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Dual-Source Procurement in the Tomahawk Program

John L. Birkler, Joseph P. Large

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SUMMARY

The Joint Cruise Missiles Project Office (JCMPO, or, today, CMP) was established in 1977 with the Navy as executive service to develop the air-launched cruise missile (ALCM) for the Air Force and a sea-launched cruise missile (SLCM) for the Navy.[1] The latter, known as Tomahawk, also had a ground-launched version (GLCM) for the Air Force. Almost from project inception, the JCMPO directed extensive use of dual competitive sources for all major elements of the missiles. The largest dual-source arrangement involves the Tomahawk family of missiles—SLCM and GLCM. They were originally developed with General Dynamics/Convair (GD/C) as the airframe producer and flight vehicle integrator and McDonnell Douglas (MDAC) as the guidance system's producer and integrator.

In January 1982, the JCMPO was authorized to enter into negotiated contracts with GD/C and MDAC for dual-source procurement of the All-Up Round (AUR), a flightworthy Tomahawk missile contained in a launch-compatible canister and capsule. The arrangement was expected to result in lower AUR costs to the government because the two contractors competed for the larger share of each annual buy. The JCMPO believed in 1982 that such competition could produce savings in excess of $500 million (in fiscal year [FY] 1982 dollars) based on the airframe alone and a buy of 4500 missiles over the period FY 1984–1993.

It is generally agreed today that savings have been achieved, but the amount will always be indeterminate because no rigorous way of establishing what the cost would have been with single-source procurement exists. (Savings are contingent on speculation about a path not taken—that is, what might have happened had a second contractor not been brought into the program.) Nevertheless, though the break-even quantity has been considerably higher than the original estimate, the cost saving (in large part resulting from sharp cost reductions in recent years) has exceeded original expectations. We believe that although competition officially began in FY 1985, it did not begin in earnest until FY 1987, when MDAC won a 60 percent share with a bid about 15 percent lower than GD/C's.

Though both contractors have responded to competitive pressures, the timing and nature of those responses vary in a manner impossible

[1]For a detailed description of the Joint Cruise Missiles Project, see E. H. Conrow, G. K. Smith, and A. A. Barbour, *The Joint Cruise Missiles Project: An Acquisition History*, The RAND Corporation, R-3039-JCMPO, August 1982.

to predict. For example, GD/C reduced AUR prices very little between FY 1985 and FY 1987, but responded vigorously in FY 1988 to MDAC's low FY 1987 prices. The MDAC AUR unit price went up in FY 1988 rather than down, but the firm came back in FY 1989 with a bid low enough to win 65 percent of the total award. As the original guidance contractor, MDAC kept the Tomahawk land attack missile (TLAM) guidance cost at approximately the same level in precompetition years, then reduced cost by 5 percent in the first competitive lot. The second source, GD/C, came in with a TLAM bid far lower than MDAC's and continued to underbid MDAC in all subsequent years.

The success of second-sourcing in the Tomahawk AUR program has resulted from specific factors not present in every program:

- The cost of entry for a second major producer was low—less than 2 percent of the projected production cost of more than 4000 missiles.
- The original airframe producer, GD/C, originally projected a relatively flat sole-source cost-improvement curve. It was not hard to demonstrate savings when single-source target prices were established at the GD/C level.
- Annual production quantities have been large enough to absorb the fixed and semifixed costs without unduly distorting AUR unit costs.
- The JCMPO has worked hard and effectively in managing the competition aspects of AUR procurement.

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I. INTRODUCTION

WHY ESTABLISH A SECOND PRODUCTION SOURCE?

The use of competition in weapon system acquisition is widely advocated in policy statements and requirements issued by Congress, the Office of Management and Budget, the Department of Defense (DoD), and the military services. This advocacy stems from the conviction that competition during the production phase will drive the unit cost of a system or subsystem down and reduce overall procurement cost to the government.[1] Other arguments for having more than one producer exist—for example, doing so provides a surge capability should the service need to expand production quickly; reduces the risk of late or faulty deliveries resulting from production problems, labor disputes, or acts of nature; strengthens U.S. technical and production expertise for a particular weapon system; and encourages higher product quality. But the crux of the competition issue is procurement cost (or, more accurately, price) and the associated problem of measuring the dollar benefits or penalties to be expected from production competition.

SECOND-SOURCING VERSUS GENUINE COMPETITION

This report focuses on one DoD strategy for establishing competitive production sources: second-source procurement, in which a single design is produced by two firms—the initial source (usually the system designer) and a second production source established at government expense. The two firms compete to determine which will produce the larger share of a split buy. Such an arrangement obviously does not meet the requirements of economic theory for the forces of competition to operate freely. Usually only a single buyer and two sellers exist (duopoly), demand is inelastic, the buyer's budgetary priorities often change and are independent of a firm's performance, entry and exit of firms may be slow and costly, large capital require-

[1]In recent years, Congress has specified that funds cannot be used to initiate Full-Scale Engineering Development of any major defense acquisition program until the Secretary of Defense provides to the Committees on Appropriations of the House and Senate (1) a certification that the system or subsystem under development will not be procured in quantities sufficient to warrant development of two or more production sources, or (2) a plan for developing two or more sources for the production of the system or subsystem under development.

ments exist and are often funded by the buyer, both firms produce the same design, and, finally, the high-cost producer is guaranteed a share of the production run. We point out these differences to illustrate that second-source procurement is a *synthetic* competition rather than the real thing. One may not obtain all the benefits that normally accrue from competition involving many sellers and many buyers, and that second-source procurement will produce savings in every major acquisition program is not self-evident.

Moreover, additional nonrecurring costs are incurred for a complete data package, for tooling and test equipment for the second producer, and for qualification testing. The incremental cost of one or more educational or directed buys also exists—buys in which items are procured from a manufacturer just beginning production rather than from one perhaps well along the cost-improvement curve.[2] Such start-up costs may be estimated with reasonable accuracy, but potential cost increases may also arise from

- Loss of economies of scale;
- Overhead costs on two plants instead of one;
- Higher engineering/management costs per unit;
- Lower production rates;
- Possible claims against the government for deficient data packages.

Some of these disadvantages may, of course, be more apparent than real. One economy of scale offered by single-source production is a quantity discount on materials, and materials (including purchased parts and subcontract items) account for a major portion of the hardware cost of some types of systems. If each prime contractor used different vendors, potential economies of scale would diminish. It is not uncommon, however, for both primes to use the same vendor for specialized items, thus allowing the vendor to keep the production rate up and overhead rate down. In such a situation, the price charged by the vendor is set in the absence of competition. Also, where the planned production rate exceeds the capacity of a single plant, overhead costs will be incurred on two plants with either single- or dual-source production.

When competition or the threat of competition is real, corporate management can respond in a number of ways to reduce product cost. These ways range from increased attention to production to

[2]An educational or directed buy is a contract to provide the second source with an opportunity to learn how to manufacture the product in accordance with a technical data package provided by the designer. Such buys take place before the competitive buys.

setting up a new facility in a low–labor cost area. Managers often assign their best people to a competitive program, allocate corporate capital for equipment, and fund value-engineering studies. In contrast, noncompetitive programs tend to be heavy in factory support and engineering personnel. At one production facility we visited in 1986, a noncompetitive program had 30 support engineers, compared to 3 in a comparable competitive program.

Management can take measures to substitute capital for labor, accelerate cost-reduction schemes, seek out alternative vendors, and produce in batch lots at an efficient production rate. The vendor can operate at an economical rate by producing enough parts in a few months to satisfy the contractual requirement for an entire year, and the same may be true of prime contractors. That is, a contractor is sometimes able to produce the necessary parts at an efficient rate, then assign the workers to other tasks for the remainder of the year.

STUDY OBJECTIVES

This study was part of a broader study examining the economic implications of establishing a second production source for the Advanced Cruise Missile (ACM). We felt that the Tomahawk experience would be directly relevant to the ACM issue, and we wanted to determine (1) whether savings were indeed realized by bringing a second producer into the Tomahawk program, and (2) what conditions are necessary to achieve savings. Also, to improve acquisition management methods, documenting experience from ongoing or recently completed projects is important, especially if those projects involved unusual situations or innovative acquisition techniques. Just as the Tomahawk experience proved valuable in our ACM analysis, so too should it prove useful in other programs considering the introduction of a second production source.

ORGANIZATION OF THE REPORT

The next section of the report provides background on the Tomahawk program and its competitive strategies. The uncertainty inherent in attempts to measure future effects is underlined by the variety of answers—some conflicting—produced by measurement of past effects.[3] Savings are contingent on speculation about a path not taken—

[3]K. A. Archibald, A. J. Harman, M. A. Hesse, J. R. Hiller, and G. K. Smith, *Factors Affecting the Use of Competition in Weapon System Acquisition*, The RAND Corporation, R-2706-DRE, February 1981.

that is, what might have happened had a second contractor not been brought into a program. Tomahawk experience is no different. Section III examines estimates made at different times by different organizations and actual experience to date. Section IV discusses single-source experience. We examine and compare Tomahawk to the Air-Launched Cruise Missile (ALCM) and Harpoon, along with other missile systems. Section V presents our conclusions.

II. TOMAHAWK PROGRAM

BACKGROUND[1]

The Joint Cruise Missiles Project constitutes an interesting example of the use of competitive dual sourcing to achieve several goals: to reduce the risk of interrupted or unsatisfactory production, to reduce program cost, and to improve quality assurance.

The Joint Cruise Missiles Project Office (JCMPO, or, today, CMP) was established in 1977 with the Navy as executive service to develop the ALCM for the Air Force and sea-launched cruise missile (SLCM) for the Navy. The latter, known as Tomahawk, had a ground-launched version (GLCM) for the Air Force. The goal was to emphasize commonality among the different missiles, specifically by using common engine and land-attack guidance systems. That objective was maintained for SLCM and GLCM even after Boeing was chosen as the prime contractor for ALCM in 1980 and management of that program transferred to the Air Force.

Almost from project inception, the CMP directed extensive use of dual-competitive sources for all major elements of the missiles.[2] The F107 engine, common to all variants of the cruise missile, was manufactured by Williams International Corporation, a small company with no experience in high-rate production. The CMP wanted a second source to reduce production and schedule risk, and considered four different second-sourcing methods, including leader/follower and the development of an alternate cruise engine. Williams was not anxious to participate in a leader/follower licensing agreement but had to give some weight to the CMP/United States Air Force (USAF) threat to start a new cruise missile engine development program. Ultimately, Williams was required, under a memorandum of understand-

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[1]The information in this section draws from E. H. Conrow, G. K. Smith, and A. A. Barbour, *The Joint Cruise Missiles Project: An Acquisition History,* The RAND Corporation, R-3039-JCMPO, August 1982.

[2]Note, however, that the CMP insisted on competition throughout the program. In addition to conducting competitions for the engine and inertial navigation element, the CMP conducted depot competitions and competitions for the weapons-control systems, launchers, items of tooling and test equipment, support contractors, mission-planning system, and the research and development programs, especially the Block III upgrade. According to the CMP, overall savings from competion amount to $3.1 billion in then-year dollars. This report deals with the All-Up Round (AUR) only.

ing with the government, to select (with CMP approval) and qualify a second production source for the F107 engine.[3]

In the case of the inertial navigation element (INE) used in the land-attack missiles, the primary objective was to reduce cost; schedule and risk factors were of less importance. Two second-sourcing approaches were under consideration: an alternative design, and leader/follower licensing. The former was ruled out because of higher estimated life-cycle costs. Litton Guidance & Control Systems, developer of the INE, was willing to enter into a licensing agreement but would not include several items considered proprietary, including the critical gyroscope and accelerometer components, unless the licensee was another division of Litton. Litton produced examples of similar arrangements in the past in which competition appeared to be genuine and one division underbid another. Consequently, after considering other dual-sourcing alternatives, the CMP agreed to a leader/follower plan for the production of cruise missile INEs with Litton Guidance & Control Systems as leader and Litton Systems Limited of Canada as follower.

The largest dual-source arrangement in the joint cruise missile project involves the Tomahawk family of missiles—SLCM and GLCM. They were developed with General Dynamics/Convair Division (GD/C) as the airframe producer and flight vehicle integrator and McDonnell Douglas (MDAC) as the guidance system's producer and integrator. Before production, the CMP began searching for a procedure that would shift a large degree of responsibility for production quality of the overall missile to the manufacturers. The objective was to obtain a complete flight vehicle with a single point of responsibility for a missile reliability warranty, excluding engine and other government-furnished equipment (GFE) items. This concept was discussed at length with both GD/C and MDAC, but GD/C was unwilling to warrant the MDAC-produced guidance system.

An increase in the planned production quantity of Tomahawk missiles made more feasible the idea of dual sources for missile production, with each source having full responsibility for both airframe and guidance. The most obvious solution was for GD/C and MDAC to exchange technology and each become a cruise missile producer. In August 1981, the CMP began negotiating with the two contractors to achieve such an exchange. Negotiations proceeded slowly, but since neither firm held proprietary rights to important elements of its individual products, the CMP could, theoretically, have brought in a third party that would obtain manufacturing rights to

[3] The memorandum provided that Williams would be paid a 12 percent fee for each engine produced by the second source.

both the airframe and guidance subsystems. When the CMP established that as a possibility, the two companies agreed to the necessary transfer of technology.

In January 1982, the DoD authorized the CMP to enter into negotiated contracts with GD/C and MDAC for dual-source procurement of the AUR—that is, a flightworthy missile contained in a launch-compatible canister or capsule. However, the Navy had denied the CMP's request for investment funding to initiate the dual-source program. The CMP's response was to

> . . . have the contractors use corporate funds to invest in the nonrecurring aspects of establishing the dual-source program with the opportunity to amortize their costs over the competitive program. The advantages to the Navy were manifold: 1) Experience had shown that the contractors involved were much more careful managers of their own investment funds than they were of direct, "up-front" government funds, even given the opportunity to amortize back all costs through an overhead structure. One notable example of this phenomenon in another program was the $54 million Boeing invested in the Kent facility to build the ALCM. 2) The JCMPO expected the contractors to reduce the amortized costs to the bare minimum, even forgoing the opportunity to bill back some of the charges if the amortization were made part of the competitive bottom line. This has been seen on numerous occasions in the technology transfer charges. 3) Since the contractors were using their own funds and retaining title to the special tooling, they were able to avail themselves of the accelerated depreciation which became available under the 1982 Economic Recovery Act. And 4) the Navy was relieved of the responsibility of analyzing and approving every piece of tooling and test equipment needed for dual source. The contractors could never claim that the Navy's approved list was inadequate to produce the product.[4]

The resulting agreement had several interesting features. First, the two contractors agreed to transfer reciprocally all necessary technology and to negotiate the terms between themselves and the government. The government agreed that those fees could be recovered as a contract cost spread over the first 1200 missiles produced by each firm. Such fees were expected to be small, however, relative to the total contract value.

A second feature was that the government had given the two companies certain incentives to carry out the technology transfer effectively and quickly so that competitive bidding could begin in the fiscal year (FY) 1984 buy. Each firm was guaranteed 30 percent of the annual buy, with the remaining 40 percent to be allocated depending on bid prices. However, if the technology transfer proceeded

[4]Informal communication provided by the CMP.

on schedule, each firm would be guaranteed 40 percent of the total buy for FY 1984 and FY 1985. Failure to meet the transfer schedule would not only cause a potential loss of business, but would also cause certain near-term penalties in reduction of progress payments for current production. As the situation turned out, neither MDAC nor GD/C was prepared to compete in FY 1984. The CMP gave MDAC a directed buy of 36 airframes and 208 guidance sets; it awarded 36 guidance sets and 208 airframes to GD/C. Competition began in FY 1985.

A third major feature of the arrangement was that each contractor agreed to warrant the AUR produced in its plant. The agreement states that each contractor

> . . . as a production-certified AUR supplier, shall be totally responsible for the delivery, support, and development of a warranty for the All-Up-Round missile system . . . The AUR delivery shall include demonstrated test compliance with government-approved test acceptance procedures.[5]

The details of the warranty were to be spelled out in subsequent contracts, where price and other features would be negotiable in a competitive environment.

The final feature of the dual-source arrangement was that it did not involve any direct investment by the government. Tooling and test equipment—both special and capital—were to be purchased by the contractors themselves, with each contractor being allowed to amortize the investment over a period of years. Capital tooling could be amortized across the companies' normal overhead base; special tooling could be amortized across cruise missile contracts only. Similarly, the contractors were asked to fund technology-transfer costs and provide data packages directly to each other, with no intermediate possession by the CMP. They could recover the technology-transfer costs by charging, at their option, 1/1200 of the investment cost for every missile delivered, up to a quantity of 1500. After full payment, the tooling and test equipment became the property of the government, which had no further termination liability.

PROGRAM DEFINITION

Tomahawk is a family of missiles with different launching modes and different missions. The two basic types are land-attack (TLAM) and antiship (TASM). The TLAM uses maps stored in an on-board

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[5]Conrow, Smith, and Barbour, *The Joint Cruise Missiles Project*.

computer to update the vehicle's inertial navigation system along the flight path. Before FY 1988, much of the TLAM guidance set was GFE. In line with the CMP's "breakback" policy, the reference measurement unit and computer and the cruise missile radar altimeter were made contractor-furnished equipment (CFE) in FY 1988 and the digital scene matching area correlator was made CFE in FY 1989. Initially, however, the TLAM guidance set was a relatively unimportant component of GD/C and MDAC AUR prices.

The TASM uses a fairly expensive radar seeker that MDAC has purchased in quantity for the Harpoon missile and that is produced by Texas Instruments for both MDAC and GD/C. In terms of CFE cost before FY 1988, the TASM cost about a half-million dollars more than the TLAM. The TASM will likely account for less than 15 percent of the total number of missiles procured, but the mix of TASM and TLAM changes each year. A higher percentage of TASM in a given year increases the average AUR cost and can affect the slope of the learning curve. Cost comparisons of AUR from year to year can be misleading, therefore, unless adjustments are made to compensate for changes in the missile mix and in the CFE-GFE content. In most of the comparisons below, AUR price includes CFE only and excludes breakback (that is, the change in procurement of selected items from GFE to CFE), and does not include an adjustment for variant mix. Table 1 shows the procurement quantities of Tomahawk used in the different studies we discuss here.

Table 1

TOMAHAWK PROCUREMENT QUANTITIES

Fiscal Year	Guidance		Airframe		All-Up Round		Total AUR	Composite Unit Price (Millions of FY 1985 dollars)
	GD/C	MDAC	GD/C	MDAC	GD/C	MDAC		
1981	0	57	57	0	57	0	57	2.537
1982	10 kits	142	142	10 kits	132	10	142	1.778
1983	22 kits	99	86	22 kits	86	22	108	1.674
1984	36	208	208	36	208	36	244	1.242
1985	(a)	(a)	(a)	(a)	180	120	300	1.041
1986	(a)	(a)	(a)	(a)	206	139	345	0.957
1987	(a)	(a)	(a)	(a)	160	240	400	0.696
1988	(a)	(a)	(a)	(a)	332	143	475	0.586
1989	(a)	(a)	(a)	(a)	99	231	330	0.563

[a]Not applicable.

III. MEASURING SAVINGS

In addition to accruing benefits from the expanded industrial base and the warranty provisions, the government expected the AUR dual-source arrangement to result in lower AUR costs because the two suppliers competed for the larger share of each annual buy. The CMP believed in 1982 that such competition could produce savings in excess of $500 million (in FY 1982 dollars) in the SLCM and GLCM projects based on the airframe alone. According to the CMP, that estimate was based on a reduction of 7.9 percent in average unit flyaway cost achieved in the GD/C contract after negotiation of the agreement between GD/C and MDAC. The sole-source estimate was based on a detailed "will-cost" analysis by the Navy.

It is generally agreed today that competition between GD/C and MDAC has brought costs down, but little agreement exists on the dollar value of savings to be realized. The basic problem is the hypothetical nature of the savings. One can never know what the actual cost would have been had a single producer supplied all the missiles, but that cost must be estimated to establish a basis for comparison with costs incurred in a dual-source procurement program. Figure 1 illustrates the most common method of estimating hypothetical single-source costs. Unit costs for all lots before the start of competition are plotted on a logarithmic grid. A line drawn between the two final points is extended out to the midpoint of the final planned production lot. That line is assumed to represent the unit costs that would be incurred with a single producer; those costs are then compared with actual costs incurred in a dual-source program to obtain an estimate of savings. As we illustrate below, different agencies arrive at different estimates of savings.

ESTIMATES OF COST SAVINGS

CMP 1987

The CMP projections of Tomahawk single- and dual-source costs in March 1987 indicated a savings of $1.2 billion (then-year dollars) over the period FY 1981–1993 for a total buy of 4591 missiles. The CMP estimated those savings as follows. First, it calculated theoretical unit prices for lots 1 through 4 (FY 1981–1984), because neither contractor began full production of AURs until lot 5, in FY 1985. It combined the GD/C airframe prices and the MDAC guidance set

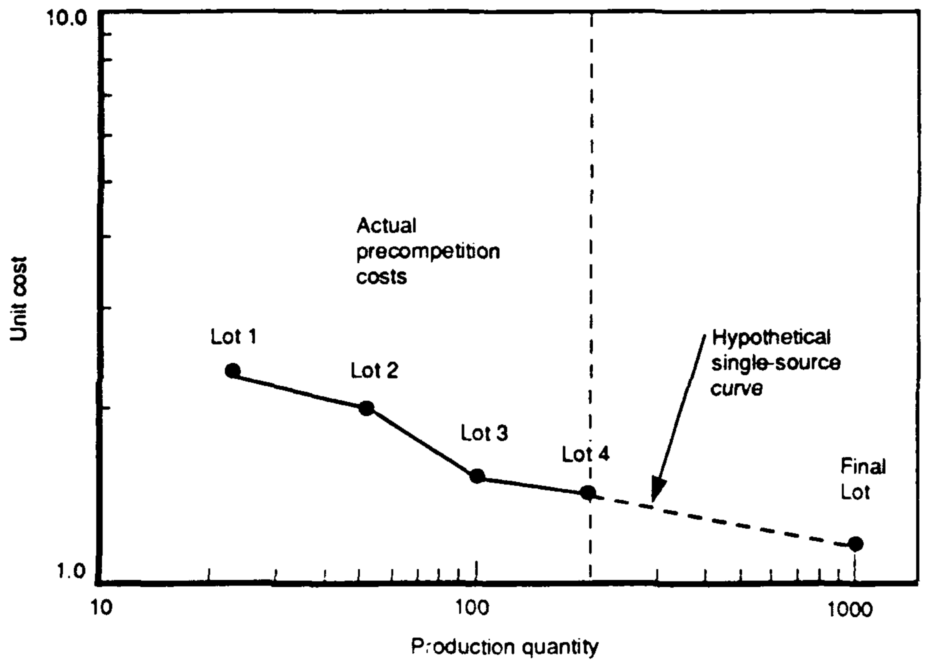

Fig. 1—Illustrative projection of single-source costs

prices to obtain a weighted average, as shown below for FY 1981 (in FY 1985 dollars):

57 GD/C airframes	@ $1.9 million	= $ 108.3 million
27 MDAC TASM guidance sets	@ $1.1 million	= $ 29.7 million
30 MDAC TLAM guidance sets	@ $0.22 million	= $ 6.6 million
Total		= $ 144.6 million

$144.6 million/57 units = $2.537 million/unit

Normally, the estimate of single-source costs would have been obtained by extending a learning curve through the last two precompetition lots, as we described above, but the CMP felt that the technology-transfer program in progress in FY 1983 and FY 1984 could have introduced a competitive element into the contract prices for those years. Consequently, the single-source learning curve was based on lots 1 and 2. That curve had a slope of 87.1 percent and a theoretical first-unit cost of $4.628 million. Based on that curve, the recurring cost of 4591 missiles would have been $4.9 billion (FY 1985 dollars). Table 2 shows the price-level index used to convert prices to FY 1985 dollars. Dual-source unit prices consisted of weighted averages for lots 1–4, average AUR prices actually paid

Table 2

CMP WEIGHTED INDEX

Fiscal Year	Index	Fiscal Year	Index
1981	1.333	1988	0.972
1982	1.235	1989	0.943
1983	1.175	1990	0.918
1984	1.129	1991	0.896
1985	1.084	1992	0.875
1986	1.042	1993	0.855
1987	1.000		

in competition for lots 5–7, and estimates for subsequent lots based on the learning curve slope established by the FY 1985 and FY 1986 buys. As Fig. 2 shows, a slight increase in AUR price occurred in FY 1988 because of the inclusion of design agent costs.

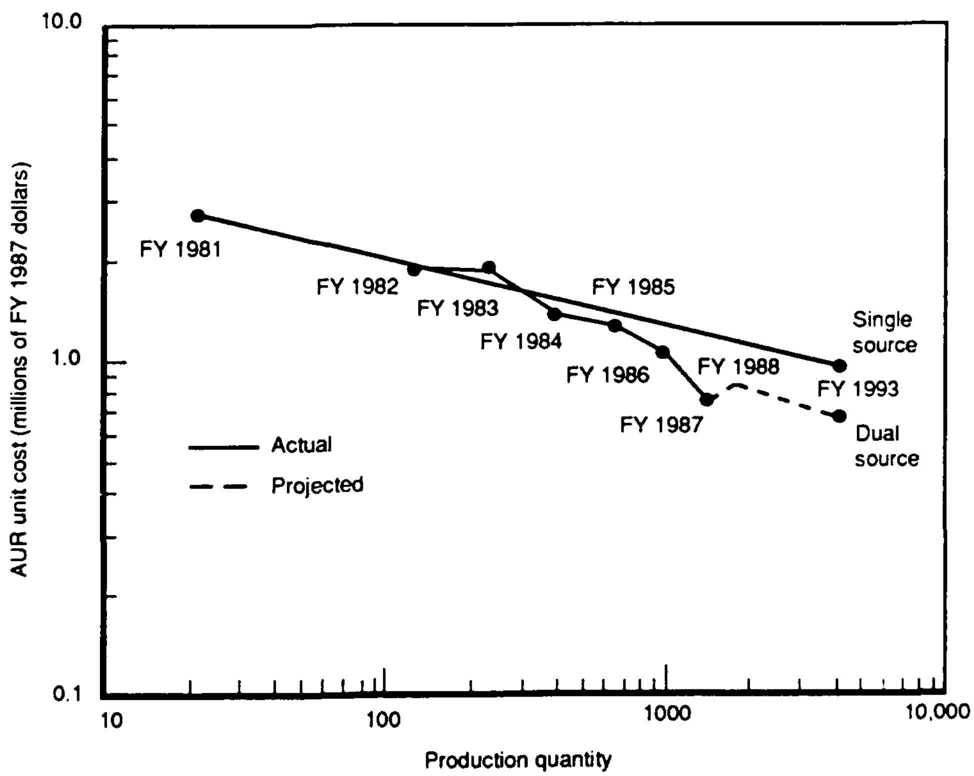

Fig. 2—1987 CMP unit cost comparison

Figure 2 shows that, according to the CMP numbers, AUR unit price was higher in the dual-source case in the third year of production, FY 1983, but dropped below the estimated single-source price in what the CMP originally intended to be the first year of competition—FY 1984. Although competition had little effect on price in FY 1985, the effect by FY 1987 is clearly visible. As shown by the CMP projection beyond FY 1987, further price reductions were expected to be minimal.

Figure 3, which compares cumulative total costs, includes special tooling and test equipment costs of $160 million for single source and $192 million (in FY 1985 dollars) for dual source. For the latter, that amount is what had actually been paid in FY 1983–1987, plus a final installment in FY 1988. For single source, it was assumed

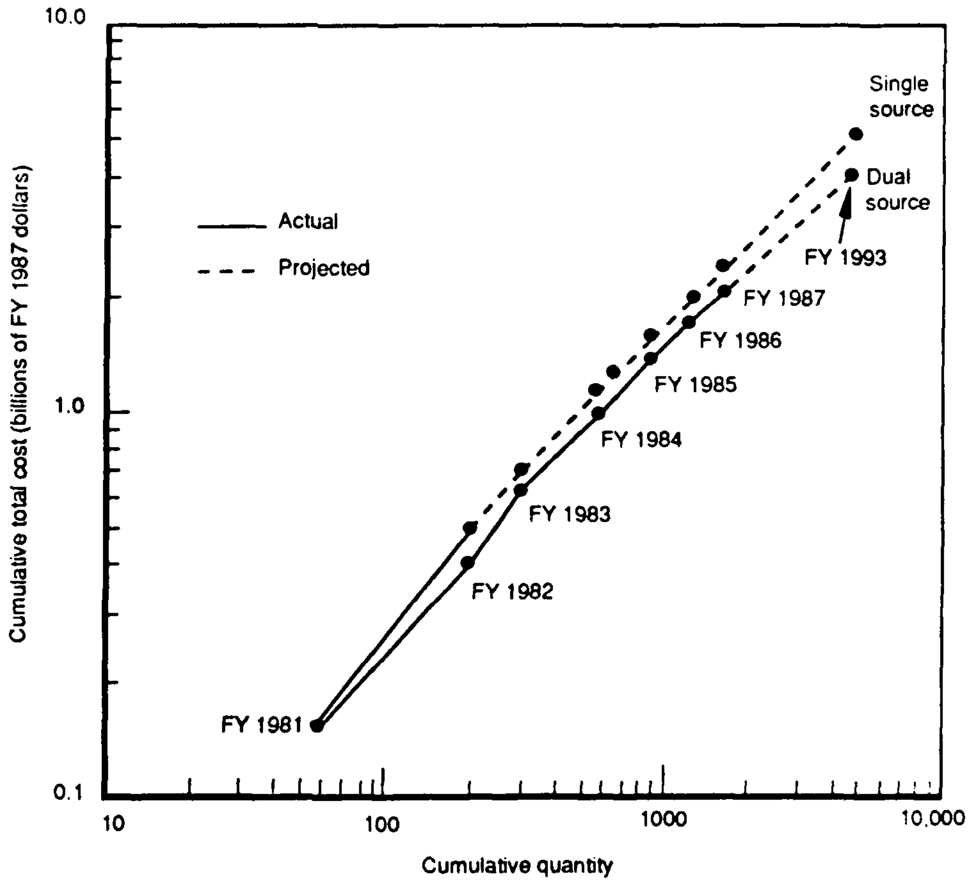

Fig. 3—1987 CMP cumulative cost comparison

that the costs would have been incurred in FY 1982–1984 because production could have started sooner. Normally, the additional tooling, test equipment, qualification, etc., necessary to bring a second contractor to the point where it can compete with the original producer make dual procurement more costly initially. Because of the earlier investment in special tooling and test equipment in the single-source alternative, second-sourcing appears more attractive from the outset of production.

GD/C 1988 Estimate

Voicing some reservations about the 1987 CMP study, GD/C said that some non-air-vehicle costs were included in the FY 1981–1982 AUR numbers, variations in the missile mix were not considered, sole-source tooling costs were front-loaded, and design agent costs were missing from the FY 1985–1987 buys. On the first issue—inclusion of non-air-vehicle costs (for example, booster, ground support equipment, trainers, etc.)—CMP disagrees, but whatever the reason, CMP's AUR unit cost for FY 1981 was 25 percent higher than the GD/C figure.

The concern about the missile mix is worth noting, because when we consider only CFE costs in the years before breakback, cost curves can be affected. The point GD/C made about design agent costs is that the 1987 CMP projection did not include them in AUR unit prices in FY 1985–1987 but did include them in FY 1988–1993, thus making the earlier units appear slightly less expensive.

Figure 4 shows the GD/C comparison of AUR unit costs for the period FY 1981–1988. (The AUR costs include guidance, airframe, integration, and tooling; design agent for dual source for FY 1985–1988; fee/profit and the cost of money. They exclude booster, ground support equipment, trainers, spares, etc.) Starting from ostensibly the same data, but normalizing it in different ways, GD/C and CMP arrive at different unit 1 costs and different learning curves. The GD/C unit curves begin at a lower value and are slightly flatter than the CMP curves. The dual-source AUR unit cost does not fall below the single-source cost until some 700 units have been produced.

A comparison of cumulative costs (see Fig. 5) indicates that the dual-source alternative does not break even until FY 1987. Note, however, that even in the GD/C comparison, the cost risk in implementing dual-source procurement was minor because GD/C stated the incremental nonrecurring cost to be only $55 million. The estimate by GD/C of total potential savings through FY 1993 was $433 million.

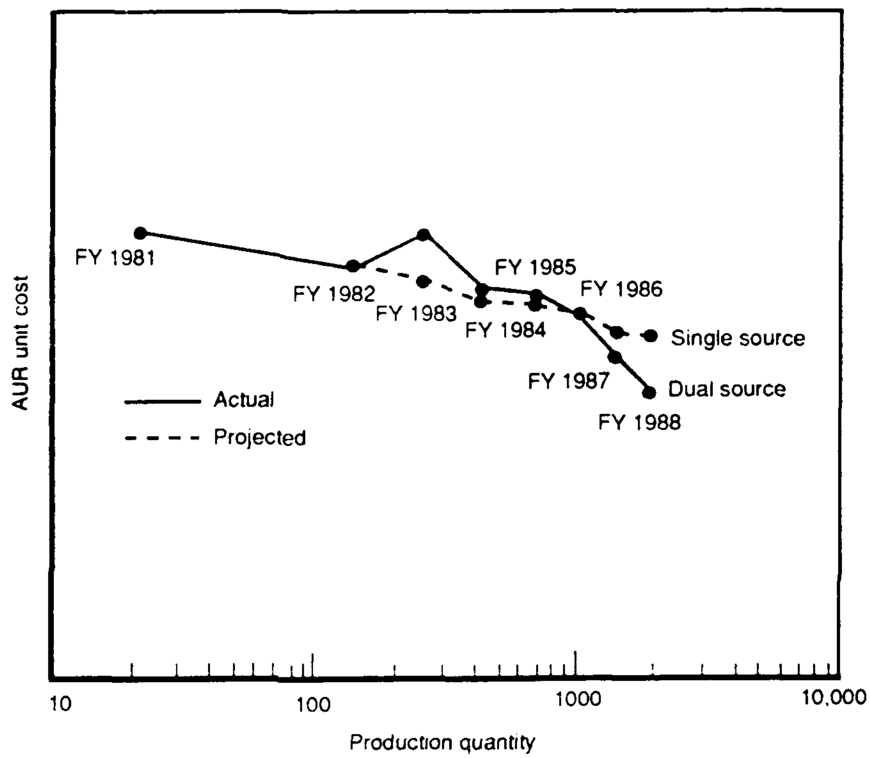

Fig. 4—1988 GD/C view of AUR unit cost

Office of the Secretary of Defense/Program Analysis and Evaluation

The Office of the Secretary of Defense/Program Analysis and Evaluation (OSD/PA&E) performed a break-even analysis (as recommended by Margolis, Bonesteele, and Wilson[1] and by Hampton[2]) in May 1984. Break-even means that at the time a decision about second-sourcing is to be made, the total incremental cost with a single contractor will be equal to the total incremental cost with dual procurement. This method does not attempt to estimate how much money will be

[1]Milton A. Margolis, Raymond G. Bonesteele, and James L. Wilson, *Method for Analyzing Competitive, Dual Source Production Programs*, presented at the 19th annual DoD Cost Analysis Symposium, September 1985.

[2]Richard J. Hampton, *A Price Competition in Weapons Production: A Framework to Analyze Its Cost-Effectiveness*, AU-ARI-84-6, Air University Press, Montgomery, Ala., June 1984.

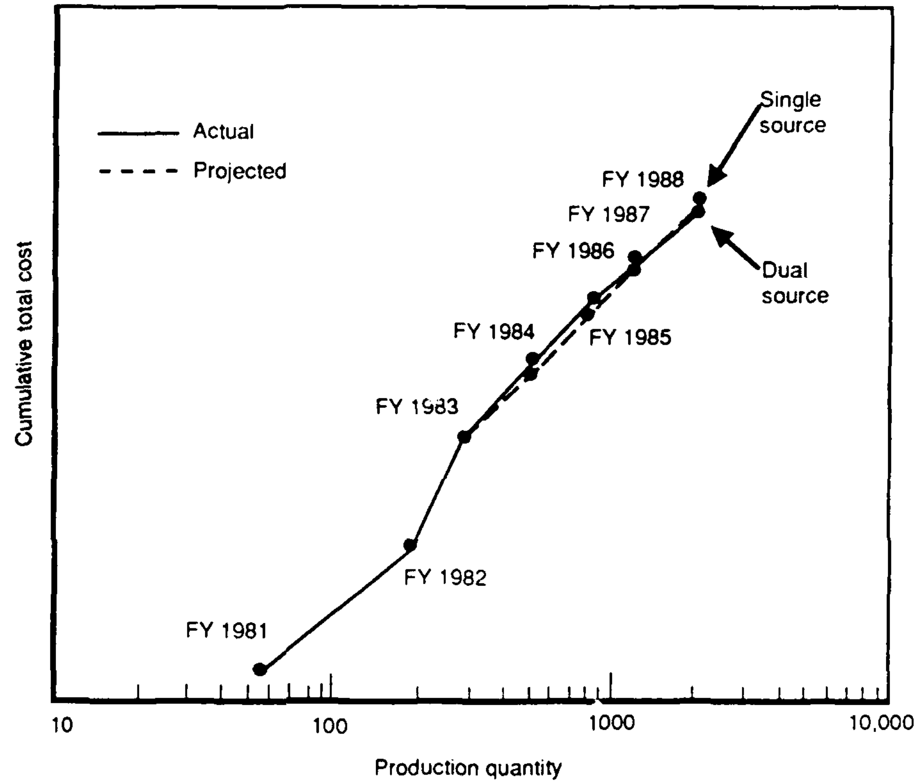

Fig. 5—1988 GD/C view of AUR cumulative cost

saved, but focuses instead on the fundamental question, Is dual-sourcing a reasonable alternative for a specific program? The study concluded that "it would be difficult but not impossible for savings related to Tomahawk competition over FY 1985–1992 to pay back the investment required to establish a dual source." It also noted: "If the total planned procurement quantity is reduced significantly (for example, 25 percent) below 4000 missiles over FY 1985–1992 or below 150 per year over several years, dual source will become less attractive."

Apart from the break-even analysis, PA&E prepared a study in 1986 comparing CMP's 1983 projections of single- and dual-source costs with actual costs through the FY 1987 buy. After adjusting the CMP costs for differences in quantity (that is, the planned quantity versus the quantities actually procured), production rate, and model mix, PA&E found that AUR unit cost in FY 1985 and 1986 was at

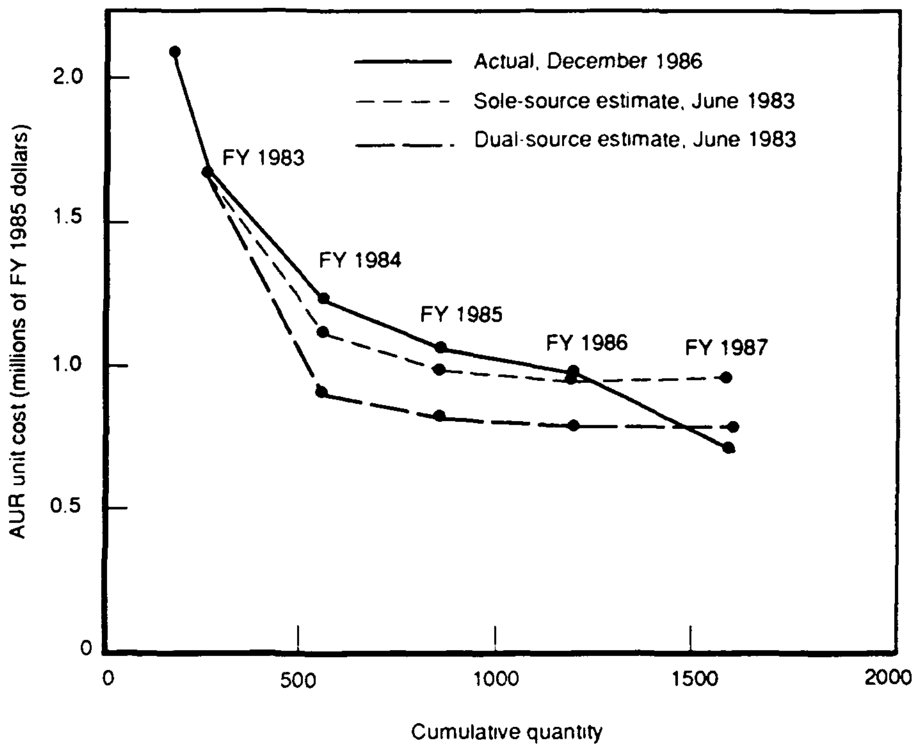

Fig. 6—PA&E view of AUR estimates and actuals

the level CMP had predicted for single-source production (see Fig. 6). Not until the third year of competition (FY 1987) did unit cost drop to the anticipated level.

Experience to Date

We prepared Fig. 7 using CMP data provided in March 1989. The CMP normalized all prices to agree with the AUR configuration of FY 1985–1987, and composite unit prices for FY 1981–1987 are the same as those Fig. 2 shows. The actual prices for FY 1988 and FY 1989, however, are lower than those projected earlier. As a result, the estimated savings from second sourcing increased from the $1.2 billion estimated in 1987 to $1.4–$1.5 billion, depending on the slope of the learning curve in the remaining years of procurement. Thus, CMP, GD/C, and PA&E studies all come to the same conclusion—

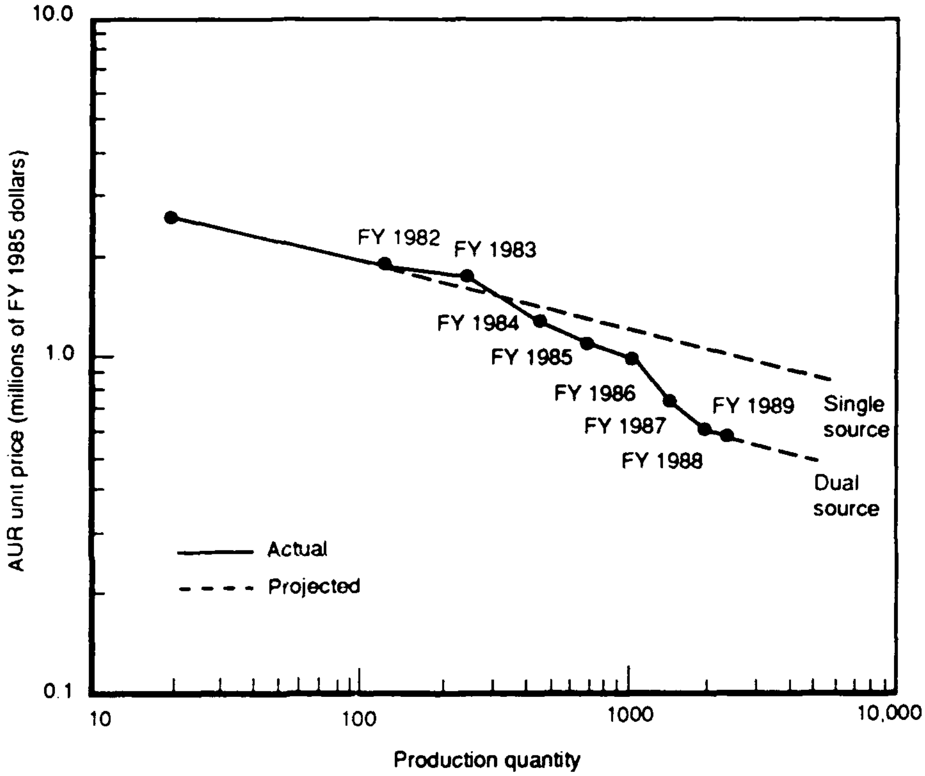

Fig. 7—1989 CMP unit price comparison

dual-sourcing saved the government money after three years of competition—but, as Table 3 shows, even after several years of competition, studies can differ on the amount of savings and the production quantity necessary to break even.

Table 3

DIFFERENCES IN STUDY RESULTS

Study	Break-even Quantity	Break-even Year	Savings through FY 1987 (Millions of FY 1987 dollars)
CMP 1987	130	FY 1982	176
GD/C 1988	1400	FY 1987	18
PA&E 1986	1400	FY 1987	46

Critical Assumptions

Estimates of the total realizable savings range from $433 million to $1.5 billion. All such estimates are based on the assumption that the composite dual-source learning curve is inherently steeper than the single-source curve. As we stated previously, the CMP projected an 87.1 percent learning curve for single-source procurement based on GD/C and MDAC prices in lots 1 and 2 because impending competition could have influenced prices in lots 3 and 4. Had a unit curve been fitted to all four precompetition points, the learning curve slope would have been 86.1 percent, and estimated savings would be reduced by about $500 million.

Experience on other missile programs indicates that at some production quantity, missile price will either bottom out or start to increase. That quantity varies from program to program and cannot be predicted accurately. Back in 1987, for the purpose of estimating savings (but not for budgeting), the CMP was projecting an 85 percent learning curve for the remaining production years; at the time, that figure appeared optimistic. The FY 1988 buy contained indications that price could increase rather than decrease in the years ahead; in fact, GD/C's FY 1989 bid was sharply higher. However, MDAC came in with a greatly reduced price, so the composite AUR price for FY 1989 was about 4 percent lower than the FY 1988 price.

INDIVIDUAL CONTRACTOR EXPERIENCE

Figure 8 displays contractor AUR prices in relative terms, normalized to reflect the FY 1985–1987 AUR configuration. Price differences between the contractors are accentuated by differences in production quantity, but even when adjusted for rate (see Fig. 9), the year-to-year changes in price are remarkable.[3]

Between FY 1985 and FY 1987, GD/C reduced prices very little, but in FY 1988 responded vigorously to MDAC's low FY 1987 price. In FY 1988 MDAC's AUR unit price went up rather than down, but the firm came back in FY 1989 with a bid low enough to win 65 percent of the total award. We cannot identify the cost elements in which MDAC was able to make reductions in FY 1989 because both MDAC and GD/C declined to furnish RAND with detailed information for that year. The pattern of cost reductions before

[3]The rate adjustment is based on an industry rule of thumb saying that cost decreases 15 percent when production is doubled. Because this rule is unlikely to be equally applicable to both contractors, the adjustments in Fig. 9 are only illustrative. We assumed an annual production quantity of 300 units for both contractors.

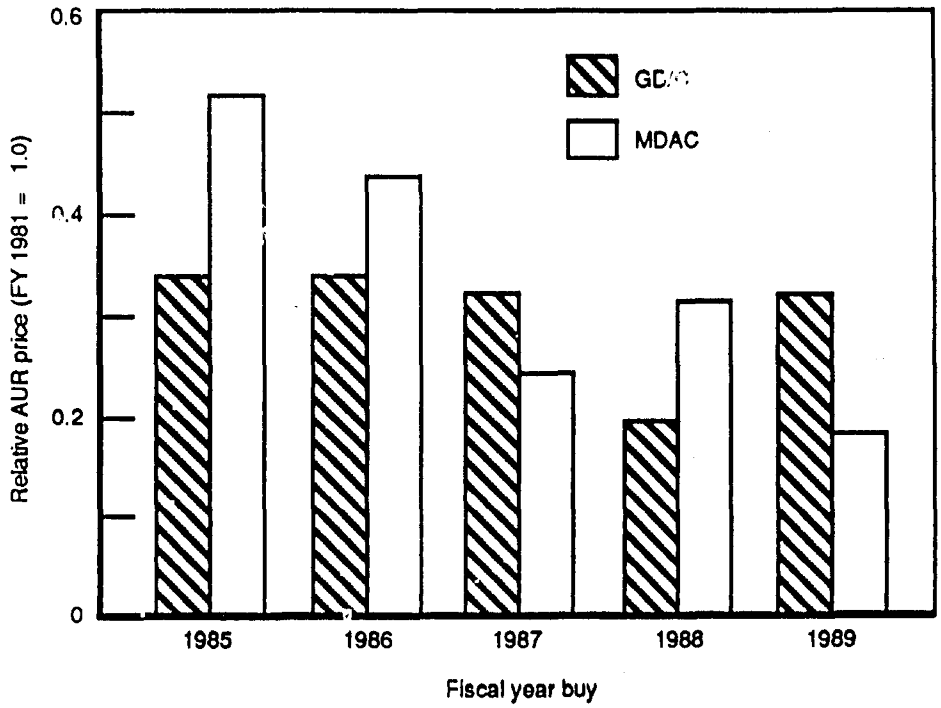

Fig. 8—Relative AUR prices

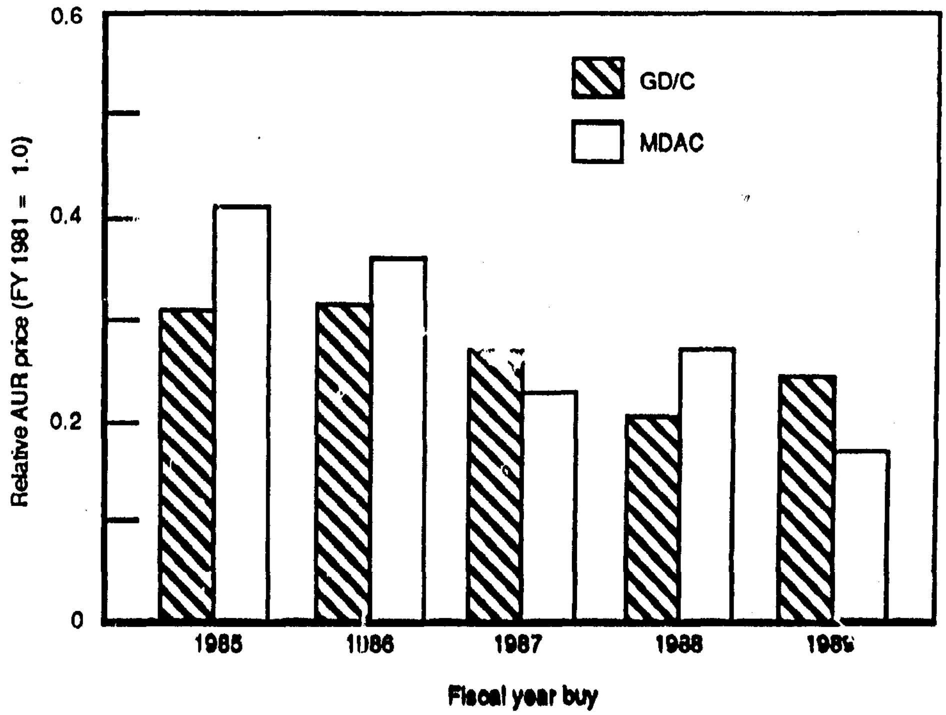

Fig. 9—Rate-adjusted relative AUR prices

FY 1989 is interesting, however, and we examine that pattern here, looking first at guidance and airframe costs separately, then at the functional cost elements (that is, engineering, manufacturing, materials, etc.).

Measured in percentage terms, the guidance system costs for both TLAM and TASM appear to have benefited most from competition. As the original guidance contractor, MDAC kept TLAM guidance cost at about the same level in FY 1982, 1983, and 1984, then reduced cost by 5 percent in the first competitive lot. The second source, GD/C, came in with a bid far lower than MDAC's, and, as Fig. 10

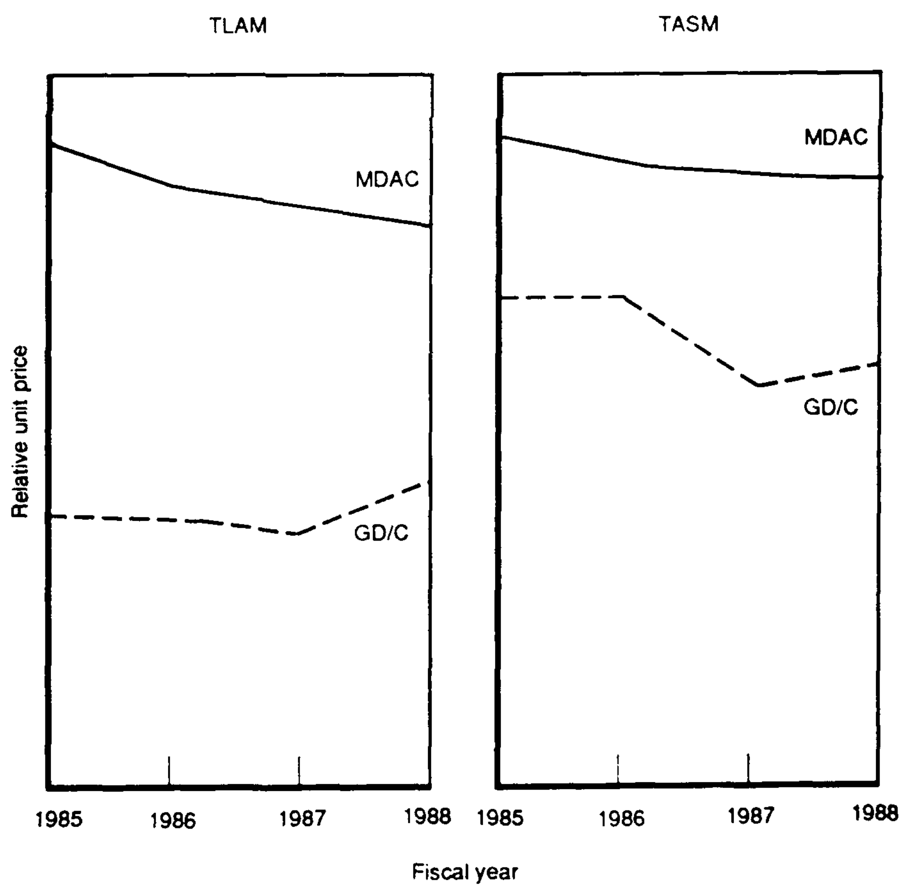

Fig. 10—Relative prices of MDAC and GD/C guidance sets (MDAC FY 1985 = 1.0)

shows, continued to underbid MDAC in subsequent years.[4] For the TASM guidance set, GD/C's FY 1985 bid was at a level government analysts had not expected MDAC to achieve until FY 1989. The same analysts thought that GD/C significantly underbid guidance labor hours in FY 1985, but GD/C reduced guidance costs still further in FY 1986 and FY 1987.

Will guidance costs continue to decline? The FY 1988 GD/C figures are higher than those in FY 1987 for both TASM and TLAM, and GD/C's FY 1989 AUR price is substantially above its FY 1988 bid. In any event, the potential for future savings is small. Only about 15 percent of the estimated cost of the remaining 2500 AURs is associated with the TLAM and TASM guidance sets (as defined pre-FY 1988). A level off in cost between FY 1988 and FY 1993 would reduce estimated savings by only $40 million.

Airframe costs have followed a more traditional pattern. As Fig. 11 shows, GD/C was the low bidder in the first two competitive lots. In the third lot, however, MDAC reduced its bid drastically and won 60 percent of AUR production. The following year, FY 1988, GD/C responded by lowering its bid by 35 percent and was awarded 70 percent of the total buy. That year MDAC's airframe price went up rather than down, but in the following year, FY 1989, the MDAC AUR price was cut by about 40 percent, and most of that would have had to come out of the airframe. The indications for the future, therefore, are mixed.

A look at the functional cost elements (see Figs. 12 and 13) before the FY 1989 buy suggests that costs could have bottomed out or even started an upward trend. The GD/C AUR price did in fact increase in FY 1989. A steep reduction in material costs in FY 1987 made it possible for MDAC to underbid GD/C, but FY 1988 saw a reversal of the downward trend in all of MDAC's cost elements. An increase in material costs often occurs at some point in missile production programs when vendors feel they have been squeezed too hard by a prime contractor. Thus, for MDAC's costs to level off at the FY 1988 level—or even to increase—would not have been surprising. The corporate decision to bid a price 37 percent below the FY 1987 price can be attributed only to a very strong desire to remain competitive.

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[4]Beginning in FY 1985 when firm fixed-price contracts were introduced, the contractors were not required to separate guidance and airframe costs. We were provided with estimates of FY 1985–1988 guidance costs by GD/C. The following method was suggested by MDAC for estimating its TLAM and TASM costs: For TLAM, use the FY 1984 unit cost and project down an 85 percent slope; for TASM, average the FY 1983 and FY 1984 unit costs and project down a 93 percent slope. Our comments on guidance and airframe costs, therefore, are based on estimates, not actual costs.

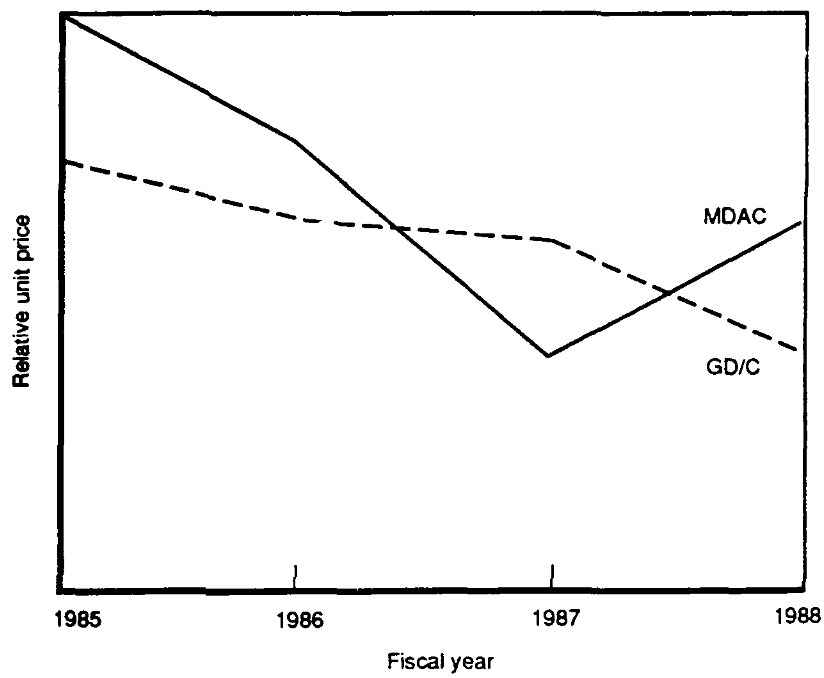

Fig. 11—Relative prices of MDAC and GD/C airframes (MDAC FY 1985 = 1.0)

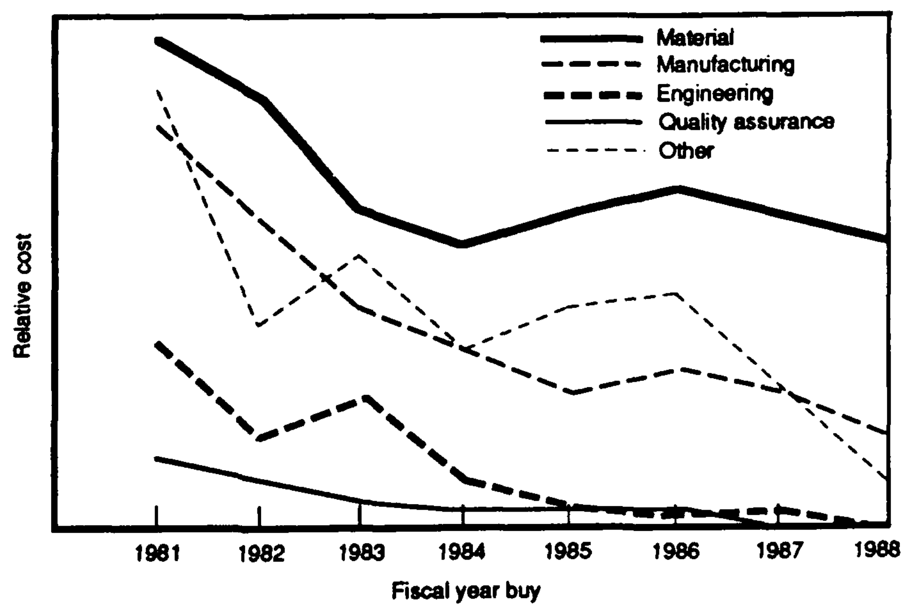

Fig. 12—GD/C functional cost elements

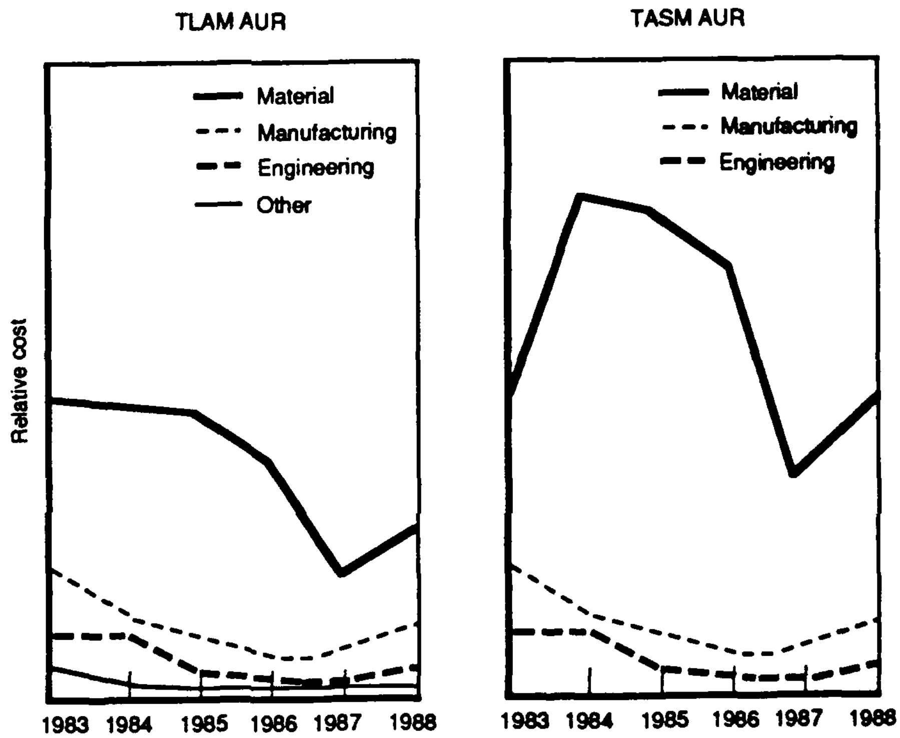

Fig. 13—MDAC functional cost elements

IV. SINGLE-SOURCE EXPERIENCE

The decision to bring a second producer into a program and to accept the incremental investment costs associated with that decision stems, at least in part, from a comparison of the estimated costs of the alternatives. When second-sourcing is selected, that after-the-fact analyses indicate savings is not surprising. However, many programs exist in which cost comparisons favored single-sourcing. One cannot generalize on the basis of Tomahawk experience that second-sourcing is always the preferred alternative.

Savings in any dual-source program hinge on the assumption that the cost-quantity curve will be steeper with two competing producers than with a single production source. When the single source predicts a relatively flat curve, as in the Tomahawk program, that assumption is generally valid. But not all single-source programs have such flat curves. Boeing's ALCM, for example, had a much steeper slope, and that program offers an opportunity to compare single- and dual-source procurement in a framework in which many of the elements are common.

Boeing started developing the subsonic cruise armed decoy (SCAD) in 1968. When that program ended in 1973, the Air Force was authorized to proceed with an air-launched cruise missile, AGM-68, that would build on the earlier SCAD experience. The AGM-68A had a relatively short range, 500–700 nautical miles, but Boeing developed a second version, AGM-68B, with a drop tank that extended the range to 1200–1500 nautical miles, a range comparable to that of Tomahawk.

In 1977, GD/C proposed an air-launched version of Tomahawk, AGM-109, as a replacement for ALCM, and formal competition between Boeing and GD/C was announced later that year. The OSD instructed the JCMPO to conduct a competitive flyoff to include operational tests with crews from the Strategic Air Command. During the ALCM competition, plans were made for a competitive production phase, and the request for proposal required Boeing and GD/C to bid on three options: leader/follower, with the competition winner as leader and the competition loser as follower; leader/follower, with the winner as leader but with further competition to select the follower; and sole-source production, with an option for multiyear procurement. The JCMPO chose the sole-source option, partially because second sources for the engine and inertial navigation element existed and because redundant suppliers for large portions of the airframe already existed.

Because of the preproduction competition, the ALCM program is not typical of single-source procurement programs. During the competition, Boeing developed dual suppliers for the four cast main body tanks in use in the AGM-86B. It did this at least in part to reduce cost by the use of competition between suppliers. That contracts for the first 625 units were awarded competitively undoubtedly affected Boeing's prices, and through the first 500 units Boeing achieved a 77 percent improvement curve. Cost then leveled off and increased slightly, but at 1600 units the single-source ALCM had declined to 15 percent of its unit 1 value, compared to 23 percent for the dual-source Tomahawk. Figure 14 shows how ALCM's production history compares with that of Tomahawk and another single-source missile, Harpoon.

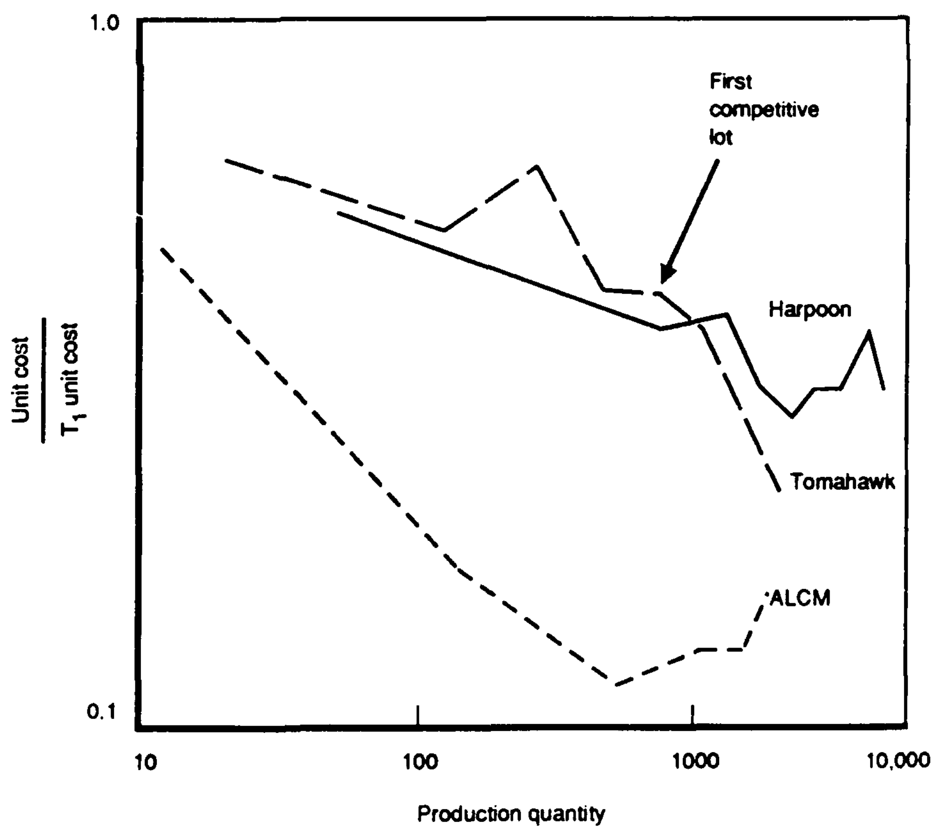

Fig. 14—Comparison of Tomahawk and two single-source programs

As sole-source producer of the Harpoon missile, MDAC's experience was much closer to the GD/C Tomahawk projection. Unit cost followed an 88.5 percent curve until lot 7, when a change in guidance design forced cost up. Cost increased again in lot 10 with a change in the sustainer section. Harpoon appears to be an outlier, however, among single-source missile production programs. A sample of six single-source programs for which published costs were available indicates that slopes of 85 percent or better are the rule rather than the exception:

Basic Hawk:	76% curve to unit 12,323
HARM:	82% curve to unit 1441; 90% from 1442 to 2841
Maverick A:	85% curve to unit 17,000
Phoenix A:	71% curve to unit 1223; 85% from 1224 to 2385
Redeye:	82% curve to unit 2033; 72% from 2034 to 25,020
Stinger:	84% curve to unit 5229; 82% from 5230 to 7283

An MDAC executive argues that the comparison between ALCM and Tomahawk is not completely fair:

> In comparing the ALCM learning curve to that of Tomahawk, a decisive factor is that Tomahawk is a significantly more complex missile design. As such, it is not as readily amenable to low-cost production processes and automated machining as the ALCM. Furthermore, the Tomahawk program pursued a number of variants simultaneously (TLAM, TASM, GLCM, AGM-109D), which decreased opportunities to concentrate on low-cost design improvements.[1]

However, despite complexity and the number of variants, both MDAC and GD/C were able to reduce price significantly in head-to-head competition. This suggests that early projections of the single-source improvement curve may have been unduly pessimistic. Fig. 15 illustrates the sensitivity of estimated savings to estimated single-source slope. When a program office anticipates that a single-source contractor will achieve no better than, say, an 89 or 90 percent slope, the *a priori* case for second-sourcing is very strong. But even CMP's projected single-source slope of 87.1 percent appears conservative compared with experience in a number of other single-source programs. Thus, that there have been substantial savings seems indisputable, but to assign a dollar value to those savings requires that an estimate be made of the cost that would have been incurred had GD/C been the sole source.

[1]Letter from R. E. Perkins, vice president, McDonnell Douglas Missile Systems Company, September 8, 1989.

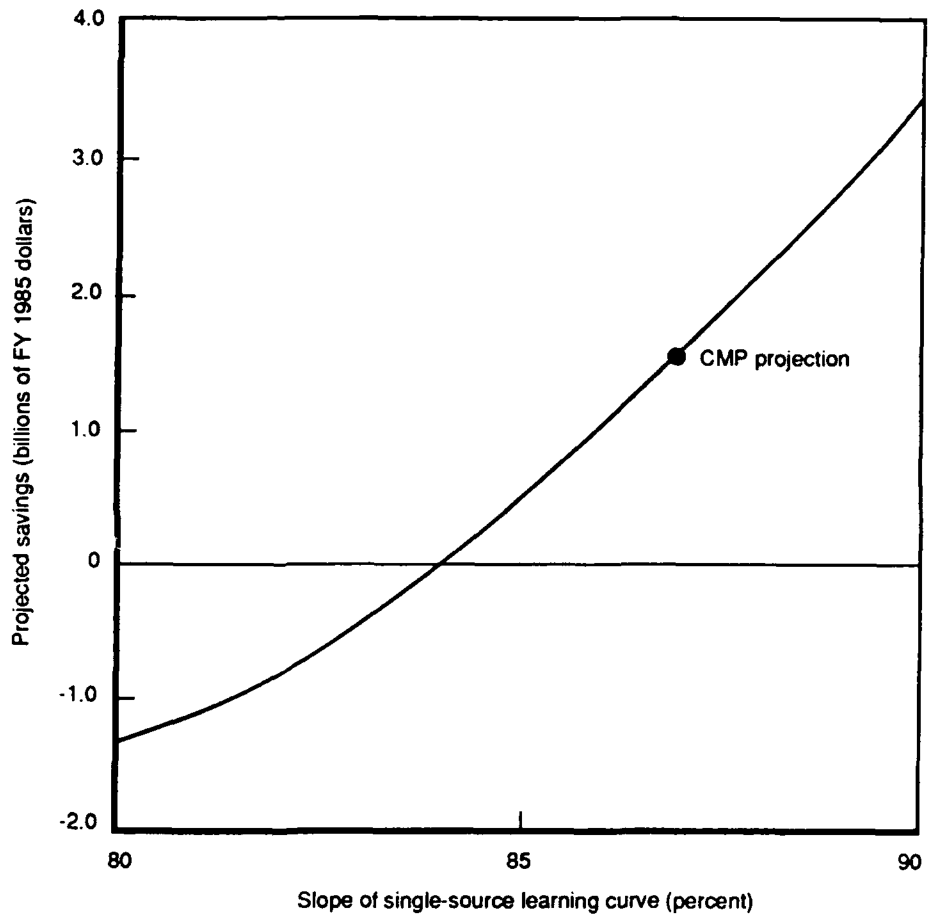

Fig. 15—Projected savings versus projected single-source learning curve slope

V. CONCLUSIONS

The Department of Defense, encouraged by Congress and the Office of Management and Budget, has worked hard in recent years to increase the amount of competition in the acquisition of major defense systems. The benefits of competition are well understood, but the unusual characteristics of major defense acquisitions militate against successful price competition in many situations. Bringing a second producer into a program implies incremental nonrecurring costs for additional tooling and special test equipment, a technical data package, licensing arrangements, qualification of a second producer, etc. Because of the loss of learning curve benefits, lower production rates for both companies, and smaller quantities over which to spread fixed and semifixed costs, recurring costs may also increase when a small production quantity is divided between two companies. Therefore, that second-sourcing will save money for the government in every major system procurement is not self-evident.

The purpose of having two AUR producers in the Tomahawk program was not primarily to save money. The CMP believed that dual sources would provide an expanded mobilization base, a greater degree of AUR reliability, and an opportunity to negotiate production contracts in a competitive environment; the initial CMP estimate of savings was based on the premise that only systems engineering and program management costs would be reduced. Nevertheless, the CMP forecasted in 1983 that, after taking into account the incremental costs incurred for tooling, qualification, etc., the break-even point for dual production would occur after 500–600 AURs were produced. In retrospect, it appears that break-even occurred at around 1400 units. The price of AUR did not fall as rapidly as predicted, and the potential for future price reductions may be limited. However, the CMP's early forecast of $500 million (then-year dollars) in savings now seems conservative. According to a 1989 Naval Center of Cost Analysis (NCA) estimate (see Fig. 16), competition savings up through FY 1994 will amount to $630 million in then-year dollars, $550 million in FY 1989 dollars, or $270 million in discounted FY 1989 dollars.[1]

[1]Naval Center of Cost Analysis, *Results of Navy Competition*, January 1989. Comparability adjustments by NCA include: conversion to FY 1989 values, adjustment of FY 1987 and previous procurement cost data for breakback, and weighting of TLAM and TASM guidance sets and airframes to allow for the variant mix between fiscal years.

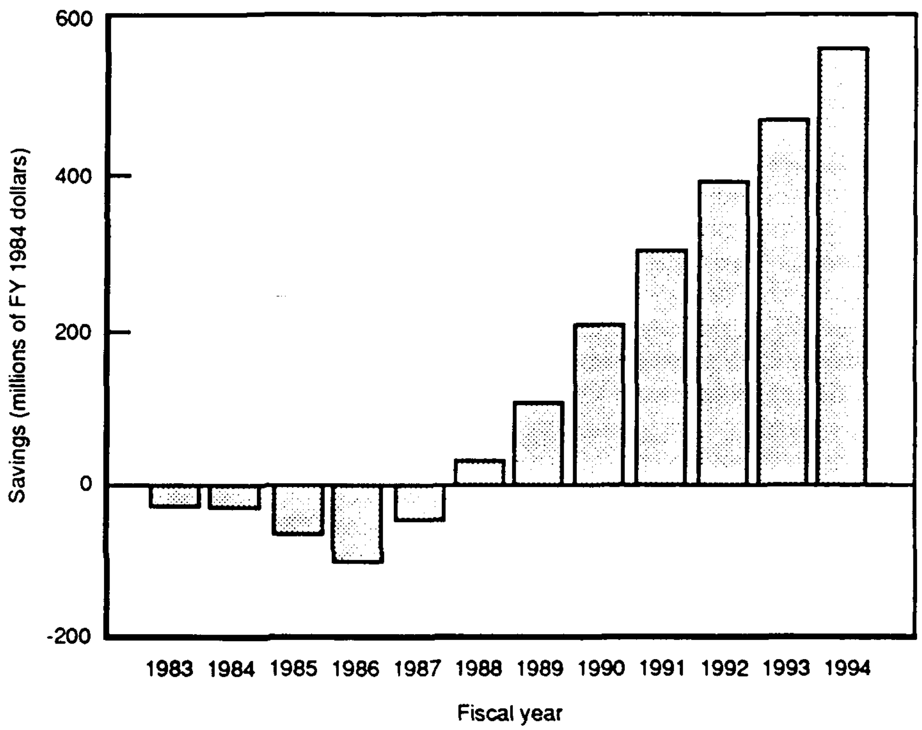

Fig. 16—1989 NCA estimate of cumulative savings

According to GD/C, the price benefits of competition could have been obtained without some of the costs had a different procurement strategy been followed. The CMP asked for, and received, two bids from both GD/C and MDAC in FY 1985—a dual-source bid and a competitive buyout bid. The latter consisted of firm fixed-price bids for FY 1985–1987 and "not-to-exceed" bids for FY 1988–1989. The Navy could have saved $189 million, GD/C maintains, by accepting the GD/C firm fixed-price proposal. The CMP does not disagree with the GD/C arithmetic, but points out that GD/C made its bid in a competitive environment. One could not count on continued cost reduction with the pressure of competition removed in the years after FY 1987, and GD/C's FY 1988 bid was in fact well below its projected sole-source price.

The comments of GD/C are not those of an impartial observer, because the firm has a natural bias favoring single-source procurement. From a standpoint of cost considerations alone, however, there is an argument to be made. Second-sourcing can be more expensive when the cost of entry is excessive or when a single source is motivated to use its inherently greater efficiency to drive down cost. Figure 16 shows that in FY 1986, the second year of head-to-head competition, a cumulative loss of about $70 million occurred. Competition did not begin in earnest until FY 1987, when MDAC won a 60 percent share with a bid about 15 percent lower than GD/C's. In FY 1988, GD/C came back to win a 70 percent share, then MDAC won a 65 percent share in FY 1989.

That contractors do respond to competition seems clear, but the timing and nature of those responses vary from program to program. The success of second-sourcing in the Tomahawk AUR program has resulted from specific factors not existing in every major system acquisition program. First, the cost of entry for a second producer was low—less than 2 percent of the projected production cost of over 4000 missiles. Second, the original airframe producer, GD/C, projected a relatively flat learning curve, 91.6 percent, in its own studies. To demonstrate savings when single-source target prices were established at the GD/C level was not hard. Virtually every other missile program has achieved a steeper slope, and GD/C showed later, under the spur of competition, that greater price reductions were achievable. Third, annual production quantities have been large enough to absorb the fixed and semifixed costs without distorting AUR unit costs unduly. Fourth, and not least in importance, the CMP worked hard and effectively at managing the competition aspects of AUR procurement.