# Does Dual Sourcing Lower Procurement Costs?

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### Abstract

Defense policy encourages the use of competition in defense procurement, especially for relatively simple technologies. A number of recent papers have raised questions about the value of dual sourcing, since it sacrifices scale economies, reduces the number of units over which each producer's learning occurs, and may induce collusion unless the bidders are unsure of each other's costs, e.g. for sophisticated technologies in the early phases of production. I explore the effects of dual sourcing using a panel dataset comprising 14 missile systems with an average of 12.5 years of production history per system. Each missile's complexity is categorized based on the nature of its guidance and control system. Consistent with theory, dual sourcing is used more often in innovation-intensive settings, in early periods of production, and after the incumbent producer demonstrates quality control problems. Nevertheless, the empirical results indicate that dual sourcing does not reduce government procurement costs.

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# 1 Introduction

Procurement of high-technology equipment presents an enormously challenging contracting problem. Relatively small production volumes for specialized products often lead to a situation of bilateral monopoly. The nature of future innovations cannot be precisely specified in advance, so contracts are inherently incomplete, and often experience substantial renegotiation over time.[1] Not surprisingly, high acquisition costs periodically prompt public outcry.

One response to these challenges has been an increased reliance on competition in the procurement process. Defense program managers are "required by law and regulation to incorporate effective competition in the acquisition of weapon systems, whenever practicable."[2] This is typically accomplished through a bidding competition that splits production between two different firms, a practice known as a "split-award auction" or "dual sourcing." (The term "second sourcing" is used when the incumbent producer is ousted upon poor performance and replaced by an entrant.) Recent consolidations in the defense industry, however, have shrunk the number of competing firms, raising concerns about maintaining adequate competition in the procurement process.[3]

The conventional wisdom about the benefits of competition has been called into question by recent theoretical work, which is generally rather pessimistic about the potential for competition to improve procurement practices.[4] The fundamental problem is that competition at the production stage tends to undermine incentives for investment at the R&D stage. These incentive effects are very difficult to identify empirically, so most empirical work has focused on savings at the production stage. Yet while numerous consultants have performed empirical analyses of production savings from dual sourcing, these studies were not grounded in economic theory, and have been roundly criticized by academics for their statistical shortcomings.[5]

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[1] Crocker and Reynolds[7] provide an empirical analysis of contractual incompleteness in defense procurement.

[2] Kratz, Drinnon and Hiller[11], p. 1-7. These authors, in their handbook for defense program managers, identify a number of specific legislative and regulatory requirements for the use of competition in procurement.

[3] Kovacic and Smallwood[10] provide a good survey of the issues raised by defense consolidation. The work of Cooper *et al.*[6] reflects the Defense Department's growing concern over the dwindling number of competitors in the defense industry.

[4] For example, Riordan and Sappington[13, p. 56] state that "Our principal conclusion is that second sourcing will often be undesirable, except possibly in special cases when the technology-transfer cost is of intermediate magnitude." Similarly, Laffont and Tirole[12, Ch. 8, p. 359] note that "We arrived at a relatively pessimistic assessment of the virtues of second sourcing...when substantial investments are at stake."

[5] Anton and Yao[3] critique these studies in detail. I discuss their criticisms in section 2 below.

Conventional views about the *types* of systems that might benefit from dual sourcing are also being challenged. For example, the Defense Systems Management College, in a handbook for defense program managers, states that "If the technology employed in the system is pushing the state-of-the-art, technology transfer is difficult to effect and production competition is difficult to establish."[6] Anton and Yao[1, p. 700], in contrast, use auction theory to argue that "In a stable technological environment where long-time competitors are likely to have good information about a competitor's costs, [bidding] coordination may be easy to achieve, and split award auctions will perform poorly from the viewpoint of the buyer. However, when innovation is a key competitive dimension, uncertainty introduced by the innovative process makes coordination in split award auctions more difficult and increases the attractiveness of a split award auction format to the buyer." In sum, our empirical knowledge of the circumstances under which procurement competition is valuable is very limited.

This paper uses a unique panel dataset to explore the performance of production competition in the procurement process. I analyze the price performance of a set of 14 tactical missiles, in production for an average of 12.5 years apiece; roughly 27% of the production years involve dual sourcing. Interesting results emerge in two areas: 1) the effects of dual sourcing on procurement costs, and 2) the conditions under which dual sourcing is used. In the first area, I find that contractor performance shows strong evidence of learning-by-doing as well as economies of scale. Dual sourcing, however, has no statistically significant effects on either of these dimensions; apparently the cost-reduction incentives created by competition just offset the loss of learning and scale economies. The conventional wisdom that dual sourcing reduces procurement costs does not appear to be true in practice. In the second area, I find that dual sourcing is used more often for complex technologies, for systems that undergo major design modifications, and in early periods of production—that is, in circumstances when bidding collusion is less likely. Non-price concerns are also important: dual sourcing is used more often after the incumbent experiences quality control problems. Finally, dual sourcing is used less often for systems procured under multiyear contracts, suggesting that competition and contractual completeness may be substitutes in the buyer's contracting toolkit. From a policy perspective, these findings suggest that dual sourcing policy should be driven, not by attempts to save money, but by non-price considerations such as providing incentives for product quality and maintaining an adequate defense industrial base.

The remainder of the paper is organized as follows. Section 2 discusses some relevant theoretical and empirical issues from the literature. Section 3 presents the basic model I

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[6] Kratz, Drinnon and Hiller[11], p. 3-5.

estimate, while section 4 describes the data used. Empirical results are presented in section 5, and section 6 concludes.

## 2 Theoretical and Empirical Issues

Previous work, both theoretical and empirical, helps frame the issues to be investigated in this paper. This section briefly reviews the main insights emerging from the literature.

### 2.1 Theory

A relatively small theoretical literature on second sourcing has emerged in recent years, most of which focuses on the possibility of ousting the incumbent and replacing it with a rival firm if incumbent performance is unsatisfactory. This literature includes the models of Anton and Yao[2], Demski, Sappington and Spiller[8], Laffont and Tirole[12, Chapter 8], and Riordan and Sappington[13]. As mentioned above, these models are generally quite pessimistic about the potential for second sourcing to improve procurement performance, due to the tension between reducing production stage rents and maintaining R&D investment. Unfortunately, the literature provides little guidance for an empirical analysis of dual sourcing (*i.e.* the splitting of production volumes between two producers), since most papers do not allow for the possibility that two producers will be used simultaneously; in the typical model, if the second source is called into action then it takes over the entire production of the incumbent. Anton and Yao[1] do offer a model of true dual sourcing (which they refer to as "split-award" auctions), but it lacks the intertemporal detail of some of the other papers cited above. Thus, there is no complete theory of dual sourcing upon which to draw for empirical purposes; nor do I attempt to produce one here. Instead, I review several theoretical papers of most relevance to this project, highlighting their testable implications and the points where modeling assumptions are at odds with the realities of defense procurement.

Before turning in more detail to papers directly related to dual sourcing or second sourcing, it is important to highlight two key elements of the defense contracting environment. First, the buyer's valuation of defense equipment is highly dependent on its quality,[7] yet it is extremely difficult to write complete contingent contracts that specify all dimensions of quality for new products whose development is still underway. Second, it is very difficult for the government to commit to not renegotiate procurement contracts. Congressional budgets are passed on a year-to-year basis, making multiyear contracting very difficult for the Department of Defense. The combination of non-contractible quality and renegotiation

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[7] The seller's investment in quality enhancement is thus a "cooperative" investment that raises the buyer's value, rather than a "selfish" investment that reduces the seller's cost. Che and Hausch[5] explore the difficulties of contracting when cooperative investments are involved.

renders contracts of limited value. Indeed, Che and Hausch[5] show that in such cases there is often no value at all in writing a long-term contract, thereby rationalizing the severe incompleteness observed in many defense procurement contracts.[8]

The initial theoretical papers on dual sourcing ignored issues of quality-increasing investment, and focused on the use of second-sourcing as a way to reduce the information rent of an incumbent producer with an informational advantage over the regulator.[9] For example, Anton and Yao[2] explicitly model the learning curve, which is a very important factor in defense procurement practice. They assume the incumbent producer knows a key parameter regarding the learning curve which is unknown to the government or to other producers. In these types of settings, a second source is more likely to be used the higher is the incumbent's initial price (or cost report).

Riordan and Sappington[13] present a model that incorporates non-contractible investment in quality on the part of the seller and lack of commitment power on the part of the buyer. They do not directly analyze dual sourcing, but they do provide a rationale for its use, as will be discussed shortly. These authors consider a model with both an R&D stage and a production stage. The government can commit to whether or not it will allow a second source to compete in the production stage with the firm that wins the R&D stage, but it cannot specify in a contract the desired level of quality or investment. After the R&D stage, the government has the ability to make a take-it-or-leave-it offer to the firm. The firms have private information about the cost of production. As a result, under sole sourcing firms have strong incentives to invest in R&D, since they are assured of earning information rents at the production stage. A winner-take-all competition at the production stage reduces information rents, but as a result it also reduces incentives for R&D. Riordan and Sappington show that the latter effect often dominates the former, so that the buyer prefers sole sourcing. Riordan and Sappington speculate that splitting production between the two sources may allow the buyer to finetune the procurement process and obtain better results than if second sourcing must be an all-or-nothing choice. The reason is that dual sourcing does not threaten to extract all of the firm's information rents, so does not have such a dampening effect on R&D. Although the authors do not mention it, it is also possible that if the firms must continue investing in R&D during the production phase, they will undertake more R&D under the competitive pressures of dual sourcing.[10] The authors' key testable result is that the optimal policy for the government is to observe the (unverifiable)

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[8] See Crocker and Reynolds[4] for details on the structure of defense procurement contracts.

[9] See Anton and Yao[2], and Demski, Sappington and Spiller[8].

[10] Several other important facets of the procurement process are ignored: the firms cannot exert effort to reduce their costs, there is no learning by doing, the incumbent firm has no bargaining power, there is perfect bidding parity between the incumbent and a new entrant at the beginning of the production stage.

quality of a newly developed product, and then select the incumbent developer to produce the product if quality is high (*i.e.*, above a certain threshold), but to oust the incumbent and replace him with a second supplier if quality is low.

Anton and Yao[1] offer a formal analysis of dual sourcing that provides more insight into its use. They develop an auction model in which two bidders each present the buyer with a schedule of bids corresponding to various possible splits of production between the two firms. Anton and Yao show that dual sourcing performs poorly if the bidders have full information about each others' costs, since in this case they have powerful incentives to tacitly coordinate their bids so as to achieve the monopoly price. With asymmetric information, however, dual sourcing can lead to a Pareto improvement relative to a winner-take-all auction. The empirical implication is that dual sourcing is more likely to be valuable to the buyer in innovation-intensive settings of substantial technological complexity, where the bidders know less about each others' costs and cannot readily coordinate their bids. As mentioned in the Introduction, this view is sharply at odds with conventional wisdom regarding when dual sourcing is likely to be valuable.

A third rationale for the use of dual sourcing is suggested by Crocker and Reynolds'[7] empirical study of Air Force engine procurement contracts. They find that procurement contracts tend to be less complete in a dual sourcing environment, and argue that this is sensible because the presence of alternative suppliers reduces the potential for contractor opportunism. With less concern about opportunism, the buyer can economize on the costs of writing more complete contracts. A complementary interpretation, not mentioned by the authors, is that dual sourcing is particularly valuable in the early stages of development and production, when technological uncertainties make complete contracting particularly difficult. Dual sourcing may then serve to discipline contractors when doing so contractually is simply not feasible.

The literature, then, offers several hypotheses about the use of dual sourcing:

1. Dual sourcing is more likely to reduce procurement costs when used for complex technologies.
2. Dual sourcing is more likely to be used after the incumbent charges a high price.
3. Dual sourcing is more likely to be used after the incumbent producer delivers products with quality defects.
4. Dual sourcing is more likely to be used for complex technologies than for simple ones.
5. Dual sourcing is more likely to be used in the early stages of production.

## 2.2 Empirical Challenges

Not surprisingly, the Department of Defense has long been interested in the role of competition in the procurement process, and has sponsored a number of empirical studies to assess the effects of dual sourcing on price competition. Anton and Yao (1990) review nine such analyses. The general conclusions from this work are: 1) The sole-source contract price declines over time; 2) It is unclear whether the learning curve is steeper under competition; 3) When there is a switch from sole-sourcing to dual-sourcing, the first competitive price is generally below the last sole-source price; 4) Electronics programs benefit more from competition than other programs, e.g. missiles or torpedoes/bombs; and 5) The second source won most of the winner-take-all competitions, but experienced (quality) problems in the post-competitive phase. All but one of the studies found that competition reduced costs.

Anton and Yao are generally quite critical of these empirical studies, for a variety of reasons. Some studies make obvious errors such as failing to incorporate learning effects, scale economies, and/or inflation. Almost all of the studies work with price data rather than cost data, so they must implicitly assume price is simply cost plus some proportional markup. Most of the studies estimate learning effects for each program separately, and thus lack enough data points to test interesting hypotheses. Some studies fail to include data for sole-source periods prior to dual sourcing. All but one of the studies fail to analyze programs that only used sole-sourcing. As a result the samples may be biased because the choice to go to dual sourcing may be conditioned upon high costs by the initial producer. In fact, this concern is supported by the fact that the second source won ensuing winner-take-all competitions in 16 of 17 cases.

In light of all the foregoing flaws, Anton and Yao make some suggestions for future empirical work. These include: 1) Pool time series data over multiple programs to allow for hypothesis tests; 2) Include both sole-source and dual-source programs; 3) Recognize that the savings from competition depend upon both sources having lowered costs to roughly the same degree, since otherwise the low-cost firm will bid to just undercut the high-cost firm's price; and 4) Recognize that incentives for cost-reduction during the competitive phase depend on the expected form of future bidding competitions, e.g. split-award vs. winner-take-all.

The empirical work of Crocker and Reynolds[7] postdates the survey of Anton and Yao[3]. Their focus is also different, since they are oriented not toward price competition, but rather toward understanding the degree of incompleteness observed in various contractual environments. Nevertheless, their work suggests that it may be interesting to study interaction effects between the use of dual sourcing and the completeness of procurement contracts.

### 2.3 Implications of Previous Work

The research summarized above has several important implications for this paper. First, technological complexity (and the attendant asymmetric information across rival firms) has important effects on the performance of dual sourcing, and should be controlled for empirically. Second, interaction effects between contractual completeness and the use of dual sourcing should offer additional insight into the importance of complexity and uncertainty in procurement management. Third, the use of panel data on a set of related procurement programs over time should allow for improvements over previous empirical work. Fourth, it is important to avoid selection bias by including both missiles with and without periods of dual sourcing. Fifth, to assess the performance of dual sourcing, it is important to separate winner-take-all auctions from split-award auctions, and to control for the prior experience of the incumbent when estimating the benefits of dual sourcing. Finally, analysis of production costs provides an incomplete basis for policy decisions. It is also necessary to examine how alternative forms of production competition affect incentives for investment in R&D. While R&D investment is beyond the scope of the present paper, it must be kept in mind when evaluating the empirical results. These six implications all figure importantly in the analysis to follow.

## 3 The Model

Both the consequences and the causes of dual sourcing are of interest. This section presents the empirical models I used for estimating these issues.

### 3.1 Price Effects of Dual Sourcing

I model the sellers' price performance according to the equation

$$Y_{it} = \alpha_i + (\beta + \gamma D_{it} + \tau W_{it}) X_{it} + \epsilon_{it}, \tag{1}$$

where $Y_{it}$ is the unit "flyaway" cost for the $i^{th}$ system in year $t$, $\alpha_i$ is a system-specific fixed effect, $X_{it}$ is a set of independent variables, $D_{it}$ is a dummy variable that captures the decision to use dual sources (a split award auction), $W_{it}$ is a dummy variable that captures the decision to use a winner-take-all auction rather than a split-award auction, and $\epsilon_{it}$ is an error term.

The structure of the model emphasizes the possibility that dual sourcing changes the relationship between the independent variables in $X$ and flyaway costs $Y$. Given the importance of learning-by-doing and scale economies in producing sophisticated weapons systems, the most important of these shifts are likely to be with respect to these two variables. I use the following functional form, standard in the literature estimating learning effects:

$$FLYAWAY_{it} = e^{a_{it}} CUMQ_{it}^{b1} QTY_{it}^{b2} \tag{2}$$

where $FLYAWAY_{it}$ is the per unit "flyaway" cost of system $i$ in period $t$, $CUMQ_{it}$ represents cumulative production of system $i$ through period $t$, and $QTY_{it}$ is current production of system $i$ in period $t$ alone. For econometric purposes this is normally estimated by taking natural logarithms on both sides of the equation to obtain

$$LNFLY_{it} = a_{it} + b_1 LNCUMQ_{it} + b_2 LNQTY_{it}. \tag{3}$$

The coefficients in equation (3) are assumed to have the following structure:

$$a_{it} = \alpha_i + \delta_1 DESGNDUM_{it} + \delta_2 MULTIDUM_{it} \tag{4}$$

$$b_1 = \beta_1 + \gamma_1 DUALDUM_{it} + \eta_1 WTADUM_{it} + \tau_1 COMPLEX_i \tag{5}$$

$$b_2 = \beta_2 + \gamma_2 DUALDUM_{it} + \eta_2 WTADUM_{it} + \tau_2 COMPLEX_i \tag{6}$$

where $DESGNDUM_{it}$ is a dummy variable indicating whether a major design change was implemented for system $i$ in period $t$, $MULTIDUM_{it}$ is a dummy variable indicating whether a multiyear contract was in use for system $i$ in period $t$, $DUALDUM_{it}$ is a dummy variable indicating whether dual sourcing was used for system $i$ in period $t$, and $WTADUM_{it}$ is a dummy variable indicating whether a winner-take-all competition was held for system $i$ in a period $t$ subsequent to a previous phase of dual sourcing.

My analysis departs from the previous empirical literature both in terms of its explicit focus on hypotheses from the theoretical literature and in its use of panel data. As noted above, most previous studies treat each system separately, thus reducing the number of datapoints for each regression to the point where testing hypotheses about dual sourcing becomes difficult if not impossible. The biggest assumption involved in pooling the systems into a single panel is that the model in equations (1) through (6) is actually the "true" model, so that variations in the coefficients $b_1$ and $b_2$ are explained by dual sourcing, but not by factors such as technological complexity. I test specifically for whether technological complexity affects the slope of the learning curve in section 5.2 below.

### 3.2 Factors Prompting the Use of Dual Sourcing

Because the dual sourcing decision is made prior to the observation of price performance, $DUALDUM_{it}$ can be treated as a pre-determined variable. Nevertheless, it is of some interest to probe the factors that induce the government to use dual sourcing for particular missiles. I thus estimate a probit model in which the dependent variable $DUALDUM$ represents the binary choice between sole sourcing and dual sourcing (with values 0 and 1, respectively).[11] My fundamental prediction is that, if the difference in expected benefits to the government between dual sourcing and sole sourcing is positive, then the government will use dual sourcing to procure a given missile system. More precisely, I are interested in the relationship

$$\Delta_{it} = \theta' Z_{it} + \mu_{it}, \tag{7}$$

where $\Delta_{it}$ is the net benefit of using dual sourcing instead of sole sourcing, for the $i^{th}$ missile and the $t^{th}$ period, $\theta$ is a vector of coefficients, $Z_{ij}$ is a matrix of independent variables, and $\mu_{ij}$ is an error term assumed to be $IN(0,1)$. Of course, the econometrician cannot observe $\Delta_{ij}$ directly. Instead I observe only the discrete choice between sole sourcing and dual sourcing, *i.e.* I observe a dummy variable $DUALDUM_{it}$ defined by

$$DUALDUM_{it} = \begin{cases} 1 & \text{if } \Delta_{it} > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

It is this variable that I estimate with the probit. More specifically, I estimate the equation

$$\begin{aligned} DUALDUM_{it} \quad = \quad & \theta_1 LNCUMQ_{it} + \theta_2 LNQTY_{it} + \theta_3 DESGNDUM_{it} \\ & + \theta_4 MULTIDUM_{it} + \theta_5 FLYRATLG_{it} + \theta_6 NUMBID_t + \theta_7 PERIOD_{it} \\ & + \theta_8 FYR_{it} + \theta_9 COMPLEX_i + \theta_{10} LENGTH_i \\ & + \theta_{11} QTOGO_{it} + \theta_{12} PROBLEMS_{it} + \mu_{it} \end{aligned} \tag{9}$$

where $NUMBID_t$ is the number of potential bidders to produce a system in period $t$, $PERIOD_{it} \equiv t$ indicates that system $i$ is in its $t^{th}$ year of production, $FYR_{it}$ is the fiscal year when system $i$ was in its $t^{th}$ period of production, $COMPLEX_i$ is a dummy variable indicating whether a particular system is technologically complex or not, $LENGTH_i$ indicates the total number of periods of production for system $i$ over its production life, $QTOGO_{it}$ is the number of units of system $i$ that will be produced over the remainder of its production life, $FLYRATLG_{it}$ is the ratio of system $i$'s flyaway costs in period $t-1$ to its

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[11] In this estimation I consider only the choice between sole sourcing and dual sourcing. As described below, I conducted a separate estimation for the choice between dual sourcing and a winner-takes-all auction.

flyaway costs in period 1, and $CUMPROB_{it}$ is the cumulative number of quality assurance problems experienced by missile $i$ through period $t$.

The motivation for selecting these particular variables comes largely from the conventional wisdom about when dual sourcing is likely to be efficacious. The monograph *Establishing Competitive Production Sources: A Handbook for Program Managers*, published by the Defense Systems Management College, provides a list of variables that form a "Preliminary Screen of Programs for Competition," indicating that dual sourcing is more promising when: *total quantity* (captured by the variable $QTOGO_{it}$) is larger; *production duration* (captured by $LENGTH_i$) is greater; the *progress curve* (captured by $FLYRATLG_{it}$) is flatter; the *technical complexity* (captured by $COMPLEX_i$) is more modest; and *contract complexity* (captured by $MULTIDUM_{it}$, which also serves as an independent variable in estimating flyaway costs) is more modest. In addition, I include a measure of the number of potential bidders who have the technological capability to serve as a second source,[12] $NUMBID_t$, reasoning that dual sourcing is more likely when the number of alternative bidders is greater. A more detailed description of these variables follows in the next section.

## 4 Data Description

Unless stated otherwise, the missile data are from the Defense Department's Selected Acquisition Reports (SAR). The variables used and summary statistics are presented in Table 1. Fourteen different missile systems were examined. The total number of observations (system-periods) is 175, so the average number of periods/system is 12.5 years. The number of system-periods of sole source procurement was 107, the number of system-periods of dual sourcing was 55, and of winner-take-all auctions was 13. The number of periods under multiyear contract was nine; Stinger was under a multiyear contract from 1988-1991, and Patriot from 1987-1991.[13] Two of the missiles (Tomahawk and Stinger) experienced major design changes during the production period.[14] The number of potential bidders was 2 in 1975, and was between 4 and 8 in all other years.[15]

As described in section 3, the dependent variable on which the analysis focuses is "flyaway costs" per missile, *i.e.* procurement prices to the government. The two basic production variables that drive costs are cumulative production (to track learning effects) and scale

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[12] See Cooper *et al.*[6] for details on this variable.

[13] Before Defense Department procurement officials can enter into a multiyear contract, they must somehow establish that the multiyear contract will produce savings of at least the Congressionally mandated minimum level of 15%. See Cooper et al.[6], p. v.

[14] Detailed descriptions of the missile systems can be found in Cooper *et al.*[6].

[15] The number of bidders was determined through the combined judgments of several experts familiar with the missile industry. More details are available in Cooper *et al.*[6].

(to track scale economies). Cumulative production was measured using the "lot midpoint" for each year. This is the quantity at which learning effects would be precisely equal to their average over the entire production lot for that year. The natural logarithm of the cost and production data was employed to simplify the estimation process. A plot of the natural log of flyaway costs vs. the natural log of cumulative production is presented in Figure 1 for the sample as a whole, with each datapoint identified by an abbreviation for the missile's name. The individual graphs for each missile separately are presented in Figure 2. Note that the production quantities include both U.S. and foreign missile sales.

| Variable | Definition | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| LNFLY | Log of Unit Cost | -0.978 | 1.576 | -4.300 | 1.770 |
| LNCUMQ | Log of Cumulative Production Quantity | 8.144 | 1.858 | 3.757 | 12.337 |
| LNQTY | Log of Current Production Quantity | 6.742 | 1.522 | 1.792 | 10.212 |
| DESGNDUM | Dummy Variable = 1 if Major Redesign | 0.079 | 0.270 | 0 | 1 |
| MULTIDUM | Dummy Variable = 1 if Multiyear Contract Used | 0.051 | 0.222 | 0 | 1 |
| DUALDUM | Dummy Variable = 1 if Dual Sourcing Used | 0.3143 | 0.466 | 0 | 1 |
| WTADUM | Dummy Variable = 1 if Winner-Take-All Auction Used After Dual Sourcing | 0.08 | 0.272 | 0 | 1 |
| NUMBID | Number of Potential Bidders | 6.890 | 1.193 | 2 | 8 |
| COMPLEX | Dummy Variable = 1 if Technology is Complex | 0.5 | 0.501 | 0 | 1 |
| LENGTH | Years of Procurement | 12.5 | 3.627 | 7 | 20 |
| FYR | Fiscal Year | 1986.173 | 4.607 | 1975 | 1995 |
| PERIOD | Period of Production | 10.5 | 5.777 | 1 | 20 |
| QTOGO | Total Future Production | 9777.868 | 27108.06 | 0 | 225639 |
| FLYRATLG | Ratio of Previous Period's Cost to Initial Period Cost | 0.397 | 0.269 | 0.054 | 1.046 |
| PROBLEMS | Cumulative Problems Noted in AW&ST | 2.189 | 3.253 | 0 | 14 |

Table 1: Summary Statistics

Technological complexity plays an important role in the analysis, particularly that of the missiles' guidance and control systems. The simplest missile in the dataset is the TOW 2, a vehicle-mounted anti-tank missile guided by an operator who keeps the target centered in a telescopic sight. Moving the sight sends electronic signals through two wires to the missile to correct its flight. At the other extreme are PATRIOT and Tomahawk, "fire-and-forget" missiles with highly sophisticated guidance and control systems that pushed the state of the art when they were fielded.[16] The complexity of the guidance and control system of each missile is described in Table 2.

| System | Type | Guidance | Complexity |
|---|---|---|---|
| Patriot | Surface-to-air | Track-via-missile | Complex |
| Tomahawk | Surface-to-surface, submarine-to-surface | Inertial navigation, TERCOM updates, digital scene matching | Complex |
| AMRAAM | Air-to-air | Active radar | Complex |
| Harpoon | Air-to-surface, surface-to-surface, submarine-to-surface | Active radar, attitude reference assembly | Complex |
| Phoenix | Air-to-air | Semi-active radar in midcourse; active radar in terminal phase | Complex |
| Standard Missile 2 | Surface-to-air | Semi-active radar | Complex |
| Sparrow AIM/RIM-7M | Air-to-air, surface-to-air, surface-to-surface | Semi-active radar | Complex |
| ATACMS | Surface-to-surface | Ring laser gyro | Simple |
| HARM | Air-to-ground | Radio frequency homing | Simple |
| $I^2R$ Maverick | Air-to-surface | Infrared homing | Simple |
| Hellfire | Air-to-ground | Semi-active laser seeking | Simple |
| Sidewinder AIM-9M | Air-to-air | Infrared homing | Simple |
| Stinger | Surface-to-air | Infrared homing | Simple |
| TOW2 | Surface-to-surface | Wire guided | Simple |

Table 2: Technological Characteristics of Missile Systems

The key policy variable for this analysis is the decision regarding how many producers to use. Table 3 provides a history for all the missiles, showing all periods for which SAR data were available, and indicating for each missile in each year whether production was sole-sourced or dual-sourced. In some cases, it was necessary to make judgement calls regarding when the transition to dual sourcing began. Take the case of the Phoenix missile, for example, as described by Cooper et al.[6, pp. 2-13 and 2-14]. Hughes Aircraft began

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[16] See Cooper *et al.*, chapter 4, for further description of each missile's technological complexity.

production as the sole source in 1980, and enjoyed a monopoly position for six years. In 1986, Raytheon obtained a contract to produce 10 “learning units,” in 1987 Raytheon produced 56 “qualification units,” and in 1988 Raytheon built 180 units under a “directed contract.” Finally, in 1989, Raytheon competed in a split-award auction against Hughes. I have chosen to classify the years 1986-1988 as dual sourced. On one hand, this is problematic, since there was no formal split-award auction and thus no chance for bidding collusion. On the other hand, classifying these years as sole sourced would arguably be worse, since Hughes was effectively on notice that it faced competition and could no longer take its monopoly position for granted. Note that several missiles shift to a “winner-take-all” bidding competition after a period of split award auctions, with the playing field presumably leveled during the period of dual sourcing. The dummy variable “WTADUM” indicates these periods of winner-take-all competition after dual sourcing.[17]

| Year | AMRAAM | ATACMS | HARM | HARP | HELL | MAV | PAT | PNX | SIDE | SPAR | STD | STG | TOM | TOW 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | | | | Sole | | | | | | | | | | |
| 1976 | | | | Sole | | | | | | | Sole | | | |
| 1977 | | | | Sole | | | | | | | Sole | | | |
| 1978 | | | | Sole | | | | | | | Sole | Sole | | |
| 1979 | | | | Sole | | | | | | | Sole | Sole | | |
| 1980 | | | | Sole | | | Sole | Sole | | Sole | Sole | Sole | Sole | |
| 1981 | | | Sole | Sole | | | Sole | Sole | Sole | Sole | Sole | Sole | Sole | Sole |
| 1982 | | | Sole | Sole | Sole | Sole | Sole | Sole | Dual | Sole | Sole | Sole | Dual | Sole |
| 1983 | | | Sole | Sole | Sole | Dual | Sole | Sole | Dual | Dual | Sole | Sole | Dual | Sole |
| 1984 | | | Sole | Sole | Dual | Dual | Sole | Sole | Dual | Sole | Sole | Sole | Sole | Sole |
| 1985 | | | Sole | Sole | Dual | Dual | Sole | Sole | Dual | Dual | Sole | Sole | Dual | Sole |
| 1986 | | | Sole | Sole | Dual | Dual | Sole | Dual | Dual | Dual | Sole | Sole | Dual | Sole |
| 1987 | Dual | | Sole | Sole | | Dual | Sole | Dual | Dual | Dual | Sole | Sole | Dual | Sole |
| 1988 | Dual | | Sole | Sole | Dual | Dual | Sole | Dual | Dual | Dual | Sole | Sole | Dual | Sole |
| 1989 | Dual | Sole | Sole | Sole | Dual | Dual | Sole | Dual | | Dual | Dual | Sole | Dual | Sole |
| 1990 | Dual | Sole | Sole | Sole | WTA | WTA | Sole | WTA | | | Dual | Dual | Dual | Sole |
| 1991 | Dual | Sole | Sole | Sole | WTA | WTA | Sole | | | | Dual | WTA | Dual | Sole |
| 1992 | Dual | Sole | Sole | | WTA | | | | | | Dual | | Dual | Sole |
| 1993 | Dual | Sole | Sole | | WTA | | | | | | Dual | WTA | Dual | Sole |
| 1994 | Dual | Sole | | | WTA | | | | | | Dual | | WTA | |
| 1995 | Dual | Sole | | | WTA | | | | | | Sole | | WTA | |

Table 3: Production Runs and Sourcing of Missile Systems

Quality control problems are a potentially important factor affecting the decision to utilize dual sourcing. I proxied for this variable by performing a search of LEXIS/NEXIS by missile, using the keywords “problem,” “delays,” “defects,” and “malfunction.” I found a total of 43 stories reporting the use of one or more of these terms for a missile in my sample. Table 4 summarizes this data for complex and simple missiles separately. Interestingly, complex missiles are more than three times as likely to suffer quality control problems than are simple missiles. Five missile systems accounted for 88/

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[17] A remarkably careful reader might note that there are only 174 entries in Table 3, while the text states there are 175 observations. The reason is that the Harpoon data include an “extra” period with date “FY7T” between “FY76” and “FY77.”

|  | Complex | Simple |
|---|---|---|
| Number of Reported Problems | 35 (21) | 8 |
| Number of Observations | 96 (87) | 79 |
| Problems/System-Year | 0.36 (.24) | 0.10 |

Table 4: Reported Quality Control Problems for Complex and Simple Missiles
(Results excluding AMRAAM in parentheses)

## 5 Empirical Results

I begin by testing whether dual sourcing lowers procurement costs, and then turn to analysis of the government's decision regarding when to use dual-sourcing.

### 5.1 Price Improvement under Dual Sourcing

The government's decision to use dual sourcing for a given missile in a given year is always made before that year's production is begun. Thus, the dual sourcing dummy is a predetermined variable and can be treated as exogenous in a regression. Note that estimation of equation (3) requires the construction of variables that reflect multiplicative interaction between $DUALDUM$, $WTA$, $COMPLEX$ and $LNCUMQ$ and $LNQTY$. These variables have the names $DUALCUMQ$, $DUALQTY$, etc. Table 5 presents estimates of flyaway costs.

**Table 5: Estimated Flyaway Costs with Missile Fixed Effects**

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| LNCUMQ | -.2287[a] | -.2491[a] | -.2393[a] |
| | (-7.602) | (-7.896) | (-7.661) |
| LNQTY | -.3219[a] | -.2925[a] | -.2568[a] |
| | (-6.054) | (-5.527) | (-5.700) |
| DESGNDUM | .5405[a] | .8214[a] | .1846 |
| | (5.280) | (6.298) | (1.270) |
| MULTIDUM | -.2999[a] | -.1953 | -.4861[a] |
| | (-2.991) | (-1.380) | (-3.613) |
| DUALCUMQ | .0028 | -.0402 | -.0638 |
| | (.065) | (-.514) | (-1.265) |
| DUALQTY | -.0103 | .0127 | .0896 |
| | (-.192) | (.141) | (1.379) |
| WTACUMQ | .0498 | .1303[c] | -.2684 |
| | (.725) | (1.902) | (-1.223) |
| WTAQTY | -.1014 | -.2119[b] | .3049 |
| | (-1.130) | (-2.430) | (.985) |
| COMPCUMQ | -.0345 | | |
| | (-.909) | | |
| COMPQTY | .0551 | | |
| | (.853) | | |
| Adjusted R-squared | .9791 | .9712 | .94047 |
| F value | 354.82 | 188.96 | 108.20 |
| Number of observations | 175 | 79 | 96 |

[a] Significant beyond the 1% level

[b] Significant beyond the 5% level

[c] Significant beyond the 10% level

The results indicate that both learning and scale economies are very important determinants (statistically and economically) of a missile system's price to the government. The "slope" of the learning curve is -.229, meaning that a doubling of cumulative output causes unit price to fall by 22.9%. Similarly, scale economies are evident in that a doubling of per-period production reduces unit price by 32.2%. Interestingly, complex and simple missiles do not differ significantly in either the steepness of the learning curve or the extent of scale economies; the coefficients on $COMPCUMQ$ and $COMPQTY$ are small in magnitude and nowhere near statistical significance.

Major design changes cause substantial and statistically significant increases in procurement prices, as is to be expected. The coefficient on $DESGNDUM$ is .5405, so a major design change raises unit flyaway cost by a factor of $\exp .5405 = 1.7169$, meaning that costs rise by 72%. Multiyear contracting, on the other hand, reduces flyaway costs by a factor of $\exp -.2999 = .7409$, implying that costs fall by 25.91%. This level exceeds the Congressionally mandated minimum of 15% savings from a multiyear contract, and suggests that the typical lack of commitment power on the part of Department of Defense procurement officials imposes significant costs on the procurement process.

Dual sourcing does not appear to have significant effects on unit procurement prices. Neither the slope of the learning curve nor the extent of scale economies changes significantly when dual sourcing is introduced, *i.e.* neither $DUALCUMQ$ nor $DUALQTY$ are significant at even the 80% level. These results fly in the face of most prior studies, which tend to conclude that dual sourcing reduces procurement costs. There are several possible explanations. First, it is important to recognize that my data include both recurring (variable) and non-recurring (fixed) costs, unlike some previous studies. Thus, while dual sourcing might stimulate greater cost-cutting effort and thus reduce recurring costs, the transfer of technology to a second source raises non-recurring costs; my results indicate that these two effects essentially cancel one another out. Similarly, greater competition might stimulate a more rapid descent of the learning curve, but with production split between two firms each firm's cumulative production will grow slower. Again, the two effects work against one another. Splitting production also causes each firm to sacrifice scale economies, but again this could be offset by the effects of greater competition. In the end, according to the data, the net effect of all these factors is a wash. Dual sourcing, normally billed as a way to reduce procurement costs, does not appear to save the government money, at least not in my panel of missile data.

Finally, I consider the impact of holding a winner-takes-all competition after a number of periods of dual sourcing. This could potentially be a useful procurement tool if the period of dual sourcing allows the second source to descend the learning curve to the point where it is cost-competitive with the incumbent, and then the winner-takes-all competition produces particularly intense bidding behavior. The data do not offer much support for this hypothesis, however, as neither $POSTCUMQ$ nor $POSTQTY$ are statistically significant. The coefficients are of the expected signs, with the move to a winner-takes-all competition slowing the rate of learning but offering some gains in terms of economies of scale.

Regressions (2) and (3) present results for the subsamples of simple and complex missiles, respectively. Turning first to the simple missiles, the general pattern of results is quite similar to that in estimation (1). The magnitude of learning and scale effects is very close to that for the pooled sample. Major design changes appear to have an even greater impact on the costs of simple missiles, raising unit prices to the government by 127%. Multiyear contracting, in contrast, is somewhat less useful for simple missiles, producing a price reduction of about 18%. Once again, dual sourcing has no significant impacts on learning or scale economies. The shift to a winner-takes-all auction after a phase of dual sourcing does have significant effects for simple missiles, with the learning curve flattening somewhat while capacity utilization (and hence scale economies) improve.

Estimation (3), which considers only the complex missiles, is again quite similar to the earlier results. Learning and scale effects do not change greatly, and dual sourcing remains a statistically insignificant factor. The magnitude of the coefficients of $DUALCUMQ$ and $DUALQTY$ are considerably higher for complex than for simple missiles, however, and so are the significance levels; nevertheless, these variables are still only significant at the 21% and 17% levels, respectively.[18] The use of winner-takes-all competition has no significant effect on the price of complex missile systems. Major design changes also have no significant impacts for complex missiles, which is consistent with the notion that complex technologies require an ongoing set of modifications even without such design adjustments. Multiyear contracting, however, appears especially valuable for complex missiles, producing a 48.5% price reduction.

None of the above results support the use of dual sourcing as a way to cut procurement costs.[19] This may be viewed as disappointing, given the expectations created by pronouncements from members of Congress and from officials in the armed forces. From another perspective, however, the insignificant effect of dual sourcing on procurement costs can be seen as comforting. If the government uses dual sourcing for reasons other than cost savings, such as disciplining contractors who produce poor quality missiles or maintaining a broad base of potential suppliers, then these benefits appear to be achievable at little or no extra cost to taxpayers. The next section turns to an examination of the factors that determine when the government elects to use dual sourcing.

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[18] Since these coefficients are not too far from conventional measures of significance, I performed a simple numerical simulation to determine how many periods of dual sourcing would be required to produce economic savings to the government. At the average annual production quantity for a complex missile (403.4), twelve years of dual sourcing would be required before the benefits of a steeper learning curve would outweigh the costs of lost scale economies.

[19] The only (weak) evidence supporting the value of dual sourcing is that *if* the dual-sourcing coefficients for simple missiles were non-zero (there is at least a 60% chance they are zero), they would indicate that dual sourcing produces savings for simple missiles from the first period onwards. This is because there is little loss of scale economies for the simple missiles.

## 5.2 The Dual-Sourcing Decision

This section explores the determinants of the government's decision to use dual-sourcing for a particular missile in a particular year. Because transitions from one sourcing mode to another occur in an ordered sequence from sole sourcing to dual sourcing to winner takes all, I proceed in two steps. First, I consider the government's choice between sole and dual sourcing, excluding from the analysis all winner-take-all auctions. Second, I consider the government's choice between dual sourcing and winner takes all, excluding all observations of sole sourcing.

Table 6 presents the results of a probit analysis of the dual-sourcing dummy variable DUALDUM, when all observations of winner-take-all auctions are excluded from analysis. Estimation (1) considers the entire sample of missiles; estimation (2) considers only the transitions from sole sourcing, *i.e.* it excludes all observations which follow a period of dual sourcing, and estimation (3) considers only the subsample of missiles that switched from sole to dual sourcing at some point during the history of production.

**Table 6: Probit Analysis of the Dual-Sourcing Decision**

(t-statistics in parentheses)

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| Flyratlg | -0.4613 | 1.0223 | 1.7690 |
| | (-.523) | (.727) | (1.234) |
| Problems | 0.2675[a] | .2994[c] | .1927 |
| | (3.311) | (1.802) | (1.362) |
| Complex | .8383[c] | .8203 | 1.0728 |
| | (1.691) | (.990) | (1.505) |
| Period | −0.4895[a] | -0.8534[b] | -.1702 |
| | (-2.989) | (-2.395) | (-1.138) |
| FYR | .1972[b] | 0.2663 | .1682 |
| | (2.054) | (1.421) | (1.134) |
| Lncumq | 1.2795[a] | 1.3830[b] | .7473 |
| | (3.167) | (2.043) | (1.180) |
| Lnqty | -.3837 | -.00004 | -.1990 |
| | (-1.066) | (.000) | (-.578) |
| Desgndum | .7529 | 1.1310 | -.3789 |
| | (1.585) | (1.272) | (-.834) |
| Multidum | −1.1323[c] | .5183 | .0750 |
| | (-1.691) | (.624) | (.081) |
| Numbid | 0.1882 | 0.5467 | .5867[a] |
| | (1.042) | (1.496) | (2.616) |
| Length | .1387 | .3659[c] | .0691 |
| | (1.322) | (1.771) | (.566) |
| QTOGO | −0.00005[a] | -.00008[c] | .00001 |
| | (-2.865) | (-1.783) | (.230) |
| Constant | -399.7563 | -544.7112 | -344.6623 |
| | (-2.079) | (-1.452) | (-1.173) |
| Number of observations | 148 | 101 | 95 |
| L-R Statistic | 82.4188 | 18.8092 | 31.1727 |

[a] Significant beyond the 1% level

[b] Significant beyond the 5% level

[c] Significant beyond the 10% level

The overall predictive power of the estimations is summarized in Tables 7-9, which compare the predicted and actual values of the dual sourcing dummy. Estimation (1) correctly predicts 84.45% of the 148 observations. Simply predicting that "sole-sourcing is always used" would correctly predict only 63.5% of the observations, so the estimation is adding predictive power. This can also be seen by using a likelihood ratio test. This test compares the maximized value of the log likelihood function of the estimated model, $l$, against the maximized value of the restricted log likelihood function, $\tilde{l}$, where all slope coefficients except the constant term are restricted to zero. The Likelihood Ratio (L-R) test statistic is $-2(\tilde{l} - l)$. Under the joint null hypothesis that all slope coefficients except the constant are zero, the L-R statistic is asymptotically distributed as a $\chi^2$ variable, with degrees of freedom equal to the number of restrictions (the number of independent variables) under the test. For estimation (1), at a significance level of 5%, the critical value from the $\chi^2$ variable with 12 degrees of freedom is 5.23. Since the L-R statistic is 82.4188, the hypothesis that all coefficients are jointly zero can be rejected at better than the .001% level.

| | PREDICTED = 0 | PREDICTED = 1 |
|---|---|---|
| DUALDUM = 0 | 86 | 8 |
| DUALDUM = 1 | 15 | 39 |

Table 7: Predicted vs. Actual Values of $DUALDUM$, Sample Excluding WTA

Turn now to the coefficients in estimation (1) of Table 6. Hypothesis 1, that dual sourcing is more likely when the incumbent fails to reduce price over time, is not supported. The coefficient on $FLYRATLG$ is negative, contrary to what is predicted, and it is not close to statistically significant. Hypothesis 2, that dual sourcing is more likely after the incumbent experiences quality assurance problems, receives strong support. The coefficient on $PROBLEMS$ is positive and significant at better than the 1% level. Hypothesis 3, that dual sourcing is more likely for complex missiles, also receives empirical support, though $COMPLEX$ is only significant at the 10% level. Hypothesis 4, that dual sourcing is more likely in early production periods, is supported at better than the 1% level. This is also consistent with the negative and significant coefficient on $QTOGO$.

In addition to testing these hypotheses from the literature, several other results emerge from estimation (1). Controlling for the production period, dual sourcing is more likely for missiles with greater cumulative production. Presumably such missiles have realized greater savings from learning, which may be transferable to the second source. Multiyear contracting makes dual sourcing less likely, supporting the notion that the two institutions are alternative ways to plug gaps in incomplete procurement contracts. The coefficient on $FYR$ is positive and highly significant, indicating a secular trend toward greater use of dual sourcing over time.

Because probit estimations are highly nonlinear, coefficients do not directly reveal how changes in an independent variable affect the probability of the dependent variable. Useful insights into the marginal effect of a variable can, however, be obtained by taking partial derivatives with respect to each variable, holding all variables at their sample means. These results are presented in Table 8 for estimation (1). For example, complex missiles were 28.3% more likely to dual sourced than were simple missiles. Similarly, an additional quality control problem increased the likelihood of dual sourcing by 28.4%.

**Table 8: Partial Derivatives of E(DUALDUM) for Estimation (1) Holding Independent Variables at their Means**

| Variable | (1) |
|---|---|
| Flyratlg | -.1562 |
| Problems | .0906 |
| Complex | .2839 |
| Period | -.1658 |
| Lncumq | .4333 |
| Lnqty | -.1299 |
| Desgndum | .2550 |
| Multidum | -.3834 |
| Numbid | .0637 |
| FYR | .0668 |
| Length | .04695 |
| QTOGO | -.000018 |

Turning to estimation (2), which is restricted to transitions from sole sourcing, it clearly does not perform as well as (1). As shown in Table 9, it correctly predicts 91.1% of the 101 observations, while simply predicting that "sole sourcing is always used" would predict 90.1% of the observations. The L-R statistic of 18.8092 allows me to reject the hypothesis that all coefficients are jointly zero at the 9% level.

| | PREDICTED = 0 | PREDICTED = 1 |
|---|---|---|
| DUALDUM = 0 | 91 | 0 |
| DUALDUM = 1 | 9 | 1 |

Table 9: Predicted vs. Actual Values of $DUALDUM$, Transitions from Sole Sourcing

Estimation (2) considers only transitions from periods of sole sourcing, which allows for a cleaner test of the impact of cumulative quality assurance problems, as now all of these problems were incurred by the incumbent during periods of sole sourcing. The number of observations is cut by about a third, however, and statistical power is not as great as in estimation (1). Nevertheless, results are not greatly different from the previous estimation. High prices still have no significant impact on the use of dual sourcing, while cumulative quality problems make dual sourcing significantly more likely. The coefficient on $COMPLEX$ is basically unchanged, but it is not statistically significant in estimation (2). Dual sourcing still appears more likely in early periods of production, especially when the cumulative production experience is great and the quantity of production units remaining is lower. Finally, dual sourcing is more likely for missiles with long production runs.

Estimation (3) focuses on only those missiles that experience a switch in sourcing modes at some point during their production life. This reduces the number of observations to 95. The estimation correctly predicts 73.7% of the observations, as shown in Table 10, while a prediction that "solve sourcing is always used" would correctly predict 51.6%. The L-R statistic of 31.1727 allows me to reject the hypothesis that all coefficients are jointly zero at the .2

| | PREDICTED = 0 | PREDICTED = 1 |
|---|---|---|
| DUALDUM = 0 | 35 | 14 |
| DUALDUM = 1 | 11 | 35 |

Table 10: Predicted vs. Actual Values of $DUALDUM$, Subsample that Switches Sourcing Modes

I turn now to the government's decision to switch between dual sourcing to a winner-takes-all auction; all observations of sole sourcing are excluded. The results are presented in Table 11. The overall predictive power of the model is good. As shown in Table 12, the model correctly predicts 95% of the observations, while a simple prediction that "winner-takes-all is never used" would correctly predict only 78.3%. In addition, at a confidence level of 95%, and with ten degrees of freedom, the chi-squared statistic is 3.94, so the joint hypothesis that all coefficients are zero can be rejected at better than the .1% level.

A winner-take-all (WTA) auction is used less often for complex missiles and for missiles with a worse history of quality control problems, though these coefficients are only significant at betwen the 10% and 12% levels. WTA is significantly more likely in later periods of production, as expected. Like dual sourcing, the use of WTA auctions has increased over time, presumably reflecting the Defense Department's increasing concern to use competition in procurement when possible. WTA auctions are less likely for greater cumulative production levels and for missiles with longer production runs.

**Table 11: Probit Analysis of the Winner-Take-All Decision**

(t-statistics in parentheses)

| Variable | (1) |
|---|---|
| Lncumq | -6.4411[c] |
| | (-1.693) |
| Lnqty | 1.7104 |
| | (.807) |
| Desgndum | −1.9584 |
| | (-.777) |
| Numbid | 3.5655 |
| | (1.298) |
| Period | 1.4917[c] |
| | (1.824) |
| FYR | 4.1117 |
| | (1.575) |
| Complex | −11.6178 |
| | (-1.524) |
| Length | -1.6805[c] |
| | (-1.750) |
| QTOGO | 0.00039 |
| | (1.347) |
| Problems | -.7160 |
| | (-1.619) |
| Constant | -8149.795 |
| | (-1.573) |
| Number of observations | 60 |
| L-R Ratio | 50.3969 |

[a] Significant beyond the 1% level

[b] Significant beyond the 5% level

[c] Significant beyond the 10% level

| | PREDICTED = 0 | PREDICTED = 1 |
|---|---|---|
| DUALDUM = 0 | 46 | 1 |
| DUALDUM = 1 | 2 | 11 |

Table 12: Predicted vs. Actual Values of $WTADUM$, Transitions from Dual Sourcing

The empirical results in Tables 6,8 and 11 provide numerous insights into the factors that motivate government use of dual sourcing. I organize my discussion around the five theoretical hypotheses identified earlier.

*Hypothesis 1: Dual sourcing is more likely to be used after the incumbent charges a high price.*

The data provides little support for this hypothesis. The key independent variable of interest is $FLYRATLG$, which measures the ratio of previous period flyaway cost to that in the initial period. The hypothesis predicts a positive sign, indicating that incumbents whose prices do not fall rapidly enough are more likely to face dual sourcing. In Table 6's estimation (1) the sign is negative, but not significant; in estimation (2) it is positive but not significant. Apparently the rate of price reduction is not an important factor in the government's decision to dual source.

*Hypothesis 2: Dual sourcing is more likely to be used after the incumbent producer delivers products with quality defects.*

This hypothesis receives substantial support. Estimation (1) in Table 6 yields a positive and significant coefficient on $PROBLEMS$, indicating that missiles with more reported quality problems are more likely to be dual sourced. Table 8 shows that when the independent variables are at their means, an additional reported quality problem increases the likelihood of dual sourcing by roughly 9%. Extrapolating this out for a missile such as Tomahawk, with 6 reported quality problems, would indicate a 54% greater likelihood of dual sourcing.

In at least one instance, the trade press reported that the switch from sole to dual sourcing was a direct result of quality problems: "The U.S. Navy will seek a second production source for the Hughes AIM-54C Phoenix air-to-air missile after a second round of inspections determined there were serious quality control problems in producing the missiles. The decision for a second production source was made after a Navy team at Hughes' Tucson, Ariz., production line recently dismantled and inspected two missiles and found that problems in producibility and quality control were continuing."[20]

*Hypothesis 3: Dual sourcing is more likely to be used for complex technologies than for simple ones.*

This hypothesis receives strong support in both estimations (1) and (2) of Table 6. Table 8 shows that on average complex missiles were 28% more likely to experience dual sourcing than were simple missiles. A related result is that the government is more likely to

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[20] "Navy Will Seek Second Source for Phoenix," *Aviation Week and Space Technology*, July 16, 1984, p. 20.

dual source systems that are undergoing major design changes. In both estimations, *DESGNDUM* enters the regression with a positive coefficients, although it is only statistically significant in (1). The results for both variables support the notion that the buyer expects greater benefits from competition when there is greater technological uncertainty. This is also the setting in which contracts are likely to be most incomplete, since technological specifications may be difficult to describe with accuracy and detail. Thus, competition may be to some extent a substitute for the ability to write complete contracts with high-powered incentives.

*Hypothesis 4: Dual sourcing is more likely to be used in the early stages of production.*

This hypothesis is closely related to Hypothesis 3, and is also based on the notion that dual sourcing is more valuable when technological and production cost uncertainty is higher. My results provide support for this hypothesis. In both estimations, dual sourcing is more likely in earlier periods of production. The effect is only statistically significant in estimation (1), however. Table 8 indicates that, for this estimation, the probability of dual sourcing declines by about 16% each period.

*Hypothesis 5: Dual sourcing is more likely to reduce procurement costs when used for complex technologies.*

This hypothesis cannot be tested using the estimations in this section, but it received scant support from the results in Table 4. There it was shown that the effects of dual sourcing are greater in magnitude and come closer to statistical significance for complex missiles, but they are still only significant at roughly the 20% level. Furthermore, although the learning curve steepened more for complex missiles, these missiles also suffered greater cost increases due to lost scale economies under dual sourcing. Thus, the evidence for procurement cost savings from dual sourcing is weak, at best, even for complex missiles.

Overall, the results support the notion that dual sourcing is used as a substitute for the ability to write complete quality-contingent contracts. Dual sourcing is used more often in the early periods of production for complex technologies or technologies undergoing major design changes. It is also used in response to observed problems with production quality by the incumbent producer.

Further evidence on the relation between contractual completeness and competition can be obtained from the multiyear contracting variable *MULTIDUM*. Multiyear contracts are considerably more complete than those that are renegotiated annually, and one might expect that dual sourcing is less valuable in such a setting. Indeed, the negative and highly significant coefficient on *MULTIDUM* indicates that dual sourcing is used significantly less often when multiyear contracting is employed. This result is complementary to the finding of Crocker and Reynolds[7] that contracts tend to be less complete when dual sourcing is used.

Another important variable affecting the decision to dual source if the number of potential bidders, *NUMBID*, indicative of the degree of concentration within the defense industry. Its coefficient is positive and highly statistically significant in both estimations. Table 8 shows that the presence of one additional bidder increases the probability of dual sourcing by between 11% and 25%. This finding is consistent with a variety of different hypotheses. Simple marginal analysis suggests that efficient procurement policy would make greater use of supplier switching when more alternative suppliers are available, as the chance of finding a supplier with lower cost and/or higher quality should increase with the number of alternatives. At the same time, the finding is consistent with the possibility of government opportunism, which reduces costs by reducing the rents paid to the incumbent producer, but also weakens incentives for research and development expenditures in future development contracts. Under either interpretation, however, this finding suggests that defense industry consolidation will affect the procurement process by weakening the government's ability to use dual sourcing.

## 6 Conclusions

This study is the first to use panel data to evaluate the performance of dual sourcing as a contractual instrument in defense procurement. By pooling data from different tactical missile systems, I was able to test hypotheses that simply cannot be addressed looking at individual systems in isolation. Furthermore, the hypotheses I consider are drawn from the recent theoretical literature on second sourcing, and have not, to my knowledge, been previously subjected to empirical testing.

My results do not support the notion that "competition" (through dual sourcing) will produce savings to the government. Over the last 15 years, defense procurement policy has increasingly pressed program officers to use dual sourcing whenever possible. The data indicate that savings have generally not been achieved from the use of dual sourcing. There are a number of reasons why dual sourcing may fail to reduce procurement costs: there are substantial fixed costs of transferring technology to the second source, learning-by-doing is slowed by reducing the production experience of each individual contractor, scale economies are lost by splitting production volumes, and split award auctions may facilitate bidding collusion. I am not able to pin down the relative importance of each of these factors, but in the aggregate they appear to be enough to nullify any increased cost-reducing effort that may be induced through dual sourcing.

The empirical results do provide fairly strong support for modern theories of incomplete contracting and bid coordination in split-award auctions. To begin with, the poor performance of dual sourcing overall is in line with the predictions of Riordan and Sappington[13] and Anton and Yao[1], both of which find limited scope for dual sourcing to be of value. Furthermore, the conditions under which dual sourcing tends to be used are also in line with theoretical predictions. Consistent with the model of Riordan and Sappington[13], defense program managers resort to dual sourcing more often when the incumbent has experienced significant problems with quality control. Consistent with the model of Anton and Yao[1], dual sourcing is used more often for complex missile systems, where technological uncertainty undermines the ability of bidders to coordinate their bids to achieve monopolistic prices in split-award auctions. More generally, incomplete contracting theory predicts that dual sourcing is most likely to be advantageous during the early phases of production, when uncertainties of technological and other origin make it impossible to write complete contracts; these are also the circumstances when collusion in split award auctions is less likely to be successful. The data indicate that defense program managers are significantly more likely to use dual sourcing in these conditions, as predicted, thereby supporting the notion that problems of incomplete contracting are a significant reason for the use of dual sourcing. In addition, defense program managers appear to treat multiyear contracts and dual sourcing as substitutes, providing further evidence that contractual incompleteness is an important reason for the use of dual sourcing.

The results reported here focus on the price benefits of competition and do not attempt to measure contractors' innovation investments, or how they are affected by competition. Rogerson[14] emphasizes that Defense Department policy has traditionally provided incentives for innovation by allowing firms to collect economic profits during the production phase of procurement. Introducing competition in production reduces those profits and threatens to weaken incentives for research and development. Future research on the connection between dual sourcing of production and innovation performance at the research and development phase of procurement would be an extremely valuable complement to the work reported here.

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