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PAPER NO. 90-1660

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June 1990

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This essay is taken from the final chapter of my dissertation at Stanford University. Tim Bresnahan, Paul David and Roger Noll provided more insightful advise than I could assimilate. Grateful thanks go to Greg Clark, Sarah Lane, Josh Rosenbloom, Geoff Rothwell, and Pablo Spiller for commenting on earlier drafts of this essay. I have received many useful suggestions from seminar participants throughout the country. I also wish to acknowledge a deep debt to Tim Bresnahan for patiently guiding me to a deeper understanding of this paper's issues. Funding was provided by the Charles Babbage Institute Dissertation Fellowship and by the National Science Foundation.

Abstract

This essay provides measurements of the economic determinants of procurement procedures used by federal agencies to acquire mainframe computers. It shows how economic models of bidding behavior can provide structure for econometric measurement. In the model of this paper, the higher the probability that an agency anticipates more than one vendor will bid on a request, the greater the likelihood that the agency will choose to use competitive procedures. The analysis shows that the extent of experience a buyer had with a vendor could have influenced the likelihood of sole-sourcing with that incumbent. In most cases, however, other economic factors dominated, especially those related to the extent of competition or the value of a procurement. Another good predictor of a competitive procurement is whether a federal agency's office had experience with IBM. This either indicates that the federal Mainframe market contained many competitors who competed against IBM, or it indicates that the federal oversight processes forced offices who had used IBM in the past to use competitive procedures more often.

I Introduction

Virtually every civilian agency and military installation has one or more general purpose mainframe computer. Despite their similarity in functions, there is surprising variance in the procurement procedures used to purchase these machines. Agencies choose to use either competitive procedures or sole-sourcing. Competitive bidding involves the solicitation of multiple bids. In sole-sourcing, however, solicitation of competitive bids is bypassed and a single vendor is designated as a "sole-supplier." What are the important economic determinants of this procedural choice -- the user's previous experience with a vendor, the value of the procurement, conditions of supply, or the identity of the incumbent vendor?

Despite much recent interest in the theoretical and empirical economics of procurement, no researcher has tried to quantify and measure the factors influencing the choice of procurement procedures.[1] This paper fills this gap by developing an approach for measuring the economic determinants of the procedural choice used to acquire a commercially standardized product, in this case, general purpose mainframe computers. One of the main insights of this paper is that behavioral models of bidding can provide structure for statistical measurement of the economic determinants of the choice of procedure. This is due to the causal links between the anticipated (but unobserved) number of bidders in a market and the observed (and endogenous) choice of procurement procedures by federal agencies.

The methods used in this paper resemble in spirit those found in recent models of firm entry into diverse geographic markets or new product markets. As in Bresnahan and Reiss (1986, 1987) and Reiss and Spiller (1990), the econometric analysis retains the structure of behavioral models of latent discrete decisions. In this case, however, the discrete decision concerns an agency's choice of procedures in anticipation of the decision of computer vendors about whether or not to bid. In addition, as in Berry (1987) and Lane (1989), the econometric structure is designed to measure the influence of a vendor's previous experiences on the profitability of subsequent actions. However, unlike Berry and Lane, which measured the relevance of a producer's previous production experience, this analysis focuses on the relevance of a vendor's previous interaction with a potential repeat customer.

Two issues shape the use of bidding models for econometric measurement of procedural choice. First, the extent of an incumbent's advantage in bidding, however measured, should indicate the likelihood of sole-sourcing with that incumbent and the unlikelihood of sole-sourcing with a non-incumbent. Hence, an appropriate econometric structure must distinguish between the two sole-sourcing outcomes and the different factors that produce them. Second, disclosure laws prevent observers from learning details about who lost competitive bids. Yet, economic models of bidding identify causal links between the competitiveness of a procurement and unobserved decisions of bidders about whether or not to bid. If the determinants of those unobserved decisions can be measured and linked to behavioral outcomes, then an econometric model can measure the importance of the various determinants of procedural choice.

The results of this study shed light on several of the micro-economic forces influencing the competitiveness of the federal computer market. Since switching costs can be quite high in this product market, it is expected that incumbents have advantages in bidding. While this factor does influence outcomes in this paper's sample, quite often other economic factors were more important. The extent of potential competition in a market segment and the value of a requested procurement are particularly important determinants of procedural choice. In addition, as found in Greenstein (1990), a buyer will behave differently if he has had experience with IBM's systems. This result implies that either many firms offered close substitutes for IBM products, resulting in more competitive bidding, or the federal oversight process systematically forced offices who previously used IBM to use more competitive procedures.

There is one important restriction to the methods and results developed here; they apply only to situations in which the potential buyer has experience with a single incumbent. This restriction reduces the complexity of the behavioral and econometric model, and it eases the computation of an "incumbent's advantage." The additional problems of multiple-incumbent situations will be addressed in later research.

II A Simple Description of Computer Procurement Procedural Choice

Government agencies distinguish between several phases in the procurement process for mainframe computers:[2] (1) phase in which both the functional needs and requirements of an agency's office are defined and funds are committed; (2) phase in which representatives from the agency's office and vendor representatives prepare for the final solicitation by clarifying benchmarks and requirements; (3) phase in which bids are formally requested, evaluated, and awarded.

Sole-sourcing is distinguished from competition in the way an agency's office proceeds through phases (2) and (3). Competition means that agencies follow procedures designed to elicit multiple bidders in phase (3). In contrast, sole-sourcing typically means that an agency's office negotiates a contract with a single vendor of choice. Sole-sourcing bypasses many of the procedures associated with soliciting multiple bids in phases (2) and (3).

Agencies face several trade-offs when choosing between sole-sourcing and competition. Competitive procedures can elicit unanticipated bids, though this is not likely to be a major factor with most commercial mainframe acquisitions. Competitive procedures are also thought to result in lower prices. Not all agencies may care about savings, however, especially when acquisitions are funded from congressional capital funds. On the other hand, sole-sourcing results in speedier delivery of systems since it skips phases (2) and (3). Similarly, sole sourcing also avoids potential protests associated with phases (2) and (3), which can also delay delivery[3]. Sole-sourcing also gives the agency absolute control over vendor choice. This is valued by agencies when decisions under competitive procedures are subject to critical outside scrutiny.

If agencies completely controlled the choice of procurement procedures and could anticipate bidder reactions to written specifications, then they would likely choose sole-sourcing when only one bidder was anticipated. When only one vendor can profitably bid, there is nothing gained by using competitive procedures. Of course, the net gains of sole-sourcing diminish when more than one vendor can profitably bid.

Many factors influence the number of anticipated bidders. The supply of "off-the-shelf" alternatives for different types of requests will influence the expected number of bidders. The costs of bidding will also vary, and this will influence the expected profitability of bidding and, thus, the anticipated number of bidders. Agencies also have limited direct control over the expected profitability of bidding. A forward-looking agency can write technical specifications so that one or another vendor is favored in a competitive bid.[4] If agencies completely controlled the procurement process, then sole-sourcing would be just a case in which procedures were manipulated so that only one vendor could profitably bid.

Oversight procedures could potentially change some of these factors. Under the Brooks Act (1965), public law 36-809, the General Services Administration (GSA) holds the right to approve all procedures used to acquire mainframe computers, as well as rule on protests. It is widely believed that GSA discouraged the use of sole-sourcing in the 1970s, resulting in more frequent use of competitive procedures. It is also widely believed that GSA's procedures limit an agency's ability to manipulate specifications. Thus, sole-sourcing could potentially have been a mixed blessing in the 1970s; "frequent" use could have triggered significant scrutiny of purchases by GSA or Congressman Jack Brooks, author of the Brooks Act and member of the House Government Operations Committee. More will be said about this later.

III A Simple Econometric Exercise

To gain insight into the influence of economic forces on procedural choice, I assembled a sample of computer mainframe acquisitions from 1971 through 1983 by comparing adjacent years of the federal inventories of computer holdings by federal agencies.[5] The sample of systems is restricted to commercially available mainframes, where information on the characteristics of the commercial systems was more readily available. This selection procedure eliminated systems that were purchased for special government functions, particularly in the defense department. It tended to bias the sample towards systems that were acquired for applications in the federal government that resembled the use of mainframes in private industry, such as keeping inventories or large data bases.[6]

The unit of analysis became the acquisition of a computer system at an agency office or "site",[7] which was dated with the acquisition of the first processor in a system at that site (the records do not reveal which system supplier(s) lost the award nor what alternatives the losers offered). The inventories reveal something about an agency's purchase history prior to the purchases of this acquisition. Each observation was appended with information about the market for systems like the one acquired. Of over 2200 acquisitions from external suppliers recovered, 526 mainframe acquisitions had all the necessary information, 118 used sole-sourcing.[8]

I restricted my attention to the 221 acquisitions in the sample that occurred at sites that had no more than one incumbent vendor[9] (41 of those used sole-sourcing). This restriction is imposed because it significantly simplifies the model discussed later. It also had the secondary benefit of eliminating many multi-vendor users in the Departments of Energy and Defense, and increasing the probability of observing system acquisitions for activities analogous to private mainframe system use -- simple, repetitive calculation using large data-bases.[10] Since the remaining vendors are large firms (i.e. IBM, Sperry-Univac, Honeywell, Burroughs, and

Control Data Corporation), it is possible to get from private censuses a reasonably good idea of the state of the private market for these commercial mainframes. Later work will try to generalize these methods to multi-incumbent situations.

The description of the procurement process, outlined previously, suggests that a simple probit of competition versus sole-sourcing provides an appropriate measure of the factors influencing vendor choice. The description shows that in phase (1) buyers first write technical specifications that reflect the office's preferences among types of systems and that may or may not favor incumbent vendors. Vendors then commit to bidding in phase (2), anticipating a bidding game to supply an alternative, as in phase (3). Thus, when choosing whether to go through with competitive procedures in stages (2) and (3), agencies anticipate vendors' decisions to bid.[11] Let bidding follows the rule:

$$\text{(1)} \qquad \begin{array}{ll} \text{Bid if} & E\pi^* > 0, \\ \text{Do not bid if} & E\pi^* \leq 0, \end{array}$$

where $E\pi^*$ are the expected profits, broadly interpreted as the total gains to bidding, less the costs to bidding. $E\pi^*$ varies depending on who bids and how many vendors bid and is assumed to be a function of characteristics of the market and costs of supply. Following Bresnahan and Reiss (1986), to measure the factors producing a single bidder rather than a multiple number of bidders, one simply has to index the profit function for the second bidder and specify an error distribution. If the error is distributed normally then this results in a probit.

Unfortunately, a simple probit is not adequate here, because it cannot measure the relative importance of an incumbent's advantage. If observers want to measure the importance of an incumbent's advantage, it is necessary to distinguish between the two sole-sourcing outcomes. This is because the extent of an incumbent's advantage in bidding, however measured, should positively predict the likelihood of sole-sourcing with that incumbent, and it should predict the unlikelihood of sole-sourcing with a non-incumbent.

In addition, it is informative to distinguish between the two competitive outcomes. If an incumbent does not win a competitive bid, it may be because he bid and lost or he may not have bid at all. When an incumbent wins a competitive bid, then it is known with certainty (trivially) that the incumbent bid.

There is also good reason to think that incumbents should have advantages in competitive bidding and in getting sole-source bids.[12] It is thought that incumbent vendors can easily acquire knowledge about the idiosyncratic needs of a buyer; Hence, an incumbent is more likely than a challenger to know precisely how to satisfy a user's unique needs (Kelman 1990, pg. 70). Case studies have also shown that incumbents are at advantages because buyers incur costs when switching suppliers -- for such things as software conversion, personnel retraining, and investment in technically complementary assets (GAO 1979, OSD 1983b, or NBS 1980).[13]

The frequency of outcomes in this sample is illustrated in Figure 1. The figure shows the relevance of the criticism of a probit. When there is a single incumbent, every possible outcome occurred: (SI) An incumbent vendor is the sole-source; (SC) A non-incumbent vendor is the sole-source; (CI) A competitive procurement takes place and the incumbent vendor makes the winning bid; (CC) A competitive procurement takes place and some non-incumbent vendor makes the winning bid. Also shown in figure 1 are the two outcomes in which there is no incumbent vendor: (SNI) There was no incumbent system vendor at a site[14] and the new acquisition was sole-sourced; (CNI) There was no incumbent vendor at the site and the new equipment was acquired in a competitive bidding process. Clearly, a model more sophisticated than a probit is required.

IV A Behavioral Model with Incumbent's Advantages

This section develops an explicit extensive form game that could plausibly produce the outcomes observed in Figure 1. It is developed with the presumption that an agency anticipates potential bidder behavior, and those expectations influence the agency's choice of procurement procedure. If only a bid from the incumbent computer vendor is anticipated, the agency sole-sources with the incumbent (i.e. outcome SI). If only a bid from one challenger is anticipated, the agency sole-sources with the challenger (i.e. outcome SC). More than one anticipated bidder results in competitive bidding procedures. When an incumbent competes against a non-incumbent, the winner cannot be predicted (i.e. outcome CI or CC). However, if multiple challengers bid but the incumbent does not, then it is certain that a non-incumbent will win (i.e. outcome CC). Thus, in the following game predicting incumbent and non-incumbent bidding will be tantamount to predicting choice of procurement procedure.

The most important point of this section is that there is a correspondence between the value of expected profit functions in a simple bidding model for a potential repeat customer and observed outcomes. Consider a model of bidding behavior in which the buyer has had experience with a single incumbent supplier prior to soliciting bids. Solving this model requires knowing the expected profits of the incumbent and challenger computer vendors under different bidding situations -- when the incumbent computer vendor bids and when he does not, when no challenger bids, when one challenger bids, and when two challengers bid. These situations are represented in extensive form in Figure 2 in a diagram in which no more than two challengers can bid, though the analysis will generalize to an arbitrary number of challengers.[15] Profit functions with superscripts I and C index incumbent or challenger. Numbers index different situations. In principle, these profits are functions an agency's manipulation of specifications, as well as characteristics of potential computer vendors.

Under five different assumptions about the bidding game, three functions will determine the unique equilibrium outcomes in Figure 2. The first assumption used in this paper is that incumbent vendors move first and act in accordance with a sub-game perfect equilibrium. This assumption is equivalent to assuming that incumbents know a little sooner about a potential bid and all potential challengers know about the incumbent's bidding decision when making their bidding decision. The incumbent bids anticipating the challenger's decisions.[16]

Second, assume that π^I1 is positive or π^C4 is positive or both are positive. This is the same as incorporating one constraint the computer inventory data imposes on any empirical work: In a sample of observed acquisitions, it must be the case that at least one vendor, either an incumbent or challenger, can profitably bid on a procurement. At any rate, in practice violations of this assumption is rare; why would an agency go through a procurement if it did not anticipate any bidders?

Third, assume that both challengers and incumbents have the same information -- specifically, estimates of the probability of winning, the costs of bidding, and the net profitability of winning. This is plausible since the vendors in the commercial mainframe market know each other quite well and generally have access to the same (generally public) information about buyers.

Fourth, assume that more competitors reduce expected profits. This imposes the constraint that the profit functions always satisfy the following: $\pi^C2 \le \pi^C4$, $\pi^C3 \le \pi^C5$, $\pi^I1 \ge \pi^I2 \ge \pi^I3$, $\pi^C2 \le \pi^C3$, and $\pi^C4 \ge \pi^C5$. These constraints seem innocuous since most reasonable models of bidding in the computer market would imply that similar inequalities held.[17]

Finally, assume that weak challengers cannot make an otherwise profitable incumbent unprofitable. This is tantamount to assuming that the inequalities $\pi^I2 < 0$, $\pi^I1 > 0$, and $\pi^C2 < 0$ cannot all hold at the same time. It is convenient to set the probability of this unlikely event to zero. Moreover, results do not appear to be sensitive to this assumption.[18]

Figure 3 lists the algebraic conditions sufficient to result in an equilibrium in Figure 2 (and in one of the six outcomes in Figure 1). With the previously mentioned assumptions, three profit functions are sufficient to determine a unique equilibrium in Figure 1 (see Greenstein 1989, appendix B). These functions are the profit function of the incumbent against one competitor, $\pi^I 2$, the profit function of the challenger if he is the only challenger to bid in competition with the incumbent, $\pi^C 2$, and the profit function of the second challenger if he challenges the first challenger when the incumbent does not bid, $\pi^C 5$.

The resulting model generalizes beyond the dichotomous structure implicit in the probit outlined above. Whether an incumbent bids or not is endogenous. If an incumbent bids (i.e. $\pi^I 2 > 0$), competition occurs when a challenger can profitably bid against the incumbent (i.e. $\pi^C 2 > 0$).[19] Otherwise, only the incumbent bids (i.e. $\pi^I 2 > 0$, $\pi^C 2 < 0$). If the incumbent does not bid (i.e. $\pi^I 2 < 0$), then competition occurs depending on whether or not a second non-incumbent can profitably bid (i.e. competition: $\pi^C 5 > 0$; only challenger: $\pi^C 5 < 0$). Generalizing to situations in which there are no incumbents is straightforward. Competition depends solely on the profitability of a challenger bidding against a challenger (i.e. $\pi^C 5$).

The important result is that there is a correspondence between the signs of the expected profit functions (shown in Figure 3) and outcomes (represented in Figures 1 and 2). To summarize the behavioral model:

A single incumbent bids (SI)	IFF	$\pi^I 2 > 0$, $\pi^C 2 < 0$
An incumbent and challenger bid (CI or CC)	IF	$\pi^I 2 > 0$, $\pi^C 2 > 0$
A single challenger bids (SC)	IFF	$\pi^I 2 < 0$, $\pi^C 5 < 0$
Two challengers, no incumbent, bid (CC)	IF	$\pi^I 2 < 0$, $\pi^C 5 > 0$

This behavioral model determines the structure of the econometric model, which is developed in the next section.

V Econometric Model

The expected profit functions are never observed directly. I hypothesize that they are functions of the extent of substitutes available, characteristics of the incumbents and challengers, and a function of incumbent advantages and challenger disadvantages. Call these Z_i, W_i, and X_i, respectively, for observation i. I assume the profit functions for the ith system acquisition take the form:

$$
\begin{aligned}
(2)\quad \pi^{I}2_i &= f^1(W_i, X_i, Z_i) - \epsilon 1, \\
\pi^{C}2_i &= f^2(W_i, X_i, Z_i) - \epsilon 2, \\
\pi^{C}5_i &= f^5(W_i, X_i, Z_i) - \epsilon 5,
\end{aligned}
$$

where f^1, f^2, and f^5 are measures of deterministic part of the vendor's expected profit functions for a set of W_i, X_i, and Z_i.

Economic reasoning will later impose restrictions on the set of admissible W_i, X_i, and Z_i in f^1, f^2, and f^5. $\epsilon 1$, $\epsilon 2$, and $\epsilon 5$ represent the measurement errors from measuring these functions incompletely.[20] These error terms are assumed to have a mean of zero and standard deviation equal to $\sigma 1$, $\sigma 2$, and $\sigma 5$, respectively. Henceforth, the i subscripts will be dropped for convenience. It follows from equation (2) that

$$
\begin{aligned}
(3)\quad \pi^{I}2 &> 0 \text{ if and only if } f^1(W,X,Z) > \epsilon 1, \text{ and} \\
\pi^{C}2 &> 0 \text{ if and only if } f^2(W,X,Z) > \epsilon 2, \text{ and} \\
\pi^{C}5 &> 0 \text{ if and only if } f^5(W,X,Z) > \epsilon 5.
\end{aligned}
$$

If distribution assumptions are placed over the errors, then f^1, f^2, and f^5 become indexes of the probability that incumbents and challengers bid. In other words, the probability that a certain outcome occurred can be rewritten as the probability that incumbent and challenger bidders bid in a manner that produced that outcome. In other words, using the equation (3) and the behavioral model outlined in the previous section, the probability for each possible outcome becomes:

$$
\begin{aligned}
P(SI) &= [\ P(f^1 > \epsilon 1,\ f^2 < \epsilon 2)\ ], \\
P(SC) &= [\ P(f^1 < \epsilon 1,\ f^5 < \epsilon 5)\ ], \\
P(CI, CC) &= [\ P(f^1 > \epsilon 1,\ f^2 > \epsilon 2) + P(f^1 < \epsilon 1,\ f^5 > \epsilon 5)], \\
P(SNI) &= [\ P(f^5 < \epsilon 5, \text{ conditional on no incumbents})], \\
P(CNI) &= [\ P(f^5 > \epsilon 5, \text{ conditional on no incumbents})],
\end{aligned}
$$

where $P(\cdot)$ represents the probability of each possible outcome, as labelled in Figures 1 and 2, and $P(\cdot , \cdot)$ represents the joint probability that two necessary actions were taken.

There is a simple means of distinguishing between outcomes (CI) and (CC). The behavioral model shows that outcome (CI) only occurs if the incumbent bids, while outcome (CC) can occur if the incumbent bids and loses or if the incumbent does not bid at all. To explicitly account for the two different paths to the different outcomes, let

$$P(CI) = [\ P(f^1 > \epsilon 1,\ f^2 > \epsilon 2)*PP\ ], \text{ and}$$
$$P(CC) = [\ P(f^1 > \epsilon 1,\ f^2 > \epsilon 2)*(1 - PP) + P(f^1 < \epsilon 1,\ f^5 > \epsilon 5)\ ],$$

where PP is the probability that the incumbent will both bid and win if he profitably bids against one challenger.[21]

VI Specification of the Index Functions

This section specifies the functional form of equations f^1, f^2, and f^5. The index for the bidding of the challenger against a challenger, f^5, is specified as follows:

$$(4) \quad f^5(W,Z) = \beta 5 + \beta_{WC}*WC + \beta_Z*Z,$$

where WC and Z are COMPSYS, DEDAP, SIZE, NETWORK, and NOINCUMB, defined below. There is no reason to expect an index of challenger behavior to be a function of an incumbent's advantages, so no such measure is included.

The index for the bidding of a challenger against an incumbent, f^2 should be a function of many of the same market segment variables as was f^5, but at the same time also a function of challenger disadvantages, for which I set parameters with the vector X. f^2 is specified as follows:

$$(5) \quad f^2(W,Z,X) = \beta 2 + \beta'_{WI}*WI + \Gamma*[\beta_{WC}*WC + \beta_Z*Z] + \beta_X*X,$$

where $\Gamma > 0$ is some proportionality factor, and where β_X*X indexes the effect of a challenger competing against an incumbent. X includes INVEST, CAPACITY, EXPERIENCE, EXPERIENCE2, and IBMINC and WI includes INCSYS, all to be defined later. The factors in WC and Z are assumed to influence the index of challenger bidding against an incumbent in exactly the same direction and with the same relative magnitudes as they influence challenger bidding against another challenger. The proportionality factor will not be recoverable, but shows how Z influences f^2 relative to the influence of Z in f^5. The estimated value for β_X*X should enter the profits of the second entrant with a negative magnitude if challenger disadvantages deter challenger bidding.

I assume that a disadvantage to a challenger has a proportional and opposite advantage to an incumbent. f^1 is specified as follows:

$$(6) \quad f^1(W,Z,X) = \beta 1 + \beta_{WI}*WI + \phi*[\beta'_{WC}*WC + \beta_Z*Z - \beta_X*X],$$

where $\phi > 0$ is another proportionality factor and WI includes INCSYS. Though ϕ will not be recoverable, it indicates that the relative importance of Z and X in f^1 relative to their importance for f^2 and f^5.[22]

The estimation will yield coefficients to equations whose errors have been normalized to a standard normal. This is accomplished by dividing each equation by the standard deviation of the errors. Hence, equations (4), (5), and (6) become

$$(7) \quad f^{5'}(W,Z) = [\beta 5 + \beta_{WC}*WC + \beta_Z*Z]/\sigma 5,$$
$$(8) \quad f^{2'}(W,Z,X) = [\beta 2 + \Gamma*(\beta'_{WI}*WI + \beta_{WC}*WC + \beta_Z*Z) + \beta_X*X]/\sigma 2,$$
$$(9) \quad f^{1'}(W,Z,X) = [\beta 1 + \beta_{WI}*WI + \phi*(\beta'_{WC}*WC + \beta_Z*Z - \beta_X*X)]/\sigma 1,$$

where the errors are now $\mu 1 = \epsilon 1/\sigma 1$, $\mu 2 = \epsilon 2/\sigma 2$, and $\mu 5 = \epsilon 5/\sigma 5$, which are all standard normal variables with mean zero and variance equal to one, under the assumption that $\epsilon 1$, $\epsilon 2$, and $\epsilon 5$ are distributed normally.

Equations (7), (8), and (9) imply that the functional forms for $f^{1'}$, $f^{2'}$, and $f^{5'}$ will be:

$$(10) \quad f^{5'}(W,Z) = \theta 5 + \theta_{WC}*WC + \theta_Z*Z,$$
$$(11) \quad f^{2'}(W,Z,X) = \theta 2 + [\theta_{WC}*WC + \theta'_{WI}*WI + \theta_Z*Z]*\delta + \theta_X*X, \text{ and}$$
$$(12) \quad f^{1'}(W,Z,X) = \theta 1 + \theta_{WI}*WI + [(\theta'_{WC}*WC + \theta_Z*Z)*\delta - \theta_X*X]*\alpha,$$

where $\theta5 = \beta5/\sigma5$, $\theta2 = \beta2/\sigma2$, $\theta1 = \beta1/\sigma1$, $\theta_{WC} = \beta_{WC}/\sigma5$, $\theta_Z = \beta_Z/\sigma5$, $\theta_X = \beta_X/\sigma2$, $\theta_{WI} = \beta_{WI}/\sigma1$, and $\delta = (\Gamma*\sigma5)/\sigma2$, and $\alpha = (\phi*\sigma2)/\sigma1$. Clearly δ and α must be positive.

To make initial estimation more tractable, I will also assume that $\epsilon1$ and $\epsilon2$ are uncorrelated, and $\epsilon1$ and $\epsilon5$ are uncorrelated. This specification can accommodate arbitrary correlation between $\epsilon2$ and $\epsilon5$, which is subsumed in the specification of δ. The net results is a redefinition of the probability of each event. That is:

$$
\begin{aligned}
P(SI) &= [\ \Phi(f^{1\prime} > \mu1)*\Phi(f^{2\prime} < \mu2)\ ],\\
P(SC) &= [\ \Phi(f^{1\prime} < \mu1)*\Phi(f^{5\prime} < \mu5)\ ],\\
P(CI) &= [\ \Phi(f^{1\prime} > \mu1)*\Phi(f^{2\prime} > \mu2)*\Phi(PPP)\ ],\\
P(CC) &= [\ \Phi(f^{1\prime} > \mu1)*\Phi(f^{2\prime} > \mu2)*\Phi(-PPP))+\Phi(f^{1\prime} < \mu1)*\Phi(f^{5\prime} > \mu5)\ ]\\
P(SNI) &= [\ \Phi(f^{5\prime} < \mu5)],\ \text{and}\\
P(CNI) &= [\ \Phi(f^{5\prime} > \mu5)],
\end{aligned}
$$

where Φ is a cumulative standard normal function, (10), (11) and (12) define $f^{1\prime}$, $f^{2\prime}$, and $f^{5\prime}$, and $PP = \Phi(PPP)$, where PPP is a constant. That is, the probability that an incumbent wins and bids under competition is a coin-flip.[23]

Using these definitions, the loglikelihood for the competitiveness of an acquisition can then be written as

$$
\begin{aligned}
LL = \ & YSI*\log[P(SI)] + YSC*\log[P(SC)] +\\
& YCI*\log[P(CI)] + YCC*\log[P(CC)] +\\
& YSNI*\log[P(SNI)] + YCNI*\log[P(CNI)],
\end{aligned}
$$

where six mutually exclusive indicator variables corresponding to outcomes in Figures 1 and 2. These are:

YSI = 1 if sole-sourcing with the incumbent is observed;
YSC = 1 if sole-sourcing with the challenger is observed;
YCI = 1 if the incumbent vendor is chosen in a competitive bid;
YCC = 1 if a challenger vendor is chosen in a competitive bid;
SNI = 1 if a single supplier is observed when there is no incumbent;
CNI = 1 if competition is observed when there is no incumbent.

In sum, this log-likelihood estimates $\theta5$, $\theta2$, $\theta1$, θ_{WC}, θ_{WI}, θ_Z, θ_X, δ and α. The estimates will indicate the signs of β_{WC}, β_{WI}, β_Z, and β_X, but never their magnitudes, except relative to a variance. The proportionality factors in (5) and (6), ϕ and Γ, are not identified except relative to estimates of the proportional difference of each equation's variance.

VII Exogenous Variables

This section lists the data used for W, X, and Z. A summary of the variables and their predicted sign in the market model is included in Table 1.[24] A table of the means, standard deviations, minima, maxima, and selected correlations is included in Table 2. The data appendix includes more detail.

VIa. Characteristics of challengers and incumbents

Measures of the ease with which firms could bid in the short run were constructed. These are divided between those for competitors and those for incumbents. These counts are called WC and WI, respectively.

Number of competitor's systems (COMPSYS). The number of systems offered by non-incumbents in the market segment of the purchase was assigned to each observation.[25] It is called COMPSYS and is included in f^5 and f^2 as WC. In principle, it could also be included in f^1, since it should influence the value of the incumbent's expected profits.

Number of systems offered by the incumbent (INCUMBSYS). In f^1 is included a count of the number systems offered by the incumbent in this market segment. This represents WI. In any year, in a particular market segment, an incumbent supplier is more likely to bid profitably, depending on the number alternatives he can offer a buyer quickly. In principle, WI could also be included in f^2, since it should influence a non-incumbent's expected profits.

VII b. Characteristics of the requested system

The following variables, labelled as Z, index whether an incumbent or challenger found it more profitable to bid on the type of system requested:

Dedicated application (DEDAP). Some dedicated applications were so specialized that only a few suppliers might provide alternatives. Even when accounting for the number of potential suppliers in a market segment, acquiring a system for a dedicated application should decrease the probability, on average, of eliciting much bidding.

The value of the procurement (SIZE). Bidding is costly for suppliers because potential vendors must assemble related equipment, pass benchmarks, and prepare related documents. Some observers have expressed concern that these costs are so high that they deter firms from bidding [See GAO (1981), or the Grace Commission (1983)]. If the fixed costs of bidding deter vendors from bidding and firms face different fixed costs, then the larger the value of the procurement, the more likely that more vendors will bid.

The likelihood that success in one sale influences another (NETWORK). Measuring the number of acquisitions at related sites should measure, to some extent, how vendor bidding at one site influenced acquisitions at related sites.[26] It may show that an agency is making many purchases in a particular year and that vendors are bidding aggressively with one office to gain advantages with another.

Competition when there is no incumbent (NOINCUMBENT). The absence of an incumbent may indicate something to bidders. This variable only appears in f^5 and only in 26 cases.

VIb The Advantages of incumbency and disadvantages to challengers

An incumbent's advantage is not directly observed. However, a buyer's previous investment with a vendor is a plausible and useful proxy of an incumbent's advantage for two reasons: First, a buyer tends to invest more extensively in a vendor he prefers -- the greater the previous purchases, the more likely the incumbent vendor has a system that suits the buyer's needs; Second, irrespective of which vendor best suits a buyer's needs, the greater a user's commitment to an existing stock of equipment, the more potential difficulty the user faces when replacing old equipment with new equipment from a producer of incompatible equipment. Call a vector measuring previous investment X_i. If $[X_i - X_j]$ measures the relative advantage of incumbent i over challenger j, then X_i is the only information needed for measuring an incumbent's advantage at single incumbent sites since X_j is zero for all non-incumbents.

The final specification of f^2 and f^1 will include the following five variables as X:

Previous investment with a supplier's equipment (INVEST). This variable takes on the recorded dollar value of the owned equipment on site, adjusted for changing producer prices. This should proxy for the value of switching costs embedded in equipment, which most studies indicate can be quite important.

Years experience with a supplier (EXPERIENCE and EXPERIENCE^2). This variable measures the experience a user has with a supplier. It equals the average age of systems a buyer possesses. Since there are only a few systems at most sites, this variable usually equals the age of the system. A squared term was included to test whether the value of experience with a supplier depreciates rapidly after systems become especially old.

Total Computing Capacity (CAPACITY). The total number of commercially available, general purpose systems on site weighted by the average system size approximates the total computing capacity on site. The larger the capacity of the site, the greater the investment in system and applications software, and the less flexibility when buying replacements. Note that this measure is highly correlated with the total number of systems on site (approx 0.9).

IBM is an incumbent (IBMINC). This variable takes on the value 1 when IBM is the incumbent system vendor at a site. It measures whether IBM seems to be at a disadvantage.[27] The disadvantage to IBM could stem either from the selective enforcement of procurement rules or from the increased entry in the 1970s of competitors to IBM.

VIII Estimation Results

Table 3 contains estimates for the log-likelihood function using equations (10), (11), and (12). In these estimates Θ'_{WI} and Θ'_{WC} were constrained to zero.[28] Since the estimates in Table 3 are difficult to fully comprehend without a lot of experience with these types of models, a useful alternative exposition is shown in Tables 4 and 5. These contain simulations using the estimates. Table 4 shows the derivatives of the predicted probabilities with respect to the exogenous variables. Table 5 shows the consequences for the predicted probabilities from changing a continuous variable by one standard deviation, while setting all other continuous variables at their mean value. Table 5 also gives changes in probabilities resulting from turning the dummy variables on and off. The discussion below will concentrate on Tables 4 and 5. The first two sub-sections describe the results and the next section interprets them.

VIIa The relative ranking of influences

Characteristics of the market segment of the purchase. DEDAP, NETWORK, and SIZE are all of the expected sign and reasonable magnitudes. Tables 4 and 5 show that a one unit increase in the SIZE has the same effect as a 2.3 increase in the number of systems acquired by related offices (NETWORK) or a one-system increase in the number of systems available to an incumbent (INCSYS). On net, a one-standard-deviation in NETWORK had more to do with shifting the probability of observing competition than any other continuous variable. The probability of observing competition increased by 0.07 when

IBM was an incumbent and by 0.16 when IBM was not. Those shifts are complemented by responses to changes in SIZE. A one-standard-deviation in size increases the probability of observing competition by 0.10 when IBM is not an incumbent and by 0.48 when it is not. The absolute magnitude of both of these shifts exceeds the shifts from any other category of variable overall. Turning DEDAP on or off decreases the probability of IBM bidding by .11, but of a non-IBM incumbent by .02. It decreases the probabilities of challengers to IBM by .04 and to a non-IBM challenger by .10. DEDAP can shift the probabilities, but this dummy could often be easily swamped by other factors.

The availability of alternatives. For the estimates in Tables 4 and 5, INCSYS says that the addition of one more system to the list of an incumbent's offerings in a size class shifts the index that an incumbent will bid by .36. The addition of one more system to the list of all non-incumbent's offerings in a size class (COMPSYS) shifts the index that a challenger will bid against a challenger by .011 and against an incumbent by .044. On net, when IBM is not an incumbent, a standard deviation in COMPSYS decreases the probability of observing sole-sourcing by .11. When IBM is an incumbent, then INCSYS influences the probability of IBM winning a competitive bid by .09, which is the second strongest predictor of success in competition.

Are these numbers small or large? A one-standard-deviation increase in COMPSYS, or 10 more systems in a market segment (or just over two firms on average), increases the probability of competition by .11. This seems to be a large amount relative to the high percentage of acquisitions that were already competitive -- i.e., it is surprising that potential competition had any effect at all. This seems to be a small amount relative to the expense of entry into this market. Other factors, which are not as socially expensive as entry, produce just as big an effect.

An incumbent's advantages and a challenger's disadvantages. EXPERIENCE, $EXPERIENCE^2$, and INVEST are of the expected sign and reasonable magnitudes. CAPACITY's effect is the opposite of expectations, but very small. The INVEST variable says that each $100,000 of investment (1967 dollars) decreases the index that a challenger will bid against an incumbent by .011, and that an incumbent will bid against a challenger by .013. Since this variable averages 12 ($100,000 units) with a standard deviation of 27, its effect is not especially large until it reaches its upper ranges (25.3 million dollars maximum), when its effect is quite large. A one standard deviation increase in INVEST increases the probability of sole-sourcing with the incumbent by 0.10 when IBM is not the incumbent and 0.04 when IBM is incumbent. EXPERIENCE can never match this magnitude of impact. The maximum impact occurs when EXPERIENCE = 3.75, with a total decrease of the index of the challenger bidding against the incumbent of .39. Moreover, the effect of EXPERIENCE reverses in sign for sites where the average age of systems is greater than 7.5. Thus, EXPERIENCE does not seem to have a large impact. CAPACITY must exceed its range to really have a large impact. I have found that these qualitative results are insensitive to including or excluding different measures of an incumbent's advantage.

On net, INVEST is the strongest indicator of an incumbent's advantage. I suspect that INVEST measures the occasional sites that have extensive investments in miscellaneous equipment. However, for most of the sample INVEST never swamps the effect of other variables. Moreover, EXPERIENCE and CAPACITY do not have strong effects. Finally, other calculations show that in only 54 percent of the cases in the sample do the challenger disadvantages subtract on net from the index of the probability of a challenger bidding against an incumbent.[29] Thus, while these measures of an incumbent's advantages can be important in predicting diminishing competition, for a large number of cases in this sample, other factors dominate.

The IBM incumbency variable, which is on for 40 percent of the sites, is the most important of the dummy variables. Table 7 shows that the IBM variable changes the probability that a challenger will bid by .17 and that an incumbent (IBM) will bid by .13, a relative change that few variables will match, except at extreme values. When IBM is the incumbent, the probability of competition increases by .14. This again demonstrates the uniqueness of federal offices where IBM is an incumbent supplier relative to offices where IBM is not an incumbent (See Greenstein 1990).

The probability of winning. Table 3 contains an estimate of the probability of the incumbent bidding and winning if the incumbent can profitably bid against a single challenger. The estimate of PPP = .61 translates into a probability of .729 of bidding and winning.[30] This point estimate says that of the 52 cases where a challenger won a competitive procurement, approximately 40 (or 76 percent of the total) were competition between incumbent and challenger. The other 12 were competition between challenger and challenger, as when an incumbent refused to bid against a number of challengers.

These results show that competitive procurement favored incumbents on average 3 to 1, but did not lock out all challengers, at least not in this sample. And while incumbents did not bid on every procurement, they did bid on most. The previously mentioned estimates indicate that incumbent suppliers did not bid on approximately 11 percent of all procurement, which resulted in 22 acquisitions automatically going to challengers (10 sole-sourced with non-incumbents plus the 12 competitive ones estimated from above).

<u>VIIb Developing an overall interpretation</u>

Tables 3, 4, and 5 reveal that the market processes underlying the outcomes are much more complex than any estimates of a probit could represent.

The overall importance of the size of the procurement (SIZE) and the number of acquisitions occurring at related sites (NETWORK) provides evidence that procurement with a high dollar value drew more competitors.

This is consistent with the view that the fixed costs of bidding can be substantial enough to influence bidding behavior.[31]

The estimates of the effects of supply (INCSYS, COMPSYS) point toward the role of differences in the potential supply across market segments and time. At the very least, this is evidence that all mainframe market segments were not uniformly competitive in the sample period and that the competitiveness of acquisitions was a function of the potential supply prevailing in the private market.

Of the measures of an incumbent's advantages, dollar investment (INVEST), but not experience or capacity, is the best predictor of sole-sourcing with an incumbent. Yet, by no means does dollar investment dominate the other variables. The single most important variable for predicting the competitiveness of procurement was whether IBM was an incumbent at a site or not. If this is solely the result of market factors, then it may be measuring potential competition that is missed by the other measures -- that is, previous users of IBM tend to be in market segments where there is relatively more competition than other sectors of the mainframe market.

The foregoing interpretation is remarkable when compared with other results (Greenstein 1990) showing that an agency's previous experience with an incumbent predicts choosing that incumbent again. When an IBM360/370 is on site, IBM appears to receive the "same advantage" from its incumbency as other firms receive from incumbency. The two results together say that even though IBM is in more competitive market segments, incumbency still provides the same advantage to IBM.[32]

The above interpretation draws a clearer picture of the economic factors underlying commercial mainframe market for federal agencies: the competitiveness of acquisitions differs from case to case, depending, first, on the value of the procurement at the office and related offices; second, on the potential supply of alternatives in the relevant market segment at the time of the acquisition; and third, to a lesser extent on the buyer's relationship with his incumbent vendor, particularly if that vendor is IBM or if the buyer has made extensive investments with an incumbent.

VIIc Supervision and inferences from the estimates

Do these estimates tell us something about the commercial mainframe computer market in the time period studied?[33] To what extent is oversight systematically altering the magnitude of the estimates?

It is well-known that GSA follows guidelines that resulted in it more closely scrutinizing more valuable procurement. It is possible that systems of larger size would tend to be more competitive if the GSA approved of sole-sourcing less frequently when it supervised large systems. The open issue concerns whether oversight could turn acquisitions that agencies would otherwise sole-source into competitive acquisitions. Oversight could ostensibly produce more competitive procurement (at least on paper) if, as some observers have stated, the satisfaction of procedural requirements for competition became ends in the themselves, irrespective of the impact on economic efficiency of the outcome.[34]

This interpretation has consequences for recommendations from these measurements. If fixed costs were solely responsible for the result that more valuable procurement was more competitive, then this study would recommend that agencies bundle purchases together to get more competitive procurement. If supervision accounted, in part, for the outcome, then agencies may have had incentives to separate acquisitions in order to avoid supervision.

Supervision may also explain in part why an incumbent's advantages did not much influence the results in this sample -- even though several departures from cost minimization in federal agency's behavior should favor incumbents more than in an ideal profit-maximizing private firm. In particular, strict GSA competitive procedures were thought to be more price sensitive than those of an agency would be, and to weigh less the "soft numbers," such as the expected benefits from future system support, servicing reliability (GAO 1981) and software-conversion expenses.[35] This difference in the weighing of factors could have induced more bidding from non-incumbent suppliers by diminishing the agency's ability to manipulate vendor selection, no matter how much experience the vendor had with the agency.

The performance of IBM in this sample also could represent some factors unique to the government and not shared by private buyers. Though Congressman Brooks retained no formal veto, it was widely believed that he closely monitored the GSA's actions from his position on the House Government Operations Committee (Petrillo 1982), interfering with a procurement when he pleased (e.g. slowed down approval, held up funding). Kelman (1990, pg. 8) states that the worry that the lack of competition favored IBM motivated Congressman Brooks to push for more competition in computer procurement. Werling's (1983) thesis on the implementation of the Brooks Act argued that this intervention did, in fact, slant oversight against IBM.[36] The above results could be made consistent with Werling's thesis in the following sense: If an agency was predisposed to purchase IBM it had to use competitive procedures with greater frequency than if it was predisposed to one of IBM's competitors.

VIII Summary

The discussion in this paper analyzed how market forces influenced the competitiveness of computer system procurement in the federal government. It concentrated on measuring the influence of an incumbent's advantage on outcomes. It developed an econometric model of procurement, in which the unobserved bidding behavior of incumbent and challenger vendors shaped the econometric structure. The method distinguished between different influences of an incumbent's advantage on sole-sourcing with an incumbent and with an non-incumbent. The empirical method also recovered information about the (implicit) unobserved decision of bidders. The model was estimated on a sample of federal computer system acquisitions in the 1970s and early 1980s.

The estimation revealed that at least several economic factors determined the competitiveness of procurement. As expected, the extent of experience a buyer has had with a vendor could have influenced the likelihood of sole-sourcing with that incumbent. However, in many cases other market factors dominated. The extent of possible substitutes in different segments of the mainframe market influenced the competitiveness of procurement across market segments. In addition, procurement of greater value induced more bidding. The potential importance of several non-market factors was also analyzed, particularly the effect of oversight on high value procurement.

There was insufficient evidence to conclude whether the federal experience with IBM reflected industry-wide trends or was unique to the federal government. Evidence was consistent with the view that the market for commercial mainframes for government use can be characterized either as a market in which many competitors in the 1970s bid against IBM or a market in which the federal procurement process placed IBM at special disadvantages.

DATA APPENDIX

<u>Characteristics of challengers and incumbents</u>

From 1976 to 1983, International Data Corporation (IDC) classified general purpose computer systems into six categories according to market size, each group composed of systems that largely substitute for one another. These are designated by the numbers 2 through 7 in IDC's "General Purpose" mainframe system surveys. For example, an IBM 1400 falls in the size class 2, models 360/20 and 370/115 in size class 3, models 360/30, 40 and 44, and 370/125 and 135 in size 4, models 360/50 and 370/145 in size 5, models 360/65 and 370/155 and 158 in size 6, and models 360/67, 75, 85, and 95, and 370/165, 168, and 195 in size 7.

From each IDC survey I counted in each size category the total number of systems offered by each vendor (The 1976 counts were applied to observations from earlier years). This captures two related notions about potential supply in a market. First, a larger number of vendors per size category should indicate a greater probability that one vendor will possess a viable option and, hence, will bid. Second, irrespective of the number of vendors, a larger number of systems offered by challengers should indicate how easily vendors found alternatives to offer as a bid, and a greater probability of more than one vendor bidding -- this holds whether the bid is made by the system manufacturer or value-added vendor that repackages a manufacturer's equipment. In this market the number of systems offered correlates highly with the number of system suppliers in a market segment (approx .8 at a 9 to 2 ratio). Note that using these variables limits the sample to commercial mainframes. Minicomputers -- even those that perform mainframe-like applications, such as DEC's VAX -- are excluded from the IDC grouping.

Constructing WI and WC is straightforward except for acquisitions of systems at sites where General Electric (GE) or RCA were incumbent system suppliers. Just prior to the beginning of the sample period, these companies were acquired by Honeywell and Sperry-Univac, respectively. It seems improper to treat GE as separate from Honeywell (and RCA from Sperry-Univac), since the sales operations were merged. It also seems improper to assign to all GE sites the advantages possessed by former Honeywell sites, since the product lines were not designed to be well integrated. Due to this problem, I estimated each equation with three different codings: (1) as if the merged firms had totally integrated product lines; (2) as if they never merged; and (3) I simply excluded all 11 sites at which GE or RCA were incumbents, which were the only cases where the issue was relevant. Note that (1) and (2) will also differ in their definition of who was an incumbent and who was not. For example, moving from GE to Honeywell is counted as choice of an incumbent under (1), but not (2). This influenced the coding of 5 of the 11 observations at which GE or RCA were incumbents. As it turned out, the 3 sets of estimates did not differ sharply (Greenstein 1989, Appendix B).

Characteristics of requested system

Dedicated application (DEDAP). The government's inventory classifies systems by their application. Dedicated applications include process control and other monitoring applications that could employ standard mainframe equipment (Most special government designs and other customized systems have been eliminated from the sample). This is different from a general management system, the class of systems making up most of the sample, where the hardware is used as a "platform" for a variety of ever-changing programming.

The value of the procurement (SIZE). There is no direct measure of a system's value, since delivery of systems is not always taken at once. The best proxy for the value of a system is the size of the system requested. SIZE is superior to the recorded price of the main CPU. Further efforts are needed to understand how recorded prices were allocated between all the components that come bundled together in a system.

The likelihood that success in one sale influences another (NETWORK): There is no direct measure of whether bidding at one agency's office influences bidding for another office's purchases. However, the acquisition history of similar offices in an agency contains related information. This variable equals the number of system acquisitions made by other offices within the same "office command bureau" in the same year as the office making the observed purchase. For the smaller civilian agencies, this variable simply equals the number of other systems acquired by the entire agency. In the larger federal agencies, particularly the Army, Navy, and Air Force, offices are typically divided into command bureaus by region (Overseas, West Coast, Southeast, etc.) and, less often, by function (research division, accounting division, etc.), and sometimes both. Despite the looseness of this definition over time and across agencies, it seemed more sensible to count the number of system acquisitions in an office command bureau, rather than an agency. Counting agency acquisitions in practice would be virtually equivalent to a dummy variable for defence agency or not, since defense agencies have much larger yearly budgets allocated to computer systems than do civilian agencies. But such a dummy does not measure the interrelationship between offices we are looking for.

Competition when there is no incumbent (NOINCUMBENT). This dummy variable is one when there is no incumbent and zero otherwise.

Incumbency advantages and challenger disadvantages

Previous investment in a supplier's equipment (INVEST). This variable takes on the recorded dollar value of the owned equipment on site, adjusted for changing producer prices.

Years experience with a supplier (EXPERIENCE and EXPERIENCE^2). This variable equals the average age of systems a buyer possesses. Since there are only a few systems at most sites, this variable usually equals the age of the system.

Total computing capacity (CAPACITY): The total number of commercially available general purpose systems on site weighted by the average system size approximates the total computing capacity on site. (Size is determined by the IDC measure). Note that this measure is highly correlated with the total number of systems on site (approx 0.9). The total number of systems and the total number of commercial systems is the same at most installations in the sample except at a few military and Department of Energy sites.

IBM is an incumbent (IBMINC): This variable takes on the value 1 when IBM is the incumbent system vendor at a site. Approximately 40 percent of all acquisitions occurring at single-incumbent sites had IBM as an incumbent, and the overwhelming majority of these sites had a system from the IBM 360/370 family on site (86 percent).

ENDNOTES

1. Recent contributions to understanding government procurement or auctions in practice includes Hendricks, Porter, and Boudreau (1987), and Hendricks and Porter (1988) on asymmetric information in oil lease auctions, Lichtenberg (1988) on Research and Development and government procurement, Crocker (1990) on Air Force engine procurement, Rogerson (1990a, b, c) on defense procurement of weapons, and Greenstein (1990) on mainframe computer vendor choice.

2. This model is based on the framework outlined in Go for 12: An Interim Report of the Elimination of Unnecessary Bottlenecks in the Acquisition Process, Appendix B (GSA 1987). Also see Grace Commission (1983), report on ADP/Office Automation, page 34, for "ideal" computer procurement procedures. Of course, reality is more complex. Kelman (1990), chapters 2 and 3, provides a detailed description and analysis of problems in the use of these procedures.

3. Kelman (1990), pg. 22, states that in a 1989 survey of federal computer procurement managers, one-third of the recently awarded contracts had been protested.

4. For example, see GAO 1983 on benchmarking practices and their abuse. The Government Accounting Office would not speculate on how widespread abuse was. Kelman (1990), chapters 2 and 3, provide details on the subtle ways in which an agency may and may not "hard wire" a contract. Allegations of manipulation of specifications have recently come to light in the national press. For allegations that the Navy systematically favors IBM, see Washington Post, 1-8-89, H1, and the New York Times, 12-9-88, page C1. Thanks to Jonathan Baker, Luis Cabral, and Greg Rosston for bringing these to my attention.

5. 1983 was the final year that the inventories recorded the procurement code. I would like to thank Professor Frank Fisher, IBM Corporation, and Martha Gray of the National Bureau of Standards for their aid locating what appears to be the last existing copy of these inventories. For summaries of individual years, see NBS 1977, 1978, & 1982, or GSA's ADP Activity Summary or ADPE Inventory summaries from various years.

6. Over 3 billion dollars was spent on "General Purpose Automatic Data Processing Equipment, Suppliers and Support" in 1986. See GSA 1987, page 15. In the IDC General Purpose Surveys, Federal computer sites never comprised more than 3 percent of the sample in any year (12/8/75, 12/5/78), indicating that Federal offices are one of many buyers in the U.S domestic market. Uses for mainframes include simple repetitive calculations that use large data-bases, and a limited amount of process control. See NBS

(1981), chapter 4, for some evidence that federal mainframe use resembles that of its private-industry counterparts.

7. An office is literally called an "ADP Unit" in the inventory. Offices within agencies tended to be differentiated by geography and sometimes by function. There is little evidence that physically linked offices were counted twice.

8. The records also do not reveal how sole-sourcing and competition were defined, leaving it to the acquiring agency to decide. The definition in this text is the most common definition used by government personnel. Differences in reporting definitions or procedures across agencies has never come to my attention. The Navy and Army codes do not indicate how competitive were acquisitions in the 1983 inventory.

9. The incumbent vendor in this data set is the vendor that designed the system used by the site in the previous year.

10. The sample eliminates very large sites. There is no indication that this procedure greatly biased the sample towards any manufacturer, system or buyer. If anything, it may be that more "scientific" work tended to be done at very large sites, which might bias the sample of acquisitions in this paper towards standard administrative applications such as inventory and payroll.

11. The rule for deciding between vendors need not be fully specified when the procedural choice is made. I need only assume that at the start of phase (2) all buyers have a partially uncertain decision rule for deciding between alternatives in phase (3). This source of uncertainty in decision-making is plausible since procurement procedures introduce volatility into decision making, and when bids are first solicited, buyers may not know precisely what they want their future system to do, and buyers may only vaguely know how to evaluate the alternatives. Logically there must be some uncertainty in bidding: In a world in which there are fixed costs of bidding, if there were no uncertainty two suppliers would never compete against one another, because all the future winners of every procurement could be anticipated; and no seller would incur the expenses of preparing for a procurement that he would surely not win.

12. This is a reasonable concern. See GAO 1977b or GAO 1980 on the influence of conversion expenses on the selection of new vendors, and Kelman (1990), pg. 70 -73, on the sources of an incumbent's advantage in procurement. Economic theorists have also been interested in how "switching costs" could alter competitive behavior. See Farrell (1987), Farrell and Shapiro (1986) and (1987), and Klemperer (1986) mathematical models, or Williamson (1975) and (1979) for a wider discussion of the causes and consequences of investment in relation-specific assets. For

theoretical work on switching costs in procurement, see McAfee and McMillan (1986) for a general framework, or Anton and Yao (1988), Demski, Sappington, and Spiller (1988), or Cabral and Greenstein (1990) for analyses of supplier switching.

13. It is also widely believed that agencies favor those vendors that require the least use of the agency's discretionary budget. An agency may simply favor the vendor whose product inconveniences their workers the least -- for example, if a system requires the least retraining or other adjustment costs. These incentives can also work to the advantage of incumbent system supplier.

14. There may have been a computer on site, but none of the potential mainframe system vendors in the sample provided a system.

15. In practice, a formal request typically elicits 2 or 3 formal bids and occasionally more, though more informal interest is not uncommon.

16. The sequential move game has an advantage over a simultaneous-move game for the application here in that it avoids any indeterminant solutions to the question of which of many players will be the sole bidder when it is profitable for only one player to bid. See Bresnahan and Reiss (1987) for elaboration on the point. In addition, simultaneous-move games in the context of bidding models require more explicit, perhaps arbitrary, specification of the exit and entry rules of bidders. This is a topic for further research.

17. Notice that the fourth assumption partially overlaps with the third assumption. It rules out some games in which asymmetric knowledge between incumbent and non-incumbent about the profitability of bidding is partially revealed by an incumbent's decision to bid or not to bid.

18. One interpretation of this assumption is that it imposes the constraint that the probability of winning a bid is quite high for the incumbent against the weak challenger. Hence, the expected revenues of the incumbent as a sole bidder and in competition with the weak challenger are greater than the expenses of putting together the bid. Alternatively, one could make $\pi^I 1$, $\pi^C 2$, and $\pi^C 5$ sufficient for predicting all outcomes by assuming that $\pi^I 1 > 0$, and $\pi^C 2 > 0$ implies either $\pi^I 2 > 0$ or $\pi^C 5 > 0$. See Greenstein (1989), Appendix A, for a discussion of this and alternative assumptions.

19. The incumbent may not eventually bid if a multiple number of challengers makes it unprofitable for the incumbent to do so. Even though an incumbent may be profitable against one challenger by assumption (i.e. $\pi^I 2 > 0$), profitability against a multiple

number of challengers is not guaranteed. Thus, either the incumbent or challenger could win in competition with one another, or the incumbent may not bid at all.

20. There is no error attributed to the "false expectations" of an agency. Any systematic mis-estimation of an incumbent's or non-incumbent's propensity to bid will be measured in the constant of the index of that player's behavior.

21. PP indexes the joint probability of bidding <u>and</u> winning. The incumbent will bid if there is only one challenger, but he may not have bid if multiple challengers made it unprofitable.

22. Notice that an alternative for equation (6) could be
(6') $f^1(W,Z,X) = \beta 1 + \beta_{WI}*WI + \phi*[\beta'_{WC}*WC + \beta_Z*Z] - \Omega[\beta_X*X]$,
where $\Omega > 0$ and $\phi > 0$ are different factors of proportionality. This implies a slightly altered estimation equation than the one reported here. Tests of this second alternative specification contributed very little to the likelihood function. Hence, the simpler specification is used. See Greenstein (1989).

23. While it is possible to paramaterize the probability that an incumbent will win a competitive bid as a function of observable characteristics of the site, I have found with this sample of acquisitions, that the estimates of the other parameters do not change much as a consequence. Since the method's purpose is to predict the probability of using competition versus sole-sourcing, rather than predict which vendor wins a competitive bid, it seemed best to use the simplest possible specification.

24. Several other variables were also tried in earlier specifications, but found to be less informative. This included measures of the technical age of the system acquired, and indicators of whether the acquired system was multi-processor, and whether is was acquired by a Department of Defence subagency such as the Army, Air Force, or Navy. Year of acquisition was also found to be uninformative when added to a specification in which SYSTEMS was included, but significant when SYSTEMS was excluded. However, the specification with only SYSTEMS had a higher likelihood and a more ready structural interpretation. Hence, the remaining variables comprise a minimal list.

25. This assumes that exogeneity of the market segment will be warranted by the breadth of the IDC segments and the government system labels employed.

26. There are frequent complaints from the period about the inability of offices to share software, so the probability that all of an agency's office's decisions are linked by strong network externalities is somewhat in doubt. Yet, one might still expect some correlation if multiple sites perform similar functions and acquire similar systems simultaneously in an effort

to standardize their information processing and learn from each other's experiences. Hence, vendors may anticipate that success in one location will influence their success elsewhere.

27. P. R. Werling (1983), who wrote a thesis on the administration of the Brooks Act, argued that the oversight especially favored vendors other than IBM and that IBM procurement was more closely monitored, especially in an non-competitive procurement (see Werling, page 177, 262 and the discussion). Yet, Werling's argument remains largely untested because his quantitative evidence could be interpreted in many ways (Greenstein 1989). Kelman (1990) also asserts that the fear that the lack of competition favored IBM motivated Brooks to push for more competition, though he does not present any quantitative evidence. In this sample, the measured characteristics of sites that have IBM as an incumbent do not differ much from other sites. Thus, there seemed to be little statistic justification for interacting the dummy with other measures of an incumbent's advantages.

28. It was found that a "rival's" potential did not contribute significantly to the estimation. Using log ratio tests to test the joint hypotheses $\theta'_{WI} = 0$ and $\theta'_{WC} = 0$ could not be rejected at the 10 percent level.

29. This calculation was made by multiplying IBMINC, INVEST, EXPERIENCE, EXPERIENCE^2 and CAPACITY by their respective coefficients and by adding up for each sample observation.

30. Measures of the extent of previous experience with the incumbent were not statistically significant predictors of the probability that an incumbent would win a competitive procurement. The only significant results showed that IBM had a slightly lower probability of winning than other firms, that the Air Force stayed with its incumbents more often and that the Navy switched more often. However, these specifications did not change the others estimates much at all, so the predicted probability of sole-sourcing versus competition also did not change. Since the goal of the analysis was to predict choice of procedures rather than the winner of competitive bids, it seemed best to report the simpler specification.

31. The importance of fixed costs and the size of the procurement may be overemphasized in federal procurement relative to private industry. When the Government Accounting Office (GAO 1981) compared private practices with federal procurement practices they observed that computer vendors needed to meet more requirements to qualify for bidding for federal agencies than did those selling to private industry.

32. However, unlike Greenstein's previous research, because only 12 of 88 sites did not contain a system from the IBM 360/370 family, we cannot distinguish between the differences at sites who were using an older generation of equipment with limited upward compatibility and those using a newer generation with expanded upward compatibility.

33. For contrasting analyses of the market in this time period, see Brock (1975); Fisher, McGowen and Greenwood (1983); and Fisher, Mckie, and Mancke (1983).

34. As the Grace Commission (1983) states: "The Government's (automatic data processing) acquisition process indicates disproportionate concern with 'process accountability.'" When Werling (1983) focuses on the implementation of the Brooks Act, he strongly emphasizes how agencies could not understand the logic behind oversight process. Kelman (1990) further argues that agency procurement should be less much rule-bound, allowing them to update technical specifications as they learn about a product in the course of a bid. For an alternative view, see GAO 1977a or House report 94-1746 (1976) for some complaints about the inability of the Brooks Act to achieve its desired ends.

35. Until the beginning of the 1980s, GSA evaluation of competitive bids were not systematically accounting for the short and long-term costs of converting existing software to incompatible vendors' systems (GAO 1980). For a summary of this debate and an analysis of related economic issues, see Cabral and Greenstein (1990). For an in depth analysis of the way the procurement institutions resolve the trade-off between prices and quality, see Kelman (1990), chapter 2. On conversion costs, see pages 103 -104.

36. Werling states (p. 262), "Within the (automatic data processing) community it has been common knowledge that the HGOC (House Government Operations Committee) would delay procurement for (automatic data processing equipment) ordered from IBM if at all possible." Also see p. 177 and discussion. Greenstein (1990) addresses the quantitative evidence using different methods.

Figure 1

Correspondence of Outcomes to number of cases

When there is a single incumbent

	Observe incumbent winning	Observe challenger winning
Observe Sole sourcing	SI: Sole Source Incumbent 26 cases	SC: Sole Source Challenger 10 cases
Observe Competition	CI: Incumbent wins competition 107 cases	CC: Challenger wins competition 52 cases

When there is no incumbent

	Observe challenger winning
Observe Sole sourcing	SNI: Sole Source Challenger 5 cases
Observe Competition	CNI: Challenger wins competition 21 cases

Note: 221 observations total.

Figure 2

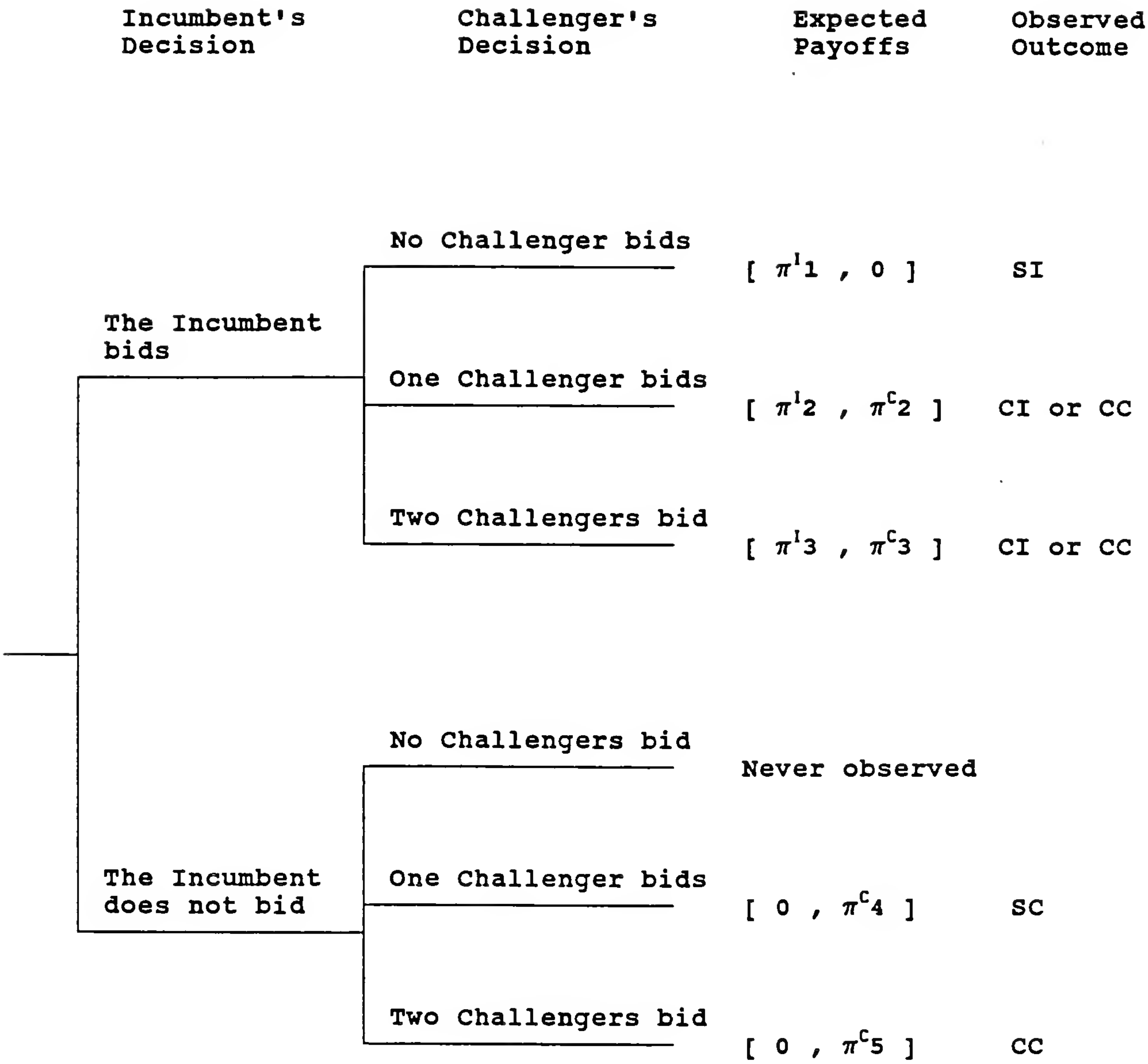
Incumbent's Decision
Challenger's Decision
Expected Payoffs
Observed Outcome
The Incumbent bids
No Challenger bids
[$\pi^I 1$, 0]
SI
One Challenger bids
[$\pi^I 2$, $\pi^C 2$]
CI or CC
Two Challengers bid
[$\pi^I 3$, $\pi^C 3$]
CI or CC
The Incumbent does not bid
No Challengers bid
Never observed
One Challenger bids
[0 , $\pi^C 4$]
SC
Two Challengers bid
[0 , $\pi^C 5$]
CC

Figure 3

Correspondence of profit functions to observed outcomes

SI. Only the incumbent bids (situation 1).

$\pi^I 1 > 0,\ \pi^C 2 < 0$

SC. Only a challenger bids, when there was an incumbent (situation 4).

$\pi^I 1 < 0,\ \pi^C 5 < 0$, or
$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^C 5 < 0,\ \pi^I 2 < 0$.

CI. Incumbent wins competition between incumbent and challenger (situation 2 or 3).

$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^C 5 > 0,\ \pi^I 2 > 0,\ \pi^C 3 < 0$ or
$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^I 2 > 0,\ \pi^C 3 > 0,\ \pi^I 3 < 0$.

CC. Challenger wins competition between incumbent and challenger or between challenger and challenger, when there was an incumbent (situation 2, 3 or 5).

$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^C 5 > 0,\ \pi^I 2 > 0,\ \pi^C 3 < 0$ or
$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^I 2 > 0,\ \pi^C 3 > 0,\ \pi^I 3 < 0$ or
$\pi^I 1 < 0,\ \pi^C 5 > 0$, or
$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^C 5 > 0,\ \pi^I 2 > 0,\ \pi^C 3 > 0,\ \pi^I 3 < 0$, or
$\pi^I 1 > 0,\ \pi^C 2 > 0,\ \pi^C 5 > 0,\ \pi^I 2 < 0$.

SNI. Challenger is sole bidder, no incumbent (situation 4).

$\pi^C 5 < 0$.

CNI. Challenger competes with another challenger, no incumbent (situation 5).

$\pi^C 5 > 0$.

Note: See figures 1 and 2 for numbering and lettering scheme.

Table 1

Covariates and the predicted sign of their coefficients

Abreviation	Variable Definition	Prediction
W: Characteristics of vendors		
COMPSYS	Number of system offerred by challengers	Positive
INCSYS	Number of systems offerred by incumbent	Positive
Z: Characteristics of the market segment		
SIZE	Size of system acquired (2 to 7)	Positive
NETWORK	Number of systems acquired at related site	Positive
DEDAP	System requested for dedicated application	Negative
NOINCUMB	No incumbent system supplier in prior year	None
X: Incumbent's advantages		
IBMINC	IBM is an incumbent on site	Positive*
INVESTMENT	Value of investment on site (1967 $100,000)	Negative*
EXPERIENCE	Average ages of site's systems	Negative*
EXPERIENCE2	EXPERIENCE squared	Positive*
CAPACITY	Estimated computer capacity	Negative*

Positive: The sign of this coefficient expected to be positive.

Negative: The sign of this coefficient expected to be negative.

*: Expected sign in f2, the expected profitability of the entrant.

Table 2

Summary statistics for exogenous variables

ABREVIATION	NOBS	MEAN	STD DEV	MINIMUM	MAXIMUM
SYSTEMS	221	39.34	10.16	20.00	74.00
COMPSYS	221	33.66	10.05	13.00	74.00
INCSYS	221	5.68	3.55	0.00	19.00
SIZE	221	4.85	1.35	2.00	7.00
NETWORK	221	4.98	6.23	1.00	34.00
DEDAP	221	0.12	0.32	0.00	1.00
NOINCUMB	221	0.12	0.32	0.00	1.00
IBMINC	221	0.39	0.49	0.00	1.00
INVESTMENT	221	12.17	27.53	0.00	253.00
EXPERIENCE	221	3.43	2.54	0.00	11.50
EXPERIENCE2	221	18.27	22.41	0.00	132.25
CAPACITY	221	10.88	20.70	0.00	118.87

Selected correlations

	AVEAGE	INVESTMENT	CAPACITY
INVESTMENT	0.340		
CAPACITY	0.078	0.232	
IBMINC	0.226	0.166	-0.047

	INCSYS	NETWORK	DEDAP	COMPSYS
NETWORK	-0.131			
DEDAP	-0.268	0.056		
COMPSYS	-0.390	0.133	0.081	
INCSYS	-0.055	0.097	0.006	-0.098

Table 3
Estimates of equations (10), (11) & (12)
(Standard errors in parenthesis)

LOGLIKELIHOOD	-198.529
NUMBER OF OBSERVATIONS	221
SINGLE BIDDER, INCUMBENT	26
SINGLE BIDDER, CHALLENGER	10
COMPETITION, INCUMBENT WINS	107
COMPETITION, CHALLENGER WINS	52
SINGLE BIDDER, NO INCUMBENT	5
COMPETITION, NO INCUMBENT	21
CONSTANT θ5	-0.34
	(0.55)
NUM COMPETITORS' SYSTEMS	0.011
	(0.008)
PROCURE SIZE	0.078
	(0.053)
NUM ACQUISITIONS IN NETWORK	0.033
	(0.024)
DEDICATED APPLICATION	-0.08
	(0.097)
CONSTANT θ2	-2.46 **
	(0.98)
IBM INCUMBENT	0.90 **
	(0.26)
DOLLAR INVESTMENT	-0.011**
	(0.004)
SUM EXPERIENCE	-0.21
	(0.13)
SUM EXPERIENCE2	0.028*
	(0.015)
COMPUTER CAPACITY	0.007
	(0.006)
CONSTANT θ1	-2.98 **
	(3.47)
NUM INCUMBENT'S SYSTEMS	0.36 **
	(0.14)
NO INCUMBENT VENDOR	0.32
	(0.47)
PPP, P OF INCUMBENT WINNING	0.61 **
	(.015)
DELTA = δ = $(\Gamma * \sigma 5/\sigma 2)$	3.91
	(2.77)
ALPHA = α = $(\ * \sigma 2/\sigma 1)$	1.26 **
	(0.57)

Note: Estimates treat GE and Honeywell, RCA and Univac as merged.

Table 4

Derivatives with respect to exogenous variables

When IBM is not an incumbent:

	P(CI,CC)	P(SI)	P(SC)	P(CI)	P(CC)	P(f5)	P(f2)	P(f1)
NETWORK	0.0214*	-0.009	-0.012	0.034	-0.013	0.011	0.013	0.038
COMPSYS	0.0042	-0.004	-0.001	0.003	0.002	0.004	0.004	0.000
SIZE	0.0496*	-0.022	-0.028	0.080	-0.030	0.026	0.030	0.088
INVEST	-0.0002*	0.001	-0.001	0.002	-0.002	0.000	-0.001	0.003
CAPACITY	0.0001	-0.001	0.001	-0.001	0.001	0.000	0.001	-0.002
INCSYS	0.0172*	0.004	-0.021	0.052	-0.035	0.000	0.000	0.075
AVEAGE	-0.0003	0.002	-0.002	0.003	-0.003	0.000	-0.002	0.005

When IBM is an incumbent:

	P(CI,CC)	P(SI)	P(SC)	P(CI)	P(CC)	P(f5)	P(f2)	P(f1)
NETWORK	0.0393**	-0.037	-0.002	0.031	0.008	0.011	0.039	0.006
COMPSYS	0.0132**	-0.013	-0.000	0.010	0.004	0.004	0.013	0.000
SIZE	0.0910**	-0.087	-0.004	0.074	0.018	0.026	0.091	0.014
INVEST	-0.0031**	0.003	-0.000	-0.002	-0.001	0.000	-0.003	0.001
CAPACITY	0.0020**	-0.002	0.000	0.001	0.001	0.000	0.002	-0.000
INCSYS	0.0006	0.003	-0.003	0.007	-0.006	0.000	0.000	0.117
AVEAGE	-0.0054**	0.006	-0.000	-0.004	-0.002	0.000	-0.006	0.001

Note: All derivatives are for a site with mean values of all continuous variables. All sites have an incumbent. All acquisitions are not for dedicated applications unless otherwise stated. If V is the exogenous variable and P(V) is the endogenous probability, then the above were approxiated with [P(1.01*V) - P(V)]/[0.01*V].

Standard errors were computed for all derivatives, but are only displayed for P(CI,CC). One star means that the t-statistic is greater than 1.64 and two stars means that the t-statistic is greater than 1.96.

See Figure 1 for definitions of outcomes. P(5) is shorthand for probability that a challenger bids against another challenger. P(2) is the probability that a challenger bids against an incumbent. P(1) is the probability that an incumbent bids when no other firm bids. See Figure 2.

Table 5

Probability change from standard deviation increase in exog. variables.

When IBM is not an incumbent:

	P(CI,CC)	P(SI)	P(SC)	P(CI)	P(CC)	P(SI,CI)
COMPSYS	0.1099**	-0.1094	-0.0005	0.0799	0.0300	-0.0294
INCSYS	0.0007	0.0030	-0.0037	0.0078	-0.0070	0.0108
NETWORK	0.1659**	-0.1622	-0.0037	0.1283	0.0376	-0.0338
SIZE	0.1037**	-0.1006	-0.0031	0.0814	0.0222	-0.0191
INVEST	-0.0991*	0.1017	-0.0025	-0.0676	-0.0315	0.0340
CAPACITY	0.0411	-0.0435	0.0023	0.0255	0.0156	-0.0179
AVEAGE	0.0357	-0.0377	0.0019	0.0223	0.0134	-0.0153
DEDAP	-0.1029	0.0957	0.0071	-0.0861	-0.0167	0.0096
IBMINC	0.1415**	-0.1779	0.0363	0.0336	0.1078	-0.1442

When IBM is an incumbent:

	P(CI,CC)	P(SI)	P(SC)	P(CI)	P(CC)	P(SI,CI)
COMPSYS	0.0316**	-0.0261	-0.0054	0.0191	0.0125	-0.0070
INCSYS	0.0304**	0.0063	-0.0367	0.0927	-0.0622	0.0990
NETWORK	0.0705**	-0.0341	-0.0363	0.1181	-0.0475	0.0839
SIZE	0.0495**	-0.0230	-0.0264	0.0818	-0.0322	0.0587
INVEST	-0.0194	0.0388	-0.0194	0.0231	-0.0426	0.0620
CAPACITY	-0.0004	-0.0129	0.0133	-0.0259	0.0255	-0.0388
AVEAGE	0.0000	-0.0113	0.0113	-0.0217	0.0217	-0.0330
DEDAP	-0.0622	0.0247	0.0374	-0.0985	0.0363	-0.0737

Note: All computations are for a site with mean values of all continuous variables. All sites have an incumbent. All acquisitions are not for dedicated applications unless otherwise stated. If V is the continuous exogenous variable, σV is one standard deviation, and P(V) is the endogenous probability, then the above were calculated with [$P(V+\sigma V) - P(V)$]. If V is a dummy variable, as with DEDAP or IBMINC, then the above were calculated with [$P(V=1) - P(V=0)$].

Only standand errors for the change in probabilities for competition are displayed. One star means that the t-statistics were greater than 1.64 and two stars means that it was greater than 1.96.

REFERENCES

Anton, James J. and Yao, Dennis A., "Second Sourcing and the Experience Curve: Price Competition in Defense Procurement," Rand Journal, Spring 1987.

Auerbach Standard EDP Reports, 1962-1975, Philadelphia Pa.

Berry, Steve, "Estimation of a Model of Entry and Exit in Airline City-Pair Markets", Mimeo, November 1988.

Bresnahan, Timothy, F. and Peter C. Reiss, "Estimation of Finite Noncooperative Games: Entry in Monopoly Markets," Stanford University, Graduate School of Business, Febuary, 1986.

Bresnahan, Timothy F. and Peter C. Reiss, "Do Entry Conditions Vary Across Markets?" Brookings Papers on Economic Activities, (3), 1987.

Brock, Gerald, US Computer Industry: A Study in Market Power, Cambridge Mass: Ballinger Publishing Co. 1975

Cabral, Luis, and Greenstein, Shane, "Switching Costs and Bidding Parity in Government Procurement of Computer Systems," BEBR Faculty Working Paper no. 90-1628, University of Illinois, February, 1990.

Crocker, Keith J., "Efficient Contract Design in Long-Term Relationships: the Case of Air Force Engine Procurement," Penn State Working Paper, April 1990.

Demski, Joel S., Sappington, David E. M., and Spiller, Pablo T., "Managing Supplier Switching", The Rand Journal, Spring 1987.

Farrell, Joe, "Competition with Lock-in," University of California working Paper, January 1987

Farrell, Joe, and Shapiro, Carl, "Dynamic Competition with Switching Costs," Rand Journal, Spring 1988.

Farrell, Joe, and Shapiro, Carl, "Optimal Contracts with Lock-in," American Economic Review, March 1989.

Fisher, McGowen, and Greenwood, Folded, Spindled and Mutilated: Economic Analysis and US vs. IBM, MIT Press, 1983.

Fisher, McKie and Mancke, IBM and the US Data Processing Industry: An Economic History, Praeger Publishers, 1983.

Greenstein, Shane, "Computers, Compatibility and Economic Choice", Unpublished doctoral dissertation, Stanford University, June 1989.

Greenstein, Shane, "Did Installed Base Give an Incumbent any (Measurable) Advantages in Federal Computer Procurement?" April, 1990, mimeo.

Hendricks, Kenneth, and Porter, Robert, "An Empirical Study of an Auction with Asymettric Information," American Economic Review, December 1988.

Hendricks, Kenneth, Porter, Robert H., and Boudreau, Bryan, "Information, Returns, and Bidding Behavior in ocs Autions: 1954 - 1969," Journal of Industrial Economics, XXXV (4), June 1987.

International Data Corporation, EDP Industry Report, Framingham, Massachusetts. Various years.

Kelman, Steven, Procurement and Public Management: The Fear of Discretion and the Quality of Government Performance, The AEI Press, Washington, D.C., 1990.

Klemperer, Paul, "Markets with Consumer Switching Costs," Quarterly Journal of Economics, Spring 1987.

Klemperer, Paul, "Intertemporal Pricing with Consumer Switching Costs," Rand Journal of Economics, Spring 1987.

Lane, Sarah J., "Entry and Industry Evolution: the Automatic Teller Machine Manufacturer's Market," Boston University, School of Management Working Paper # 89-32, December 1989.

Lichtenberg, Frank R., "The Private R&D Investment Response to Federal Design and Technical Competition," American Economic Review, June 1988.

R. Preston McAfee, and John McMillan, "Auctions and Bidding," Journal of Economic Literature, June 1987.

McComb, Noll, and Wiengast, "Administrative Procedrues as Instruments of Political Control," Journal of Law, Economics and Organizations, 1987

Petrillo, Joseph J. Government ADP Procurement, Federal Publications Inc., 1982.

Phister, Montgomery, Jr. Data Processing Technology and Economics, Digital Press, Santa Monica, 1979.

Reiss, Peter C. and Spiller Pablo T., "Competition and Entry in Small Airline Markets," Jounal of Law and Economic, April 1990.

Rogerson, William P., "Excess Capacity in Weapons Production: An Empirical Analysis," Mimeo, February, 1990.

Rogerson, William P., "Incentives, The Budgetary Process, and Inefficiently Low Production Rates in Defense Proucurement," mimeo, January, 1990.

Rogerson, William P., "Quality versus Quantity in Military Procurement: An Organizational Theory of Decision Bias," American Economic Review, Forthcoming.

Werling, Paul Richard, Alternative Models of Organization Reality: The Case of Public Law 89-306, Dissertation, USC, Dec. 1983.

Williamson, Oliver E., Markets and Heirachies: Analysis and Antitrust Implications, New York: Free Press, 1975.

Williamson, Oliver E., "Transaction Cost Economics: The Governance of Contractual Relations," Journal of Law and Economics, 1979.

U.S. Government Publications:

General Accounting Office:

1977a, "Problems Found with Government Acquisition and Use of Computers From November 1965 to December 1976," March 15, 1977, FGMSD-77-14.

1977b, "Millions in Savings Possible in Converting Programs from one Computer to Another," Sept. 15, 1977, FGMSD-77-34.

1980, "Conversion: A Costly, Disruptive Process That Must be Considered When Buying Computers," June 3, 1980, FGMSD-80-35.

1981, "Non-Federal Computer Acquisition Practices Provide Useful Information for Streamlining Federal Methods," Oct. 2, 1981, AFMD-81-104.

1983, "Benchmarking: A Costly and Difficult, but Often Necessary When Buying Computer Equipment or Services," 10-22-1982, GA1.13:AFMD-83-5.

General Services Administration:

Automatic Data Processing Activities Summary in the United States Government, 1972-1982, 1986, GS12.9:972-982

Automatic Data Processing Equipment Inventory, 1960-1983, 1986, GS2.15:972-983, GS2.15:967-971, PrEX2.12:960-966.

1987, Information Resources Management Service, Go for 12, An Interim Report on the Elimination of Unnecessary Bottlenecks in the Acquisition Process, March 1987.

Office of Software Development and Information Technology:

1983b, Software Conversion Lessons Learned, Volume I, FCSC-83/003, 1983

National Bureau of Standards:

1980, Conversion of Federal ADP Systems: A Tutorial, August, 1980, C13.10:500-62.

1980, Data Base Directions -- The Conversion Problem, September, 1980, C13.10:500-64.

1983, Institute for Computer Science and Technology, Future Information Processing Technology - 1983, August 1983, C13.10:500-103.

Martha Mulford Gray, An Assessment and Forecast of ADP in the Federal Government, August 1981, C13.10:500-79.

-- , Federal ADP Equipment: A Compilation of Statistics --1981, Nov. 1982, C13.10:500-97.

-- , Computers in the Federal Government: A compilation of Statistics --1978, April 1979, C13.10:500-46.

-- , Computers in the Federal Government: A compilation of Statistics, June 1977, C13.10:500-7.