a program's history. Competition may only be used at the Concept definition phase. More frequently, competition is also used at the advanced development phase with all subsequent

[14]Instructions on how to achieve this goal are developed at length in Jack W. Robertson, Selling to the Federal Government, Electronic News Publishers, 1978.

procurement sole source. In fact, reliance upon competition only at an early phase or phases, of an acquisition program can be regarded as the traditional method of defense acquisition.

A good illustration of the traditional defense acquisition strategy is the air force's acquisition of AMRAAM. The concept definition phase of the AMRAAM program dates from 1977, but probably could be pushed back to the decision to not continue to update the Sparrow missile and design an entirely new missile. In any case, in early 1979 two contractors, Hughes Aircraft and Raytheon, were selected for advanced development contracts from among five contestants. In december 1981, Hughes was announced the winner of the competition, after a competitive shoot-out of the two companies prototypes. Hughes was awarded a $421 million FPI contract for a 50-month full-scale development effort. Further, as part of its bid, Hughes also had to enter FPI contracts for the first two production options. Lot I is for the production of 204 missiles at a target price of $212 million. Lot II is for 720 missiles at a target price of $408 million.[15]

It is to be expected that the Air Force obtained a very competitive price for the full-scale development and production contracts. The companies bids were solicited competitively and the buyer controlled the terms and flows of information to the bidders. In the absence of collusion between the bidders or an excessively restrictive bid solicitation, each firm had to be motivated to reveal the least amount of money it would

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[15]The details of the AMRAAM competition are given in <u>NATO's 16 Nations</u>, December 1983-january 1984, pp. 68-70.

be willing to accept rather than lose the business opportunity. It is unlikely that Hughes Aircraft will realize any significant profit until after the company negotiates later sole source production lots. Of course, even the opportunities for a large profit at that time are relatively well eliminated by the "Truth in Negotiations" clauses in the Defense Acquisition Regulations. Raytheon has already been named as a second production source, although the date and the means of coordinating the company's entry into production have not been announced as yet.

It should be emphasized that during the course of the advanced development competition, Hughes and Raytheon are reported to have, collectively, spent over $100 million of company funds.[16] This is over and above the amounts awarded the companies under Air force contracts. Thus, the winning contractor will not have an opportunity to possibly profit from his sole source production status until after 1988. some 13 years will have elapsed from the time Hughes Aircraft initially committed company resources to the AMRAAM program until it is able to exercise its sole source position.

It is altogether likely that Hughes Aircraft, as well as the losing firm, consciously underbid the FSD and first two production contracts as a means of remaining competitive. A quite recent, and non-DoD, example of this practice is the acknowledged buy-in by the Hazeltine Corporation of a Federal Aviation Agency contract for development and production of a

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[16]The dollar amoung is mentioned in various issues of <u>Aviation Week</u> during the Fall and Winter of 1981.

microwave landing system. The company's management has publicly stated that the contract which covers production for a five-year period starting in 1985, was bid at a loss of over $1.25 per share of company stock to attain a preferential market position for future business.[17]

The ASPJ program's acquisition structure encouraged similar behavior: the Westinghouse/ITT team consciously bid the ASPJ FSD contract at a price too low to cover their expected costs. In addition, the companies management decided to enhance their probability of winning the FSD contract by offering a cost-sharing arrangement as part of the basic FPI contract. The two companies has already made a significant investment of company funds during the advanced development competitive phase.[18] Since the value of the ASPJ production will probably be in excess of $2 billion, it can be surmised that both Westinghouse and ITT have already invested between $50 million and $100 million of company funds on enhancement of the ASPJ development effort. Both companies must still make an investment in production facilities before any profits from the ASPJ program will be realized.

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[17]Wall Street Journal, January 16, 1984.

[18]The contractor representative were reluctant to mention any specific dollar investment figure for the companies' subsidy to the competition. It was acknowledged that such an investment decision was made by company management before the start of the competition. Further, it was pointed out that such an investment was an expected practice among today's defense contractors. In other design competitions the writer has investigated, the competitors have invested company funds ranging from 5% to 10% of the contract value. These investments are over and above a company's Independent Research and Development or Proposal and Bidding expenditures, which are reimburseable, up to some maximum authorized amount, as part of indirect costs on other defense contracts.

In summary, the competitive contractor teaming feature in the ASPJ acquisition strategy has induced the same kind of contractor behavior that the more traditional sole source contract award strategy encourages. Because of the way the competitions are structured, bidders are given a modest sum of money to prepare a proposal, i.e., a prototype, etc., for which the winning bidder can expect to receive a long term profitable production commitment. Under such circumstances a contractor would be short-sighted if he did not attempt to enhance his chances of winning by investing additional company funds. Indeed, it is common knowledge that the government is able to underfund its Advanced Development activities. Companies are expected to invest their own funds if they wish to be viable competitors. Given the FPI or FFP nature of the production contracts that have been awarded on many defense competitions, defense contractors are said to be required to "bet their money" as a condition of winning. One knowledgeable observer has compared the outcome of the traditional defense acquisition strategy to the game of "liars dice."[19]

An important deduction can be made concerning the efficiency of the traditional defense acquisition strategy. Namely, so long as competition is used at least once in the early phases of a program then the winning contractor's profits on the entire program will not exceed the rate of return that is normal for a competitive industry.

Why does this hold? So long as each bidder realizes that

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[19]W. A. LaBerge. "Defense Acquisition: A Game of Liar's Dice?" Concepts, 5. Winter 1982, pp. 56-63.

his probability of winning is directly related to the magnitude of the investment he makes in preparing his bid, then he will invest an amount such that the present value of the future stream of profits he may win, weighted by his probability of winning, is just equal to economy's competitive rate of return, i.e., his alternative opportunity cost. It is assumed the future profit stream is discounted at the market interest rate., i.e., the bidder can borrow funds to invest at this rate and his profit maximization requires that the marginal expected return from his investment is just equal to the maximum rate he can earn elsewhere in the economy. The discounted profits must be weighted by this probability of winning; if he plays the game a number of times, then his expected profit on the aggregate of all his investments will just be equal to the competitive rate of return.[20]

The deduction can be stated another way: An acquisition strategy that uses competition at any point previous to the award of a sole source contract will obtain a supply of output for the total program that yields the supplier a rate of return that will be equal to the competitive rate of return in the economy. It is commonly believed that once a defense contractor is able to maneuver himself into a sole source position he is able to fully exploit his monopoly position. But the government

[20]Risk averse behavior introduces only the complication that the perceived rate of return on his investment must exceed the competitive rate of return. It must also be assumed that the duration of a competition is sufficient to permit the competitors time to plan and implement the commitment of company resources. Prototype competitions with "shoot-outs" are illustrative. When the duration of a competition is excessively brief, it is usually believed that the contract is "wired" for a favored bidder.

is the sole buyer, i.e., a monosony, and is able to control the contractor's pricing methods, his accounting system and the information he must furnish to support a bid.[21]

In light of the frequent and sever criticism of defense contractors and of the traditional defense acquisition strategy, this conclusion is quite difficult to accept. Note that it implies that the use of competitive contractor teaming should not yield a superior outcome. The two contractors will still make, jointly, investments that yield only the competitive rate of return. Nothing appears to be gained by carrying two firms through development to compete for a share of production.

The conclusion does not mean that a defense contractor might not make an excessively high return on his production contracts. But the conclusion does mean that the contractor will have spent the excess profit earlier in the program as an investment in the activities that were necessary for him to win the competitive phase. In other words, the effect of introducing competition in the early phases of an acquisition strategy is to redistribute a competitive profit within the total program's duration. It is wrong to judge the profitability of a contractor's efforts

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[21]The workability of DoD's forward pricing system, which has evolved over forty years as a means to reduce transaction costs and constrain contractors' ability to exploit a sole source bargaining position, has never been investigated. It is rather surprising to see the vast amount of research that has been done on public utility price determination, or administrative price determination by the ICC, CAB or DOE when not a single study of DoD pricing practices has been published. For the efficiency of non-DoD price determination practices see B. M. Mitchell and P. R. Kleindorfer, eds., Regulated Industries and Public Enterprice, Lexington Books, 1980; and G. Fromm, ed., Studies in Public Regulation, MIT Press, 1981.

by just looking at the return on his production contracts. One must take the viewpoint of the entire program's duration and ascertain what investments were made by the contractor early in the program. The usual accounting practices followed by defense contractors work against adoption of this point of view since many investment-type expenditures are treated as expenses in the year they are made, instead of being capitalized. Also, a large part of a contractor's facility investment is accomplished via leasing, which is only imperfectly reflected on the contractor's balance sheet.

The conclusion may appear at variance with common observations of the course of progress on defense programs. Many, not all, defense programs have excessive cost over-runs and schedule slippages, especially early in the production phase. The SAR system of contract performance reporting was established at the direction of Congress just because of the ubiquity of over-runs and schedule slippages. How can this be accommodated in the analysis of acquisition efficiency?

There are at least two ways to explain these cost variances. Only one of them seems plausible. The implausible one is that a contractor is able to manipulate and control the pace of technical progress on his contract and thus to increase the scope of the effort. But is it implausible to assume such an extreme asymmetry in knowledge on the parts of the government buyer and the supplier. A more plausible explanation is that neither the contractor nor the government fully comprehend the technical advances required to fulfill the promises made during the earlier competition.

This is a disconcerting argument. It implies that competition in the early phases of a program was no better than a lottery. No party to the competitive transaction fully understands what is required nor the effort needed to realize the stated technical objectives. The competitive award is based on trivial or ephemeral grounds. The writer has no reason to believe the ASPJ competition was not conducted in a knowledgeable manner.[22] The purpose, again, is to explain why large cost over-runs occur during the production phase of some weapon system acquisitions. However, on other development competitions that the author has investigated there were certainly obvious gaps in technical awareness for some of them. The contract may have been awarded to the firm with the superior technical approach, but the award was given for specious reasons.[23]

WHY SOLE SOURCE PRODUCTION MAY BE MOST EFFICIENT

It was suggested earlier that a sole source acquisition strategy may be more efficient than a contractor teaming arrangement, and not only just as efficient. This is for two possible reasons. First, economies of scale may result in substantial savings in production. Second, and more importantly, introduction of a second

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[22]It was not possible to obtain the RFP or technical documentation that was used in the competitive phase. One can only infer from subsequent events, and, perhaps, insufficient evidence has accumulated to date.

[23]Development competitions are always conducted on a premise that sufficient information is produced during the competition to permit identification of a winner. A badly needed improvement in development competitions is to introduce as a possible course of action either a continuation of the competition or a declaration that no winner can be identified based on the information available.

source may lead to lower prices in the short run but much higher prices in the long run. Each reason will now be discussed.

Economies of scale

An effort was made to determine if estimated production costs for the ASPJ could be significantly reduced when the monthly rate of production was doubled, i.e., only a single source. The response indicated that unit costs would only be constant, i.e., no economies of scale were anticipated. Of course, it is not clear at this early point in the ASPJ program if production will be located at existing facilities or entirely new facilities will be constructed. In any case, the size of the production run is inadequate to warrant a facility sized to produced only the ASPJ. Thus, any economies of scale will take on more the economies of scope, since a production facility will have to be able to accommodate the production of a variety of electronic subassemblies and equipments.

Yet economies of scale should be an important consideration in ASPJ production planning. The efforts by DoD to standardize electronic equipment production methods allows the widespread use of automated processes and insertion fixtures.[24] In common with some 200 other DoD acquisition programs for which electronic equipment is an important part, the ASPJ program is constrained to use the technology insertion capabilities of VLSI devices. Again, the commercial electronics production appears to be ahead

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[24]"One Micron VLSI Chips for Military Systems," Defense Electronic, November 1983.

of defense electronic production in adoption of automated production lines. The new Apple Computer Company's factory for producing its MacIntosh personal computer illustrates the point. Another example is IBM's approach to the production of its personal computer.

To be sure, the size of the entire production run for the ASPJ is equivalent to only a few days' production of a successful commercial electronics product. Yet the degree of standardization in chip size, printed circuit board dimensions and assembly procedures suggests that the economies of scope should be significant. A contractor who is simultaneously producing assemblies on a number of different defense contracts should be able to realize production economies using a common manufacturing facility. Certainly, the size of the investment required to construct a modern electronics manufacturing facility suggests that two producers will be much more expensive than one.[25]

Short and Long Run Effects of Introducing a Second Source

A number of investigations support a finding that introduction of a second source will result in an immediate price reduction followed by continued price reductions on subsequent competitions.[26] There is a subsequential dispersion in the expected price reduction, however. There may even be price increases. Satisfactory explanation of either the expected price reduction or the large

[25]"VHSIC/VLSI Capabilities for DoD?" Defense Electronics, February 1984.

[26]The relevant literature is summarized in P. M. Carrick, "Limitation on Competition in Defense Procurement," Institute for Defense Analysis, P-1533, November 1980.

dispersion do not exist. Conceptually, in a commercial setting a sole production source should attempt to deter entry by erecting barriers to discourage a potential entrant.[27] This should lead a sole source to a pricing policy that will be capable of sustaining the monopoly.[28] "Riding the yield curve" is a recognized business strategy. If entry is to be discouraged when the sole source knows that entry barriers are controlled by the buyer, the adopted pricing policy cannot allow the monopolist more than a competitive return.[29]

There is an obvious sharp clash between what has been observed in defense acquisitions and the theoretical economic literature. No simple explanation for this discrepancy is possible. Some of the cases where large price reductions were observed may be due to X-inefficiencies on the part of the sole source, i.e., the sole source may have adopted inefficient production methods which resulted in his excessively high production costs. But there is another explanation possible. Namely, the price reduction in the short run may disappear in the long run.

The basis for this line of explanation turns on the difficulties of a firm exiting from production commitments. It is plausible to expect a firm to deploy its resources so that the marginal return from each business area it pursues will yield the same expected marginal return (not the same average return per business area). As explained earlier, a defense contractor makes a subsidy

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[27]See Avinash Dixit, "Recent Developments in Oligopoly theory," American Economic Review, 72, May 1982.

[28]Baumol, et al., op. cit., pp. 279-310.

[29]Ibid.

(investment) during the early competitive phases of a program to enhance his opportunity of winning a production contract. He then prices his production effort to provide a competitively acceptable return. But if a second source is introduced unexpectedly, the new producer will be able to achieve a competitive return at a lower price because he will not have made the earlier investment. But this is only true for the short run, however. The original source will be forced to match the reduced price and, in doing so, will receive less than a competitive return. As soon as the original supplier is able to extricate himself from the production commitment, i.e., to exit from a program's production commitments, he will probably not use his old strategy again. He will now either make smaller investments during the competitive development phase or set prices for his sole sourced production to obtain a high return during the time period before a second source is introduced.

Note that when a sole supplier expects a second source to be introduced during the production phase, the apparent magnitude of the competitive savings may appear very large because the sole source's initial price will have been set quite high. Thus, over time the apparent magnitude of savings from introducing a second source should be increasing. However, a correct measure of competitive savings requires the calculation to be based upon a program's total revenue, expense and investment streams. The prediction is, then, that the savings from introducing a second source will tend to zero in the long run. Given the recent popularity of second sourcing, defense firms may have already adjusted their expectations and pricing practices to reflect the inevitability of competitive production conditions.

The inference is, then, that the savings from introducing a second source are only short run in nature. They can only occur when the introduction of a second source is unexpected. Suppliers will adjust their behavior and the deployment of their resources to assure a long run competitive return. Competitive savings appear to occur only because of the sole source's large sunk costs.[30]

When competitive contractor teaming is used, neither producer is equivalent to a sole source supplier. Each firm can expect to obtain only a share of the total procurement. Sunk costs will still be an important factor and both firms might be induced to accept a lower price in the short run than will adequately compensate them in the long run for all their costs of doing business. But if the firm's earlier expectations as to their market shares are correct, then the prices they received should also be adequate for encouraging continued investments. It would only be when the sales expectations of one of the suppliers is not met that any reluctance to continue would occur. But this additional uncertainty should exact a price. Each member of a competitive team should require a higher return than would be required by a sole source supplier to compensate for the additional uncertainty concerning market share. Thus, a competitive contracting team arrangement may result in higher prices than if a sole source procurement were used.

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[30]The importance of sunk costs in explaining firm behavior is developed thoroughly in Baumol, et al., op. cit., pp. 279-310.

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