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Did Installed Base Give an Incumbent Any (Measurable) Advantages in Federal Computer Procurement?

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This essay is taken from the third chapter of my dissertation. Tim Bresnahan, Paul David, and Roger Noll provided more sagacious advice than I could possibly follow. Tom Downes, Pablo Spiller, and seminar participants at the Stanford Technology and Productivity seminar and the Illinois Political Economy seminar provided many valuable comments on an earlier draft of this work. The Center for Economic Policy Research at Stanford University, the Charles Babbage Institute, and the National Science Foundation provided funding for my dissertation. All remaining errors are my own.

Abstract

This research examines the relative strength and significance of the status of "incumbent contractor" in Federal computer procurement. It statistically measures the relationship between vendor selection and previous user experience for a sample of commercial mainframe computer system acquisitions by federal agencies in the 1970s. This research shows that while incumbency may be important, compatibility between existing and proposed systems is as influential.

IBM's experience provides an interesting illustration of this thesis. IBM seems to get less advantage from being an incumbent than its rivals, a trend that suggests that procurement was systematically biased against IBM. However, new evidence shows that IBM's disadvantage is largely due to incompatibilities in IBM's product line. This result, while not surprising to anyone who has followed the literature on switching costs, is still quite significant. It is the first econometric measurement of the competitive effects of incompatibility. This evidence also shapes the interpretation of the effect of the computer procurement regulations on commercial mainframe procurement, suggesting that the procurement oversight system was less harmful than previously thought.

Introduction.

Economists have made many theoretical gains in understanding the economics of procurement. Yet, researchers have produced few empirical studies to complement these theoretical developments. A number of recent quantitative analyses of micro-level procurement data have tried to fill this void, but many important product markets and economic issues remain unexamined.[1]

One area that has not been examined is the relative strength and significance of the status of "incumbent contractor" for Federal procurement decisions. Though there are many theoretical reasons for incumbent vendors to possess competitive advantages over inexperienced rivals, opinions differ widely about the actual magnitude of the advantages from incumbency. Little empirical research has attempted to address this topic.

This research statistically measures the relationship between vendor selection and previous user experience for a sample of commercial mainframe computer system acquisitions by federal agencies in the 1970s. This research shows that while incumbency may be important, many other factors are as influential. Of particular note, compatibility between existing systems and potential replacements helps contribute to a vendor's advantage. Compatibility is distinct from incumbency since a computer vendor can market either a line of fully compatible systems or not. As this paper argues, this result has important implications for interpretations of the effects of oversight on computer procurement. In contrast to previous research, it suggests that oversight by an external agency was less harmful to incumbent vendors than previously thought.

IBM's experiences with Federal agencies provide an interesting illustration of this thesis. Initial results show that IBM frequently failed to benefit from its incumbent status, consistent with previous research arguing that the oversight system was biased against IBM. However, new evidence shows that a large part of the tendency for former IBM users to switch to other vendors arose primarily from the fact that limited compatible upgrades were available for users of very old IBM equipment (e.g. IBM 1400 series). Federal buyers who previously used IBM equipment and could upgrade to a new compatible system (e.g IBM360/370) tended to choose IBM as often as users of other vendors selected those vendors again.

As with all empirical research on "lock-in" effects, the effects of lock-in are not directly measured. The degree of lock-in can never truly be identified, because it is nearly impossible to distinguish between the economic, institutional, and spurious statistical factors that together produce a correlation between an observed vendor choice and a user's historical choices. In the presence of such an identification problem, all possible interpretations that are consistent with the observed patterns of behavior are equally likely.

This paper takes a novel approach to this problem. It uses technical compatibility as one measure of the influence of a buyer's experience on vendor choice. This is reasonable, because compatibility between an existing system and a potential replacement is believed to contribute to lock-in effects (David and Greenstein, 1990). However, because little empirical work has examined this belief in depth (See David, 1985, Greenstein 1990), the paper must develop both an appropriate model and appropriate measures.

This paper presents estimates from a multi-nomial logit model that summarizes agency behavior. This statistical model predicts which of the five largest computer mainframe vendors an agency's office chose based on its installed base of systems. The probability that a procurement would be won by an incumbent vendor is made a function of historical factors such as (a) the presence of a vendor at an agency's office, (b) measures of the extent of that presence (the size of the installed base), and (c) measures of the differences in the "preferences" of agencies for different vendors. Measures of the influence of compatibility are then added to this basic model. This model's results are the first econometric analysis of the relevance of compatibility for vendor choice.

The paper is also novel for its detailed examination of the federal computer procurement. Computer systems are important for virtually all government activity. However, until recently, computer procurement was difficult to analyze, because acquisitions were spread out over many years and many agencies, and were thus difficult to observe systematically[2]. The creation of a sample of observations of commercial mainframe computer acquisitions by federal agency work sites from 1972 to 1983 has now made such analysis possible.[3]

The paper first discusses the economic and institutional factors affecting the relationship between incumbency and vendor choice. Next it develops a model and addresses measurement issues. The final part of the paper interprets the estimation results.

II. Vendor selection and Bureaucratic Conflict

A. Economic factors affecting procurement

Though every procurement varies from the next, most acquisitions tend to follow a set of stages.[4] In the first stage, an agency defines its needs and secures funding for its planned acquisition. Next, agencies and industry representatives negotiate over benchmarks and technical requirements in the requests for bids. Then bids are formally requested, evaluated and awarded. The vendor that offers the system that best meets the stated needs at the lowest price is awarded the contract. In the final stages, losing bidders may file protests and potentially start the process again somewhere in the middle.

Incumbents should have an economic advantage in this process if buyers incur many switching costs. Non-incumbent vendors are usually required to meet explicitly in their bids the costs of switching to the incompatible product. There are a variety of bidding assessment procedures possible (OSD 1980, 1981). Either (1) the incompatible non-incumbent vendor adds a cost (estimated by people within the government) to the overall price of his bid and the agency arranges for the conversion (either through contractors or in-house conversion), or (2) the vendors accept some responsibility for uncovered portions of switching costs, either up to the level estimated or based on their own estimates. Because of the difficulties and risks associated with outside conversion contracts, agencies typically use the first procedure.[5] In other words, the incumbent bids P_I and the buyer pays P_I, while the non-incumbent bids P_N and the buyer pays P_N plus some switching cost.[6] The first switching costs must also be implicitly covered by a non-incumbent when agencies write strict compatibility requirements into the technical specifications requesting a bid, also advantages incumbents.

Due to switching costs, previous experience with a vendor should positively predict future purchases from the same vendor. Yet, this is not the only reason for incumbency to predict future vendor choice. If a particular vendor continues to be the best at providing a system which satisfies the user's unique needs, then the user is likely to choose that vendor again. Indeed, a vendor may learn from previous experience with a user about special features of the customer, which provides him an advantage in putting together his proposal. In sum, previous vendor-buyer interaction is a good predictor of subsequent procurement choice for two reasons, switching costs and satisfactory previous experience.[7]

B. Bureaucratic conflict

Although it seems that incumbency should predict subsequent vendor choice, the relationship between incumbency and outcomes is complicated by the inherent conflicts over procurement between an agency and Congress (Greenstein 1989). The criteria that an agency uses to evaluate the systems of competing vendor do not always reflect congressional priorities, especially budget priorities. Because capital budgets are not fungible across projects, the value of the dollar within the capital budget need not correspond to the marginal evaluation of a dollar within an agency's operating budget. Moreover, Congress assigns agencies tasks and duties, but those who work within the agency may prioritize these activities differently, particularly when a computer system shapes an office's general working conditions. Disagreement typically arises over whether the government is in the market for the computer-equivalent of a "Chevrolet or a Cadillac" (Kelman, 1990, page 20-26). Hence, even if the marginal value of the capital budget dollar were the same, an agency's evaluation of the marginal worth of competing system features is likely to diverge from that of Congress'.

Partially in response to these differences in incentives Congress established an oversight process for computer procurement. Agencies can be spared any oversight, as for acquisitions of low value, or the General Services Administration (GSA), can tightly circumscribe the procurement process, as authorized under the Brooks Act (1965), Public law 36-809.[8] The typical procurement for a mainframe will consist of agency decision-making subject to oversight approval. The influence of oversight will depend on the success of the strategies used by agencies and oversight committees to achieve control over vendor selection (Greenstein ,1989).

There is some reason to believe that non-incumbents may have been favored in a tightly supervised bid relative to an unsupervised procurement. GSA competitive procedures were allegedly more price-sensitive than those of agencies and focused only on necessary functions of the desired system. They did not give much weight to subjective estimates of intangible benefits, such as future support, upgrades, servicing reliability and most important, conversion expenses. It was commonly believed that strict GSA procedures did not systematically account for the long-term or short term costs of converting software from an old to a new manufacturer.[9] Agencies saw this as a potentially costly oversight that resulted in "unnecessary switching."[10] A well-known contrary opinion argued that accounting for switching costs too easily restricted competition.[11]

On average, absolute control over vendor selection did not lie with either agency or overseer. In practice, the oversight agency is not omnipotent, because it does not have a sufficient number of personnel to regulate all acquisitions effectively (Werling 1983). Nor are agency actions always rubber-stamped by the oversight personnel.

If an agency entirely controls vendor choice, then incumbency should predict vendor choice fairly well. However, an especially effective oversight system could partially weaken the relevance of switching costs for procurement decisions, reducing the links between incumbency and future vendor choice.

C. IBM and the Brooks Act

Congressional intervention allegedly influenced the enforcement of procedures to the disadvantage of some vendors. It was widely believed that a member (and eventual chairman) of the House Government Operations Committee (HGOC), Congressman Jack Brooks (D-Texas), especially favored vendors other than IBM and that he monitored a procurement more closely when IBM was involved, especially in an uncompetitive procurement.[12] As Werling said in his study:

> "Within the Federal ADP (automatic data processing) community it has been common knowledge that the HGOC would delay procurement for ADPE (automatic data processing equipment) ordered from IBM if at all possible." (pg. 262)

In Werling's view, the cost to the agency's office of purchasing IBM equipment increased, because of the extra procedural burden imposed on the acquisition of IBM equipment. By making IBM less attractive, the agency oversight process should have reduced IBM's advantage as incumbent. Thus, incumbency should not predict vendor choice for IBM as well as for other incumbent vendors.

IV. A simple measure of the advantages of incumbency

An examination of sales figures and buyer loyalty rates provides an overview of patterns in vendor choice and highlights some of its puzzles.

This analysis will show that on average incumbency predicts vendor choice, as expected. In addition, it establishes that IBM's sales history with the Federal government is puzzling. IBM is dominant in private industry, but not nearly so with Federal buyers. Moreover, an unusually high percentage of Federal agency offices who formerly used IBM make their next purchase from another vendor. However, because this simple analysis is limited, it motivates use of the multi-nomial logit analysis in the next section.

With notable exceptions, a majority of government agencies use commercial mainframes for much the same tasks as their private industry counterparts (NBS (1981), ch. 4). To facilitate comparison between Federal agency computer system use and private industry computer system use, exceptions must be identified. The analysis below applies to standardized systems that perform functions not unique to government, i.e. systems in private use and government use that perform the same basic tasks. Exclusion of systems labelled "special government design" and inclusion of models found in contemporary private industry mainframe computer censuses take care of most of the relevant cases.[13] I call the included group "commercially available general purpose" (CAGP) systems.

Table 1 presents the system stock for CAGP systems. IBM dominates the Federal stock of systems early in the decade, as Federal agencies inherited purchases made from the two early leaders in mainframe computers in the 1960s, IBM and Univac. The trends across the decade resemble those of an earlier (Werling 1983) analysis of a similar sample of "general management class" systems: IBM's share of a (roughly) fixed number of mainframe systems in stock falls throughout the decade. Of course, there are many possible explanations for this trend.[14]

A history of computer system acquisitions was constructed by comparing successive years of federal inventories at agency offices.[15] This removed the effect of retirements, which are probably the least accurately recorded element in the inventory.[16] Table 2 presents the rather surprising results of this effort. Contrary to its performance in the private sector, IBM does not display dominant sales figures for this set of general purpose mainframe computer systems among federal buyers. While IBM certainly is the largest supplier over the entire period, there are many years in which it is not the largest.

Table 3 demonstrates another difference between federal and the private sector buying patterns. In the private sector surveys, IBM loyalty is consistently highest, in the sense that a small percentage of IBM users leave IBM. IBM users and buyers typically displayed 90 percent loyalty rates and all other vendors regularly displayed rates of 60 percent to 80 percent in International Data Corporation's (IDC) "Loyalty Surveys."[17] As in the private sector surveys, the table examines sites with a single system vendor prior to the observed acquisition. As in those surveys, incumbency tends to be a good predictor of future choice. Yet, what is striking about the table is that IBM does not have the highest loyalty rates. In fact, the firm's sites come no where near their numbers in the private sector during this period.

Without more information about Federal procurement, the three tables together are puzzling. Federal users made heavier investments in IBM in the 1960s that in the 1970s, while most private buyers continued to use IBM. It is surprising that two sets of buyers of essentially the same category of systems for the same type of applications displayed parallel behavior in the 1960s, but not a decade and a half later.

The information presented in Table 3 complicates the puzzle, but does not solve it. Many factors influence vendor choice in addition to factors associated with incumbency. If one controls for buyer preferences, for example, incumbency may not be such a good predictor of winning a procurement. Thus, an empirical framework that accounts for many of the additional factors at work is warranted. A multi-nomial model provides that framework.

V. The Structure Behind the Measurement

The statistical model presented below provides a more sophisticated analysis of the data presented in Table 3 -- more sophisticated in the sense that it controls for some of the variety of circumstances that influence vendor choice but typically differ among buyers. This empirical model will focus on the relationship between previous buyer experience and vendor choice and try to measure those factors that predict the vendor chosen by an agency.

A. The structure of the model

All computer buyers associate some utility with each vendor, U_{ij}, where utility takes the form of random utility model, $U_{ij} = u_{ij} + \epsilon_{ij}$, where vendors are indexed by j and an acquisition by i. Since it is impossible to identify the individual responsible for choosing a system, a random utility model offers a plausible and useful, if somewhat sweeping, representation of the mix of deterministic and random factors which normally affect decision making in the bidding process. The deterministic component, u_{ij}, represent previous agency-vendor interaction, the relative preference of agencies for particular vendors, and other market factors influencing the evaluation of vendors. The stochastic element, ϵ_{ij}, represents idiosyncratic political events, the peculiarities of decision-makers and other unsystematic unobserved elements of the process. For example, we do not observe whether an acquisition is a replacement acquisition, an expansion of existing systems, or an initial acquisition for a new program. Previous experience with a vendor influences vendor choice to different degrees in the three types of acquisitions. Inability to distinguish between these different types of acquisitions will produce measurement error.

It is well known (e.g. Amemiya, ch. 9) that if and only if the random components are independent and distributed $f(\epsilon_{ij}) = \exp(-\exp(-\epsilon_{ij}))$, then the probability that a buyer will prefer vendor number 1 over all other vendors must be

(1) $Pr_i(1) = Pr(U_{i1} > U_{i2}, U_{i1} > U_{i3}, \ldots)$

$= \exp(u_{i1})/[\Sigma_{ij} \exp(u_{ij})]$,

where $\Sigma_j Pr_i(j) = 1$ by design, and j = 1, 2, 3, and so on. A similar equation describes the probability of choosing any other vendor. Equation (1) is useful, because it shows how different deterministic factors influence the probability of choosing any vendor. Once the u_{ij} are made a function of observable determinants, the likelihood function for equation (1) is then given by

(2) $\text{Loglikelihood} = \Sigma_j \Sigma_i Y_{ij} * \log \{ \Sigma_k [\exp(u_{ik} - u_{ij})]^{-1} \}$,

where Y_{ij} is an indicator variable for the observed choice and where the functional form for u_{ij} is yet to be determined. The plausibility of the distributional assumptions on ϵ_{ij} is discussed below, but the primary reason for using this distribution is that it yields closed-form solutions which are computationally feasible.

A vector of factors will measure heterogeneity in the extent of previous buyer-vendor interaction. These are called X_{ij}. Another vector of factors measures heterogeneity in buyer characteristics, which are presumed to predilect a buyer towards a particular vendor. These are called Z_i. The exact variables measuring X_{ij} and Z_i are specified in the next section. The evaluation of a vendor is given by

(3) $u_{ij} = \alpha + X_{ij}\beta + Z_i\delta_j$.

Equation (3) implies that maximizing (2) will yield estimates for the vector β and for the matrix $(\delta_j - \delta_0)$ (for all j except 0), where choice 0 is serves as a base choice. Since β indicates something about the relationship between previous buyer-seller interaction and vendor choice, the discussion will generally focus on the signs of the estimates of β.

The model implicitly assumes that the more a buyer has invested with one supplier in the past the more likely that buyer is to purchase from the same supplier in the future. This simply assumes that a buyer has repeatedly expressed his preferences for a particular supplier in the past, by investing in that supplier. This could be because there are costs to switching to alternative vendors (Greenstein 1989, ch. 2), or because one particular vendor has consistently satisfied the buyer's needs. Since the buyer's preference for a vendor will be partially accounted for by the Z_j, X_{ij} can either correlate with switching costs or reflect an unobserved and unmeasured preference for an incumbent.

The model also assumes that investments with supplier j do not affect the systematic component of the utility the buyer gets from a system from supplier k. This means that if X_{ij} measures the observed stock of equipment a buyer possesses from vendor j before acquiring a new computer system then the coefficient estimate on this X_{ij} measures the relative weight in the buyer's preferences for a new system from vendor j and no other vendor. This second assumption is innocuous so long as competing vendors market <u>incompatible</u> systems, which is almost always true in the sample examined in the text. More will be said about this below.

It is operationally convenient to restrict attention to acquisitions by users who had systems from no more than one vendor prior to the new acquisition. This allows attributes of an incumbent's advantages to be given to a single vendor. A secondary benefit derives from the elimination of large government installations (e.g. Los Alomos and Livermore), where most of the compatible systems from different vendors end up (e.g. Amdahl and IBM). By eliminating these sites, we temporarily avoid many of the problems associated with violating the assumption that one vendor's installed base does not affect the buyer's evaluation of another vendor. Developing an appropriate specification for this case is a task for later work.

At single vendor sites, when X_{ij} is composed only of measures of the previous stock of equipment, equation (3) can be rewritten as follows:

(4) If j is the incumbent then $u_{ij} = \alpha + X_{ij}\beta + Z_i\delta_j$,
If j is the incumbent then $u_{ik} = \alpha + Z_i\delta_k,\ k \neq j$.

In other words, when the buyer is evaluating all suppliers prior to his observed choice, previous investment with a vendor gives the vendor an extra advantage if β is positive. Of course, equation (4) will look slightly different when X_{ij} are not entirely a function of the previous stock of equipment, but the principle still holds.

In order to focus on the distinctiveness of buyer-vendor relationships when IBM is the incumbent, buyers are assumed to weigh equally similar previous experience with all the vendors except IBM. This assumption yields:

(5) If IBM is the incumbent, then $u_{ij} = \alpha + X_{ij}(\beta + \theta) + Z_i\delta_j$, j = IBM.

Equation (5) introduces the vector θ, which measures the extent to which incumbency influences IBM to a degree different from the other vendors.

The statistical model in equations (1), (2), (3), (4), and (5) is sufficient for the task at hand. It provides a reduced form measurement of the advantages attributable to incumbency. The model does not rely on very specific assumptions about vendor-bidder interactions. This parsimony is by choice, not necessity. It is possible to make this measurement consistent with a class of standard vendor-bidding models, but such consistency is not essential. An example is presented in the appendix.

B. What hypotheses can be tested?

Estimates of the coefficients in equations (1), (2), and (3) and (4) and (5) shed light on some, but not all, of the hypotheses of interest. There is still an unavoidable identification problem.

There are three possible interpretations for an estimate of β when that estimate is positive, that is, when incumbency predicts vendor choice: (1) Conversion expenses are high and influence vendor choice in a majority of cases, while procurement oversight does not diminish the importance of incumbency. (2) Conversion expenses are not high and do not influence vendor choice in a majority of cases, but agencies tend to use the same vendors repeatedly. In this case, the measures of buyer heterogeneity do not measure without error the reasons for buyer choices. Thus, previous buyer choices correlate with the unmeasured preferences for the incumbent. (3) Conversion expenses are high and influence vendor choice in a majority of cases, but oversight tends to diminish the importance of these expenses greatly. Nevertheless, the same vendors repeatedly win procurement from the same agencies, and the measures of buyer heterogeneity do not measure the reasons for buyer choices without error. Thus, previous buyer choice once again correlates with unmeasured preferences. There is no way to distinguish among these three explanations without more information.

Now consider the possible explanations for an estimate of β when that estimate is zero. This can occur for two reasons: (1') Conversion expenses are high and would influence vendor choice in the absence of oversight, but tended not to do so in this sample because the oversight process weakened the links between incumbency and vendor choice. (2') Conversion expenses are not often very high and do not tend to influence vendor choice in this product market.

Clearly there are more interpretations than parameters to estimate. At best, any estimate will confirm or reject one of a group of interpretations. The consequences of switching costs for vendor choice cannot be distinguished from unmeasured buyer satisfaction with incumbent vendors, or from the influence of the procurement system.

The hypothesis concerning IBM will also be tested within this framework. The estimates for the parameter θ, combined with the results for

β, should narrow the list of possible interpretations of the relationship between incumbency and vendor choice. If the links between incumbency and vendor choice are weaker for IBM than for any other vendor, then $\theta < 0$ whenever $\beta > 0$. If IBM is not different from any other vendor, then θ should be zero. All these interpretations are summarized in Table 4.

VI. Measures and Weights

This section provides details about the variables used to measure incumbent installed base and buyer characteristics. A definition of the variables and their predicted sign in the market model is included in Table 5. A table of the means, standard deviations, minimums and maximums is included in Table 6 for general information.

A. X_{ij}, Previous buyer-incumbent interaction

The X_{ij} should predict future vendor choice, because they reflect some switching costs or unmeasured preference of a buyer for the incumbent vendor.

Previous investment with a supplier's equipment. The greater a site's commitment to an existing stock of equipment, the more difficulty the site potentially faces when replacing old equipment. This variable takes on the book value of owned equipment on site, adjusted for changing producer prices.

Total computing capacity. This variable equals the number of commercially available general purpose systems on site weighted by the average system size. It is expected that the larger the capacity of the site, the greater the investment in system and applications software, and the less flexibility in buying replacements. This measure is highly correlated (.9) with the total number of systems on site.

Incumbency in providing a system. This dummy variable indicates whether a seller has ever sold a system to a site before. This dummy differs from measures of the extent of incumbency because it captures the extent to which having a system at a location, regardless of its size, predicts future selection of that incumbent.

Minimum age of a system. This variable equals the age of the youngest system a buyer possesses, and should indicate whether the user has had recent experience with a supplier. It is often stated that a user is hesitant to switch to a non-incumbent just after he has honed his skills with a supplier's new equipment, but is more willing to leave an older and possibly technically less-advanced system.[18]

An IBM interaction effect. All the above variables interact with an IBM dummy to estimate θ. This results in four new coefficient estimates.

B. X_{ij} Vendor traits applied to all firms.

Incumbency in any form. One variable indicates whether a seller has ever sold any computer equipment to a site prior to the sale of this machine. This experience should give the seller some advantage in knowing how to satisfy the personnel's needs at the site, although less than if the seller had provided a system to the site. Since this variable is one for IBM at virtually every site, there was nothing to be learned through interaction with an IBM dummy.

Percentage of systems in a market segment. From 1976 to 1983, International data corporation (IDC) classified general purpose computer systems into six categories according to market size groupings. Each group was composed of systems which compete against one another.[19] This variable equals the total number of systems offered by each vendor, as counted by IDC, divided by the total number offered by all vendors. The 1976 counts were applied to observations from earlier years.

There are several reasons why the coefficient on the percentage of systems offered by a vendor should be positive: (1) The greater the number (and hence, percentage) of systems offered by a supplier, the more likely a vendor offers something close to a buyer's needs which another seller cannot match. (2) In long run equilibrium, sellers will enter with an ever widening product line into market segments in which they excel and will stay out of market segments in which they do not excel. Hence, a higher percentage of systems offered by a seller may proxy for success with private industry buyers in a market segment. Greater success with private industry buyers should predict success with the federal government, especially if federal buyers are using the systems for the same purposes as private industry. (3) If federal procurement procedures were poorly administered, then the success of suppliers may be close to being random. In that case, it would not be surprising if the probability of success is proportional to the extent of entry into the supply of alternative systems, irrespective of the identity of supplier.

C. Z_i, Buyer characteristics that reflect preferences

The coefficients on these variables are not the focus of the estimation, but it is important to specify these variables for two reasons. First, it is necessary to control for some obvious differences in types of computer buyers and their requests. Second, the coefficients are of some inherent interest, because there exists no previous econometric work on computer vendor choice. The following were used:

Dedicated application (versus general management class). General management systems are a class of systems familiar to most people: the hardware is used as a "platform" for a variety of ever-changing programming activities. In contrast, some dedicated applications are so specialized that some suppliers ought to have more "off-the-shelf" alternatives than others.[20] Thus, we would expect that demand for a system to perform a dedicated application should affect the probability that a vendor will bid.

Multi processor systems (versus single processor systems). Some systems have more than one processor working together at least part of the time or remote units interacted with the main processor. I hypothesize that multi-processor systems are specialized configurations of computer equipment and certain suppliers should be better providers of them than others.

Acquired system's size. Some sellers are better at making larger systems than smaller systems. This may not be captured by the measurement of supply characteristics.

Department of Defense. Dummies were included for each of the military branches to test a general perception that particular branches of the military tended to favor certain vendors. However, this interpretation must be cautiously applied to this sample since special military applications were eliminated from the sample.

Previous investment with processors. One variable equals the number of processors in stock at the installation in the year prior to the acquisition, with no weight given for size or manufacturer.[21] This variable correlates with the number of systems, except at sites that have processors for tasks other than mainframe work. Sites with many processors employ more technically advanced personnel and tend to use many small processors for simple process control work in scientific applications. As a result, they need less commercially packaged software. Vendors offering large system support may be favored at sites that do not have scientific applications.

VII. The sample of acquisitions

The unit of observation is an observed acquisition at a Federal agency office, as in table 3. However, the econometric estimation is performed on a slightly different sample than that examined in Table 3. First, it includes acquisitions from sites where there was no system prior to the acquisition. These observations yield information about situations in which switching costs are low. Second, it excludes certain observations for several reasons. Not all the acquisitions at single-vendor sites could be coded with the supply variables. IDC provides size estimates for most commercial general purpose mainframes, but not for minicomputers -- even those performing mainframe-like general purpose functions. Since the data are unavailable, minicomputer acquisitions were excluded from the sample used in the econometric estimates.

Acquisitions from several firms also had to be excluded because of insufficient observations to estimate the parameters associated with that option. Purchases of Amdahl, Cray, Dec, and NCR could not be included in the sample for this reason. Due to the experiment design, acquisitions at sites where these firms had been incumbents also had to be excluded. What remained were purchases from the five largest incumbent firms, Burroughs, Control Data, Honeywell, IBM, and Sperry-Univac and two smaller firms, General Electric and RCA.

It should be noted that since all observations are comprised of purchases, we also implicitly exclude observations where users choose to not purchase or to purchase outside the class of commercial general purpose systems. Hence, all inferences must be conditional on observing any purchase of a mainframe at all.

Acquisitions of systems designed by General Electric (GE) or RCA, or acquisitions at sites that contained only GE and RCA systems present a potentially troublesome coding problem. Both these firms left the computer industry just before the beginning of the sample period and sold their operations to rival concerns (Honeywell and Sperry-Univac, respectively). As a result, the econometrician is faced with both a substantive problem and with an analogous coding problem. There are defensible reasons to consider relabelling systems originally designed by GE and RCA as now belonging to the larger firms, particularly since both Honeywell and RCA continued to operate these divisions successfully after acquisition (Fisher, McKie and Mancke, 1983). Such a move might then correctly capture a buyer purchasing a Honeywell machine because of a previous investment with GE. Similarly for RCA and Univac.

To test for the (ir)relevance of this coding problem, the following four samples were used: (1) An observation are excluded if the incumbent or the acquisition are from systems originally coded as designed by GE or RCA. (2) A system is excluded if GE or RCA is an incumbent, but not if GE or RCA are the manufacturer of the acquired system. In the latter case, GE is relabelled as a Honeywell purchase and RCA as a Univac Purchase. (3) A system is excluded if a GE or RCA system has been acquired, but not if GE and RCA are incumbents. In the latter case, GE incumbents are relabeled as Honeywell incumbents and RCA incumbents are relabelled as Univac incumbents. (4) All RCA incumbents and purchases are relabelled as Univac, and all GE incumbents and purchases are relabelled as Honeywell. Everything is included in the sample.[22] In the tables of estimates, the different samples will be labelled 1 through 4.

One other consideration should be mentioned. It is well known that multinomial logit models possess a property known as "Independence from Irrelevant Alternatives" (IIA), which is violated if the choices possess very similar attributes. On this point several things should be said: (1) IIA would most probably be violated under the present specification if Amdahl and IBM were both included in the sample since Amdahl's hardware is virtually a duplicate of IBM's. Fortunately, in this time period, Amdahl sales comprised such a minuscule portion of the sample, that this seems to be a small concern.[23] (2) Similar issues arise concerning systems designed by IBM's competitors, principally RCA's Spectra series, which were compatible with the IBM system-360. There were fourteen acquisitions of this model series in the sample, six of which occurred at sites where IBM was incumbent. Of eleven sites where RCA was the incumbent, only two acquired systems from the IBM 360 family. If this problem influences the estimates in practice, then it will be revealed in the estimates using different samples.[24] However, because the sample size exceeds 550, the estimates are not likely to change when the spectra series is included or excluded.

IX. A Description of Results

Two equations were initially estimated, one in which θ is set to zero, as if IBM were not thought to be unusual, and one in which θ is estimated. These are presented in table 7 and 8 respectively for samples (1) and (4) (samples (2) and (3) did not differ significantly). Below I summarize the results and in the next section I assess their implications for the different hypotheses about the role of oversight.

Characteristics of the choice: Table 7 and table 8 show that the presence of an incumbent predicts that a buyer will choose that incumbent again. If a buyer has had any experience with a supplier in the past, then that supplier is likely to be chosen again in future acquisitions. If a buyer has had experience with a supplier's systems in the past, then that supplier is even more likely to be chosen in a future acquisition. As one would expect, experience with a system is a better predictor than experience with a piece of equipment.

In Table 7 the positive coefficient on the capacity variable provides moderate support for the hypothesis that the extent of investment works to an incumbent's favor, while the estimates suggest that dollar investment with a supplier is a handicap. Both results lose their significance in Table 8 when IBM is singled out as different, suggesting that the extent of investment generally does not predict incumbent selection. The latter conclusion is reinforced by the magnitude of the coefficients. Large deviations in the extent of investment will not move the probability index as much as the coefficient on the dummy variables indicating presence. Only at the extreme values will these measures of the extent of experience significantly influence the predicted probability of choice.[25]

We see from Table 8 that buyers who had an IBM system on site were less likely to procure an IBM system in their next purchase than buyers with another vendor were to choose that vendor again. The estimates in

Table 8 also provide moderate evidence that <u>extensive</u> investment with IBM was a special handicap to IBM's sales. Hence, the evidence seems to support the view that IBM benefits less from its incumbency than its rivals.

The market supply variable does not predict very well. This may be attributed in part to coding problems; counting formerly RCA and GE systems as Univac and Honeywell may incorrectly indicate that Univac and Honeywell offer many systems. The measure could also be faulted for weighing all systems equally within a market segment when other factors probably indicate a firm's advantage in a market segment better.

In sum, the presence of an incumbent predicts choosing the incumbent again, while the extent of that presence only sometimes predicts choosing the incumbent. However, an IBM installed base was not as strong a predictor of repeat purchases as the installed base was for the other major mainframe vendors.

Characteristics of the chooser: While these estimates are not the central focus of the estimation, it is clear that characteristics of the choosers can significantly contribute to the probability of selecting a particular vendor. Sometimes these factors outweigh those measuring the relative effects of incumbency.

The coefficients of the influence of user characteristics are estimated relative to Burroughs, and there are few surprises. Procurement of dedicated applications statistically favors Univac and IBM relative to Burroughs, but generally all the coefficients are numerically close. Procurement of multi-processor systems favors IBM least, which is consistent with the notion that IBM is most successful with off-the-shelf single-processor systems for basic general purpose tasks. Procurement of larger systems, even controlling for supply conditions, tends to give CDC a relative advantage, while smaller systems favor Burroughs and Univac. These results are not out of line with the relative advantages of these firms in private industry reported in the trade press during this time period.

X. Assessing the results

The estimates of ß and θ thus have some zero elements and some non-zero elements. Previous experience with an incumbent vendor does predict future choice. There is only a moderate link between the <u>extent</u> of investment with a single incumbent and the next system supplier chosen. IBM is distinctive and possibly disadvantaged. Most of the estimates in Table 8 have their predicted sign, even if they are not always significant. Moreover, the four additional variables are jointly significant at the 1 percent level.

Xa. Accounting for product family

A reasonable concern is that IBM's distinctiveness may partly be an artifact of the sampling period and many government agency's extensive early investment in IBM equipment in the 1960s. That is, no industry observer would expect IBM's incumbency to predict future success when an office had old and not very upwardly compatible IBM equipment.

To determine whether the data are consistent with this alternative explanation, equations (1) through (5) were estimated using information about the incumbent IBM system as an additional element in X. The results for sample 1 and sample 4 are reported in Table 9 (samples 2 and 3 do not look much different). Two dummy variables were tried: one that indicated the presence of an incumbent system from the IBM 1400 series on site (just over 40% of all acquisitions in which IBM is an incumbent) and one which indicated when there was an incumbent system from the IBM 360/370 series on site (just over two thirds of all acquisitions where IBM was an incumbent).[26] Just over 10 percent of all acquisitions where IBM was an incumbent had systems from both families. Only the estimates the 360/370 family dummy are reported, because it was found that this specification was superior to the alternatives.[27]

The results have the same character in all samples. The IBM 360/370 dummy positively predicts purchasing from the incumbent again, in this case, IBM. Moreover, the magnitude of the estimate is generally of the same order as the disadvantage attributable to having IBM as an incumbent. Hence, having an IBM 360/370 as an incumbent system predicted choosing IBM about as often as incumbency of another vendor predicted choosing that vendor again.[28] In contrast, the presence of an IBM system that was not from the 360/370 series was not a good predictor of choosing IBM again. In other words, when no system from the IBM 360/370 family is on site, it is as if IBM were not a system incumbent at all.

Xb. Assessing the results

Table 9 shows that many factors influenced procurement choice. The following discussion will argue that concerns with upward compatibility likely dominated many of those choices. Thus, Table 9 provides the first econometric evidence that incompatibilities between generations of products influences competitive outcomes.

There is one interpretation of the results in Tables 7 and 8 and 9 that is consistent with the belief that switching costs influenced vendor choice. If the majority of switching costs are one time set-up costs, e.g. establishing the operating system and training personnel, then there is little reason to expect them to correlate with the extent of investment by a buyer. If this view is correct, then only the presence of an incumbent should indicate that these complementary investments have been made. This is, in fact, what was observed, although the coefficient also has other interpretations.

Perhaps the easiest interpretation for the estimates in Table 9 is that when an IBM 360/370 was on site, agencies typically did not want to switch to another vendor and IBM gained an advantage as a consequence. When an IBM 360/370 was not on site, there was less justification for staying with the incumbent vendor and hence, IBM's competitors succeeded in winning bids more often. If this is correct, the perceived IBM disadvantage in Table 8 (and in Table 2 and in Werling) is an artifact of the extensive government investment in 1400 series equipment in the early 1960s, which did not translate into much of an advantage for IBM in the government mainframe computer market of the 1970s. From this perception, IBM's disadvantage is as much a result of incompatibilities in generations of IBM's product line as it is a result of procurement procedures.

Another interpretation to these results also leads to the conclusion that oversight was not harmful. For example, these results could be made consistent with the view that government procurement procedures "levelled the playing field," in the sense of ignoring conversion expenses. However, such an interpretation is quite limited by the estimates in Table 9. If the importance of switching costs was minimized in the selection process, then the differences between sites that had IBM 360/370 family systems and those that had other IBM systems should correlate with procurement needs that the IBM models of the late 1970s were best able to meet. The IBM 360 had to be even that much better than its rivals before the "procedural bias" set in. Moreover, the 1400 dummy cannot correlate with those needs. Otherwise, there is no other way that incumbency with an IBM 360/370 could produce a significantly positive coefficient. In this interpretation, the alleged disadvantaged to IBM from procurement procedures seems less harmful than previously suggested, i.e. procedural biases against IBM were applied most heavily when older generations of IBM equipment were on site.

One final interpretation reconciles these results with all the allegations about procedural bias against IBM, but it also leads to the conclusion that oversight was not too harmful to IBM. It is very possible that the allegations of bias, like those found in Werling (1983), accurately describe several prominent and well-known acquisitions. However, a few prominent cases need not reflect patterns in the vast majority of acquisitions. In this view, IBM may have been disadvantaged, but not over enough cases to affect the estimates much. This may explain why IBM is still at a slight disadvantage relative to other vendors in Tables 8 and 9.

In other words, if the disadvantage to IBM operated solely through breaking the link between switching costs and repeat buyer choice, then it was mainly effective in only a few procurement cases. The fact that the disadvantage was not widespread is demonstrated by the cases in which IBM360/370 systems were incumbents and the disregard of switching costs should have had the greatest impact.

There is no question that IBM was distinctive in this sample. Previous investment with IBM systems that were not from the 360/370 family did not yield as great an advantage for IBM as incumbent of 360/370 systems. In addition, the presence of these systems on site did not benefit IBM in subsequent procurement to the same extent that the presence of on-site systems benefited other vendors. Nevertheless, it makes a world of difference in the interpretation of that result if IBM's distinctiveness resulted from regulations restricting consideration of conversion expenses or from technical incompatibilities among IBM systems. Most probably, it was a combination of both factors, though this experiment suggests that concerns about incompatibility may have dominated overall.

Xc. Who had the Upper Hand?

Based on the evidence just presented, it is difficult to determine unambiguously whether oversight of the procurement system restricted the advantages of an incumbent. Any interpretation must reconcile the general unimportance of the measures of the extent of investment with an incumbent with the general importance of the coefficients measuring the presence of an incumbent and with the significance of the 360/370 family dummy. The former result indicates that the switching costs were probably not widely important, while the latter two are consistent with the hypothesis that they were. Yet, as already indicated, while these results do not settle all open issues, they severely limit one's interpretation of the consequences of oversight on computer procurement.

On the presumption that agencies favored incumbents and that preference was correlated with the extent of investment with the incumbent, the agencies appear to be constrained. The constraint seemed to bind less when agencies had new equipment with compatible upgrades, as with the 360/370 system. However, if one only expected switching costs to correlate with the presence and not the extent of investment, then these results quite plausibly demonstrate that agencies were able to choose an incumbent supplier in situations where a compatible upgrade was available.

Two scenarios seem consistent with the estimates: (1) If overseers sought to enforce bidding parity, they likely expended their limited resources in situations where an agency was not likely to argue that switching costs were high (as when a 1400 is on site); (2) If agencies sought to expend their limited resources on cases they were more likely to win, it was in situations when the presence of the incumbent led to switching costs that justified using the incumbent again (as when a 360/370 was on site). Either scenario leads to the conclusion that oversight did not greatly influence vendor choices, and thus, was not as harmful as previously thought.

XI. Summary

This paper analyzed a newly reconstructed history of federal agency acquisitions of commercial general purpose mainframes. It investigated the empirical relationship between incumbency and computer system vendor choice. The work here also reconsidered whether federal computer procurement procedures contributed to the relatively poor performance of IBM equipment in Federal sales.

The analysis found that the presence of an incumbent, though not the extent of that presence, predicted choosing that incumbent again. However, IBM differed from its rivals. In contrast to previous conclusions (Werling 1983), further estimates suggested that IBM was disadvantaged as much by the incompatibilities in generations of its product line as by any disadvantages stemming from bias in procurement procedures. Most probably a combination of both factors operated, though this analysis suggests that the concern about upward compatibility dominated. This provides the first econometric evidence that incompatibilities between generations of products influences competitive outcomes.

Any interpretation must reconcile the general unimportance of the measures of the extent of investment with an incumbent with the general importance of the coefficients measuring the presence of an incumbent and with the significance of the 360/370 family dummy. The former two results indicated that the switching costs were probably not widely important, while the latter is consistent with the hypothesis that they were. Hence, further work should attempt to estimates statistically coefficients associated with choice among incompatible system families, in addition to choice of suppliers. This might provide a test of the relevance of advantages attributable to switching between incompatible systems, rather than firms.

Appendix: The consistency of multi-nomial logit with bidding models.

This appendix shows how multi-nomial model can be made consistent with a class of vendor bidding models. This appendix presents a bidding game with two bidders. The model easily extends to multiple number of bidders.

Two vendors bid to provide a system. The decision is made in two stages. In the first stage vendors bid. In the second stage, winners are chosen. Reflecting the uncertainty (to vendors) in the decision-making process, at stage 1 vendors make estimates about the probability of winning a bid under different conditions. All vendors use the same function to estimate these probabilities. Prior to bidding, each vendor knows its own and rival's costs. Each vendor also knows of its own and rival's experience, if any, with the potential buyer. These structural assumptions are easy justify based on actual procedures (Greenstein 1989, 1990).

Vendor's estimates of the probability of winning a bid are

(A1) $Pr(1) = Pr(U_1 > U_2)$,

where the notation is the same as that used in the text. For simplicity of illustration, parameterize equation (A1) as

(A2) $Pr(1) = \exp(u_1)/[\exp(u_1) + \exp(u_2)]$,

where $Pr(1) + Pr(2) = 1$. The deterministic component is given by

(A3) $u_1 = [X_1 - P_1 - (X_2 - P_2)]$,

where X_i is the normalized advantage provided vendor i due to his incumbency and/or superior product, and P_i is the price bid by vendor i. Other functional forms can suffice.[29]

Vendors are assumed to be risk neutral and maximize expected profit. Since the important insight of this model does not depend on modelling the participation constraint that results when bidding costs are large, assume that there are no bidding costs. The Nash equilibrium to this game results in vendors who bid according to the maximization of

$$\text{(A4)}\quad P_1^* \quad = \quad \text{argmax}\ \{[P_1 - C_1]Pr(1)\},$$

where C_1 is vendor 1's cost of providing a system. A similar equation holds for vendor 2. The equilibrium bid prices, P_1^* and P_2^*, satisfy

$$\text{(A5)}\quad [P_1 - C_1]Pr'(1) + Pr(1) = 0,$$
$$[P_2 - C_2]Pr'(2) + Pr(2) = 0.$$

Let $Pr^*(1)$ and $Pr^*(2)$ equal the probabilities of choosing each vendor with equilibrium bid prices. Total differentiation of (A5) and straightforward calculations show that

$$\text{(A6)}\quad dP_1^*/dX_1 > 0 \text{ and } dP_1^*/dX_2 < 0.$$

Hence, even accounting for equilibrium bidding behavior, an increase in the relative advantage of a vendor results in a positive increase in the probability that that vendor will be chosen. This is the basic structural assumption underlying the estimation in the text.

1. For a review of the relevant theoretical literature of auctions and government contracting, see McAfee and McMillan (1987) and (1988). Other papers of interest include Demski, Sappington and Spiller (1987), and Anton and Yao (1987). Recent empirical papers on procurement and auctions include Crocker (1990), Crocker and Reynolds (1990), Lichtenberg (1988), Rogerson (1989a, 1989b, 1990a, 1990b) and Kendricks and Porter (1989a, 1989b).

2. Previous work tends to examine a few cases very closely for their general lessons. Excellent examples of case studies of computer procurement include GAO (1980), NBS (1980), Werling (1983) and Kelman (1990). For a summary of their implications for the economics of switching costs, see Greenstein (1990).

3. See Greenstein (1989), data appendix, for detail about the construction of this data set. Related papers that use this data include Greenstein (1990). I would like to thank Professor Frank Fisher, Martha Mulford Gray of NIST, and IBM corporation for help in locating the last existing copy of this data.

4. This account is based on GSA (1987), GAO (1980), appendix, and Kelman (1990), chapters 2 and 3.

5. Agencies have reasons to avoid having non-incumbent vendors estimate their own switching costs if they want to prevent outside contractors from doing the conversions. Since the establishment of the Office of Software Development, the GSA has as much in-house expertise in conversion as could probably be found in the private market. In-house conversions will be sensitive to the needs of the agency. Moreover, outside conversions invariably leave much for the agency to do in-house anyway. Finally, non-incumbent vendors are subject to "winner's curse," underestimating the costs of conversion and winning the bid, but learning later that the costs were higher than anticipated, resulting in an "unnecessary switch." Agencies still pay for the "unnecessary switch" because they must cover the expenses associated with problems the outside conversion personnel did improperly. These expenses can potentially be high. See GAO (1981).

6. The case of an acquisition to replace an existing system entails the highest switching costs. Switching costs do influence initial mainframe acquisitions to the extent that buyers are anticipating the problems associated with future purchases. Switching costs also influence the decision to add a new system to existing facilities in so far as personnel must be retrained and new software must be written if the new system is incompatible with the old. In a capacity addition, there is also

the issue associated with loss of efficiency in joint-system performance as a consequence of the lack of integration of the systems.

7. These competing interpretations are analogous to the difficulties in labor econometrics between measuring "state-dependance" and "unobserved heterogeneity" -- see Heckman and Singer, 1979.

8. Oversight has changed somewhat since the passage of the Competition in Contracting Act (1984). These changes are not discussed because the paper's sample of acquisitions ends in 1983, before the Act was passed.

9. At the end of the 1970s, systematic conversion estimation procedures were adopted (in principle) when it was clearly demonstrated that tangible conversion expenses could be enormous (GAO 1980). However, it took some time to construct a systematic and practical method for estimating conversion expenses (GSA 1986). Thus, the discussion in the text about the absence of such procedures is relevant to the sample of acquisitions examined in the empirical section. These cover 1972 through 1983.

10. For an analysis of this debate, see Cabral and Greenstein (1990). A summary can be found in Kelman (1990), pp. 103 -104.

11. It may also have been that restricting competition to IBM compatible equipment was what prevented switching costs from playing such a large role. In the context of a discussion about the standardization that followed the introduction of the IBM 360, Werling says, "Standardization... with IBM setting the standard, was disagreeable to many. HGOC, for example, refused to allow GSA to consider as fully competitive a procurement limited to the many vendors of IBM-compatible equipment."

12. Werling suggests that Brooks was motivated by a number of factors. In the first place, he wished to promote industry competitiveness. Second, IBM was undergoing an antitrust investigations. Finally, Brooks may have misinterpreted the idiosyncratic relationship between computer supplier and buyer as rigged bidding. See Werling, page 177, 262 and the discussion therein. Kelman (1990), page 8, states that Brooks worried that lack of competition favored IBM, which motivated his drive for more competitive procurement.

13. All systems marked "special government design" were eliminated, as were all military systems with unrecognizable names. The list of included systems closely parallels those in International Data Corporation's General Purpose System surveys from the 1970s with a few additions from Phister (1979). See Greenstein (1989), data appendix.

14. Government reports suggest, though they do not prove conclusively, that it could partially be an artifact of increasing replacement of the many small IBM systems (first acquired in the early 1960s) by larger systems made by IBM, among others. See NBS 1981, pages 1-11, for similar estimates and a description of the trend away from smaller mainframes.

15. An office is what is literally called an "ADP Unit" in the inventories. By all appearances, these are equivalent to agency offices at individual locations.

16. See NBS 1983, chapter 5 for examples of the inaccuracy of retirements.

17. See IDC Loyalty surveys, 12/18/74, 2/12/75, 12/8/75, 1/21/77, 12/5/78, 12/29/80 in the EDP Industry Report. There is a sample selection problem with these surveys in that only buyers who acquired a system are recorded and not the many users who chose not to buy anything. A similar sample selection problem affects the statistics above.

18. Though it was not essential, this was one factor for which a quadratic term seemed justifiable. A quadratic term was eventually tried and then dropped. It did not contribute significantly to the loglikelihood function.

19. 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.

20. Since most special government designs and other customized systems have been eliminated from the sample, dedicated applications include process control and other monitoring applications that are not special to military or unique government functions.

21. It is important not to confuse the definition of a system and a processor. A processor is one component of a system and can be made by a manufacturer other than the system designer. The largest processor in a system tends to be from the system designer.

22. Note that this recoding will not affect the coding of the supply variable. In all cases, the percentage of the systems offered by Honeywell and Univac is coded counting the formerly GE and RCA systems with their new owners.

23. Note that such cases would also violate assumption 2.

24. What this problem really points out is the difficulty of investigating incumbent firms' advantages when the technical sources of some of those advantages do not always cut across firms. One may be able to improve on this in further work by distinguishing between computer system families.

25. For example, even if <u>each of</u> the variables concurrently increased by one standard deviation, the aggregate probability would change by only 1.0 when IBM is not the incumbent (sample 1). This compares with a dummy coefficient that is greater than 2.

26. Upward-compatibility issues were much less compelling when switching from old IBM 1400 series and 7000 series computers to the larger 360/370 families, the popular system of the 1970s. While IBM did make an effort to provide 1400 users a way of upgrading to the 360 series (Fisher, McGowan and Greenwood ,1983), their solution had its problems. IBM provided a program that allowed a 360 to "emulate" a 1400 system's operating system. Government auditors recommended redesigning a system rather than relying on "emulators." Emulation was thought to be a poor long-term solution because it did not efficiently use the new hardware.

27. For Sample 4, the loglikelihood for estimates which added only the 1400 dummy was -501.252, for only the 360/370 dummy -494.374, and for both together -494.253. Adding the 360/370 dummy clearly results in all the explanatory power that is necessary and the 1400 is not statistically significant (by the Log ratio test, for example).

28. IBM's advantages are just below those of other firms because the full incumbent's advantages must also account for the extent of investment with the incumbent. Since extensive investment with IBM is estimated to be negative (though not significant), the sum of the estimates points to a slight diminished advantage for IBM when an IBM 360/370 is the incumbent system.

29. For example, let $Pr(1) = f[X_1 - P_1 - (X_2 - P_2)]$. Then $f' > 0$ and $f'' < 0$ is sufficient for what follows.

Table 1

System Supplier for Stock of General Purpose Systems in the 1970s.

MANU	71	72	73	74	75	76	77	78	79	83
AMD	.	.	.	.	.	.	1	1	3	10
BUR	204	201	202	213	201	189	187	209	218	286
CDC	148	166	190	208	201	217	220	222	208	191
CRY	.	.	.	.	.	.	1	1	4	7
DEC	20	23	28	29	34	43	51	56	71	244
GEL	81	98	97	93	95	89	82	78	68	21
HON	169	177	193	217	192	182	195	201	208	283
IBM	1205	1186	1166	1087	1044	924	923	897	819	661
NCR	287	235	213	118	101	100	101	97	96	37
RCA	157	169	161	125	106	87	83	75	64	30
SIN	.	1	1	1	1	1	1	1	1	1
UNI	708	734	706	708	680	624	619	658	664	578
XDS	50	63	70	81	82	90	94	91	87	46

Source: Federal ADP Equipment Inventory, 1971-1979, 1983, original data. See GSA ADP Activities Summary, various years, and Gray (1977), (1978), (1979), and (1981), and Greenstein (1987) for summaries and detail. Also see pages 1 - 11 of NBS 1981 for similar estimates.

Notes: The table includes only commercially available general purpose mainframe systems, as defined by IDC EDP industry reports (various years), and Digital Equipment Corporation VAX systems. The table only includes acquisition of federally owned or leased systems from external supplier.

RCA and GE systems retain the designing firm's label, and not that of Univac or Honeywell. No effort was made to check for consistent use of either the original or the acquiring firm's name for an RCA or GE system. Hence, these number probably understate RCA and GE systems sales somewhat.

Table 2

Commercially Available General Purpose Mainframe Systems Acquired Each Year From External Suppliers by Federal Agencies

Manu	72	73	74	75	76	77	78	79	80-83	Total
AMD	0	0	0	0	0	1	0	2	7	10
BUR	39	15	19	4	22	8	37	23	87	254
CDC	22	25	25	11	29	6	9	9	33	169
CRY	0	0	0	0	0	0	0	2	4	6
DEC	3	7	4	5	12	5	4	16	183	239
GEL	21	8	1	2	5	1	0	2	0	40
HON	13	24	54	12	26	16	12	33	152	342
IBM	57	69	79	43	77	26	26	24	157	558
NCR	1	1	2	0	3	4	1	2	22	34
RCA	14	5	7	11	2	1	2	0	0	43
SIN	1	0	0	0	0	0	0	0	1	2
UNI	114	57	74	41	48	25	47	42	65	513
XDS	11	9	14	3	20	4	2	1	0	64
Total	296	220	279	132	244	97	140	154	720	2282

Notes: Acquisitions were estimated by comparing systems at Federal agency offices in adjacent inventory years. Year is the year the first processor for a system first appeared in the data inventories. Due to unavailability of original data for years 1980, 1981, and 1982, all acquisitions in these years were estimated from inventories for 1983.

The table may overestimate total acquisitions if all intra and inter agency transfers are not recorded, but internal consistency checks revealed that this problem is not likely to be large.

For reasons mentioned in the notes to Table 1, it is also true here that these values for the RCA and GE sales over the 1970s are probably underestimates of the total number of sales. Some may have been labelled for their acquiring firms, Univace or Honeywell.

Table 3

Acquisitions from External Sources at Single Vendor Sites for Major Mainframe Vendors.
(Number acquired and **percent loyal to incumbent**)

ACQUIRED VENDOR	INCUMBENT SYSTEM VENDOR: AMD	BUR	CDC	DEQ	GEL	HON	IBM	NCR	RCA	UNI	XDS
AMD	1	0	0	0	0	0	4	0	0	0	0
	100%	0	0	0	0	0	1.3%	0	0	0	0
BUR	0	15	4	1	1	1	65	1	1	0	0
	0	**60%**	15%	4.5%	4.5%	1.8%	21%	6.6%	6.6%	0	0
CDC	0	0	12	2	0	1	7	0	0	0	0
	0	0	**46%**	9.1%	0	1.8%	2.2%	0	0	0	0
CRY	0	0	1	0	0	0	0	0	0	0	0
	0	0	3.8%	0	0	0	0	0	0	0	0
DEQ	0	0	3	12	0	4	10	0	0	1	2
	0	0	12%	**54%**	0	7.3%	3.2%	0	0	1.1%	100%
GEL/ HON	0	7	2	3	21	46	22	7	3	8	0
	0	28%	7.7	13%	**95%**	**84%**	6.9%	46%	20%	9.2%	0
IBM	0	1	3	3	0	2	175	0	3	14	0
	0	4.0%	12%	13%	0	3.6%	**56%**	0	20%	16%	0
NCR	0	1	0	0	0	0	2	7	1	0	0
	0	4.0%	0	0	0	0	.6%	**47%**	6.7%	0	0
RCA/ UNI	0	1	1	1	0	1	25	0	10	66	0
	0	4.0%	3.8%	4.5%	0	1.8%	8.0%	0	**47%**	**73%**	0

Note: General Electric acquisitions were combined with Honeywell, and RCA acquisitions with Sperry-Univac because of mergers and inconsistency in the coding of system manufacturers for formerly GE and RCA systems.

Table 4

Summary of Model and Predictions

(1) $U_{ij} = u_{ij} + \epsilon_{ij}$, where i = { observation },

j = { Burroughs, Control Data, Honeywell, IBM, and Univac }

(2) If $f(\epsilon_{ij}) = \exp(-\exp(-\epsilon_{ij}))$, and

$Pr_i(B) = Pr_i(U_{iB} > U_{iC}, U_{iB} > U_{iH}, \ldots)$ and so on,

then $Pr_i(j) = \exp(u_{ij})/[\Sigma_k \exp(u_{ik})]$, $\Sigma_j Pr_i(j) = 1$.

(3) $LL = \Sigma_j \Sigma_i Y_{ij} \cdot \log \{ \Sigma_k [\exp(u_{ik} - u_{ij})]^{-1} \}$,

(4) If j is the incumbent, j $\neq$ IBM then $u_{ij} = \alpha + X_{ij}\beta + Z_i\delta_j$,

(5) If IBM is the incumbent then $u_{ij} = \alpha + X_{ij}(\beta + \theta) + Z_i\delta_j$,

X_{ij} is a measure of incumbent advantages and supply effect. These characteristic affect all choices equally.

Z_i is a measure of differnt types of buyers. These characteristic affect all choices differently.

Definitions of variables are given in Table 5.

Category of Variable	Prediction	List of Variables
ß, influence of previous experience on choice of vendor	positive (?) in an unsupervised procurement	INVEST, INCUMBSYS COMPCAP, INCEQUIP, PERCENTSYS
	negative	MINAGE
θ, influence of IBM characteristics	opposite of above if IBM is disadvantaged	INVEST IBM, MINAGE IBM COMPCAP IBM, INCUMBSYS IBM
$\delta_j - \delta_0$, influence of buyer characterisitcs	will vary	DEDAPP, DUMMULTI, SIZE DUMAIRFAORCE, DUMNAVY, DUMARMY, DUMTCA, SUMCPU

Table 5

Exogenous variables and their definitions.
The unit of observation is an acquisition for an agency office

Abbreviation	Definition
Characteristics of the Choice	
INVEST	Dollar investment in incumbent vendor
MINAGE	Age of the youngest system on site
COMPCAP	Number of systems weighted by average site size
INCUMBSYS	Vendor previously had a system on site
INCEQUIP	Vendor previously had any equipment on site
PERCENTSYS	Percentage of systems in market class offered by vendor
Factors affecting IBM only	
INVEST IBM	Dollar investment in IBM
MINAGE IBM	Age of the youngest IBM system on site
COMPCAP IBM	Number of IBM systems weighted by average site size
INCUMBSYS IBM	IBM previously had a system on site
Factors affecting vendors differently	
DEDAPP	System is bought for dedicated application (vs. General purpose)
DUMMULTI	System is bought for multi-processor application
DUMARMY	System is bought by US Army office
DUMAIRFORCE	System is bought by US Air Force office
DUMNAVY	System is bought by US Navy office
DUMTCA	System is bought by Traditional Civilian agency (non-military, not NASA nor Energy)
SUMCPU	Number of processors on site
SIZE	IDC size class of requested system

Table 6

Means, Standard Deviations, Minimums and Maximums for Sample Number 1

	MEAN	STD DEV	MINIMUM	MAXIMUM
Characteristics of the Choice				
INVEST	11.47	27.76	0.00	253.94
COMPCAP	10.06	20.17	0.00	121.99
MINAGE	2.474	2.44	0.00	13.00
INCUMBSYS BUR	0.039	0.19	0.00	1.00
INCUMBSYS CDC	0.051	0.22	0.00	1.00
INCUMBSYS HON	0.100	0.30	0.00	1.00
INCUMBSYS IBM	0.524	0.50	0.00	1.00
INCUMBSYS UNI	0.165	0.37	0.00	1.00
INCEQUIP BUR	0.069	0.25	0.00	1.00
INCEQUIP CDC	0.076	0.27	0.00	1.00
INCEQUIP HON	0.121	0.33	0.00	1.00
INCEQUIP IBM	0.964	0.19	0.00	1.00
INCEQUIP UNI	0.364	0.48	0.00	1.00
PERCENTSYS BUR	0.089	0.039	0.021	0.200
PERCENTSYS CDC	0.118	0.114	0.000	0.347
PERCENTSYS HON	0.209	0.059	0.088	0.311
PERCENTSYS IBM	0.196	0.065	0.109	0.434
PERCENTSYS UNI	0.191	0.046	0.086	0.264
Factors affecting vendors differently				
DEDAPPL	0.13	0.34	0.00	1.00
DUMMULTI	0.18	0.38	0.00	1.00
DUMDEF	0.70	0.45	0.00	1.00
DUMTCA	0.26	0.44	0.00	1.00
DUMACQDA	0.37	0.48	0.00	1.00
DUMACQDF	0.11	0.32	0.00	1.00
DUMACQDN	0.16	0.37	0.00	1.00
SUMCPU	4.47	8.15	1.00	45.00
SIZE	4.44	1.37	2.00	7.00

Note: Sample 1 contains no acquisitions or incumbents labelled RCA or GE. The means, standard deviations, minimums and maximums will differ slightly for samples 2, 3 and 4, which do contain formerly RCA and GE systems.

Table 7

Coefficient Estimates for Constrained Experiment
(Standard Errors in Parentheses)

	Sample 1	Sample 4
NUMBER BUR ACQUISITIONS	93	95
NUMBER CDC ACQUISITIONS	32	32
NUMBER HON ACQUISITIONS	106	137
NUMBER IBM ACQUISITIONS	230	233
NUMBER UNI ACQUISITIONS	98	116
LOGLIKELIHOOD	-454.446	-527.976
NUMBER OF OBSERVATIONS	559	613
Characteristic of choice		
INVEST	-0.009**	-0.009*
	(0.005)	(0.004)
MINAGE	-0.062	-0.021
	(0.048)	(0.042)
COMPCAP	0.049**	0.05 **
	(0.023)	(0.02)
INCUMBSYS	1.73 **	1.77 **
	(0.28)	(0.25)
INCEQUIP	1.18 **	0.82 **
	(0.26)	(0.23)
PERCENTSYS	-2.41 **	-0.44
	(1.22)	(1.12)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Sample defined at the end of the table.

Table 7 continued

Factors affecting vendors differently		
CONSTANT CDC	-9.36 **	-8.71 **
	(1.85)	(1.82)
DEDAPPL CDC	1.26	1.30
	(1.16)	(1.12)
DUMMULTI CDC	-1.47 **	-1.47 **
	(0.75)	(0.73)
DUMARMY CDC	-2.30 **	-2.40 **
	(1.01)	(0.97)
DUMAIRFORCE C	-3.00 **	-3.41 **
	(1.49)	(1.46)
DUMNAVY CDC	-1.85 **	-2.07 *
	(1.09)	(1.07)
DUMTCA CDC	-2.23 **	-2.45 **
	(1.07)	(1.07)
SUMCPU CDC	0.08	0.07
	(0.05)	(0.05)
SIZE CDC	2.12 **	2.01 **
	(0.31)	(0.31)
CONSTANT HON	-4.31 **	-3.99 **
	(1.17)	(1.09)
DEDAPPL HON	0.42	0.53
	(0.75)	(0.69)
DUMMULTI HON	-0.81	-1.00 *
	(0.56)	(0.54)
DUMARMY HON	-0.96	-0.96
	(0.88)	(0.82)
DUMAIRFORCE H	-1.48	-2.01 *
	(1.13)	(1.09)
DUMNAVY HON	-0.03	-0.32
	(0.91)	(0.87)
DUMTCA HON	-0.13	-0.32
	(0.92)	(0.87)
SUMCPU HON	-0.01	-0.02
	(0.05)	(0.05)
SIZE HON	1.24 **	1.23 **
	(0.18)	(0.18)

*   T-statistic greater than 1.64
**   T-statistic greater than 1.96

Sample defined at the end of the table.

Table 7 continued

CONSTANT IBM	-3.79 **	-3.85 **
	(1.09)	(1.06)
DEDAPPL IBM	1.58 **	1.56 **
	(0.59)	(0.58)
DUMMULTI IBM	-2.13 **	-2.19 **
	(0.56)	(0.55)
DUMARMY IBM	-1.34 *	-1.47 *
	(0.83)	(0.81)
DUMAIRFORCE I	-3.03 **	-3.18 **
	(1.11)	(1.09)
DUMNAVY IBM	-1.12	-1.05
	(0.87)	(0.86)
DUMTCA IBM	-0.31	-0.57
	(0.87)	(0.87)
SUMCPU IBM	-0.01	-0.01
	(0.04)	(0.04)
SIZE IBM	1.05 **	1.10 **
	(0.16)	(0.17)
CONSTANT UNI	-2.58 **	-2.07 *
	(1.26)	(1.14)
DEDAPPL UNI	1.89 **	1.50 **
	(0.65)	(0.62)
DUMMULTI UNI	0.55	0.46
	(0.58)	(0.54)
DUMARMY UNI	-1.90 *	-1.66 *
	(1.98)	(0.99)
DUMAIRFORCE U	0.36	-0.04
	(1.07)	(1.00)
DUMNAVY UNI	-1.01	-1.22
	(1.03)	(0.96)
DUMTCA UNI	0.30	0.26
	(0.99)	(0.92)
SUMCPU UNI	0.04	0.03
	(0.04)	(0.04)
SIZE UNI	0.51 **	0.47 **
	(0.20)	(0.19)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Note: Sample 1 excludes acquisitions or incumbents labelled GE or RCA. Sample 4 relabels all GE and RCA acquisitions and incumbents as Honeywell and Univac.

Table 8

Coefficient Estimates for Unconstrained Experiment
(Standard Errors in Parentheses)

	Sample 1	Sample 4
NUMBER BUR ACQUISITIONS	93	95
NUMBER CDC ACQUISITIONS	32	32
NUMBER HON ACQUISITIONS	106	137
NUMBER IBM ACQUISITIONS	230	233
NUMBER UNI ACQUISITIONS	98	116
LOGLIKELIHOOD	-446.493	-517.615
NUMBER OF OBSERVATIONS	559	613
Characteristic of choice		
INVEST	0.009	0.007
	(0.014)	(0.01)
MINAGE	-0.18 **	-0.055
	(0.088)	(0.067)
COMPCAP	0.03	0.06
	(0.05)	(0.05)
INCUMBSYS	2.90 **	2.56 **
	(0.55)	(0.45)
INCEQUIP	0.73 **	0.38
	(0.32)	(0.27)
PERCENTSYS	-2.02 *	0.03
	(1.21)	(1.11)
Factors affecting IBM only		
INVEST IBM	-0.025*	-0.021
	(0.015)	(0.015)
COMPCAP IBM	0.01	-0.03
	(0.06)	(0.06)
MINAGE IBM	0.17	0.044
	(0.11)	(0.087)
INCUMBSYS IBM	-1.78 **	-1.40 **
	(0.69)	(0.59)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Sample defined at the end of the table.

Table 8 continued

Factors affecting vendors differently		
CONSTANT CDC	-9.20 **	-8.37 **
	(1.91)	(1.88)
DEDAPPL CDC	1.41	1.58
	(1.20)	(1.16)
DUMMULTI CDC	-1.34 *	-1.32 *
	(0.80)	(0.77)
DUMARMY CDC	-2.08 **	-2.27 **
	(1.05)	(1.02)
DUMAIRFORCE C	-2.48 *	-2.90 **
	(1.47)	(1.45)
DUMNAVY CDC	-2.08 *	-2.37 **
	(1.21)	(1.19)
DUMTCA CDC	-2.30 **	-2.50 **
	(1.11)	(1.08)
SUMCPU CDC	0.03	0.03
	(0.09)	(0.09)
SIZE CDC	2.07 **	1.93 **
	(0.32)	(0.32)
CONSTANT HON	-4.73 **	-4.44 **
	(1.22)	(1.15)
DEDAPPL HON	0.47	0.60
	(0.75)	(0.70)
DUMMULTI HON	-0.74	-0.94 *
	(0.58)	(0.56)
DUMARMY HON	-0.68	-0.75
	(0.91)	(0.86)
DUMAIRFORCE H	-1.25	-1.79
	(1.15)	(1.11)
DUMNAVY HON	-0.21	-0.15
	(0.94)	(0.90)
DUMTCA HON	0.03	-0.20
	(0.94)	(0.90)
SUMCPU HON	-0.02	-0.04
	(0.06)	(0.05)
SIZE HON	1.28 **	1.28 **
	(0.20)	(0.18)

*   T-statistic greater than 1.64
**   T-statistic greater than 1.96

Sample defined at the end of the table.

Table 8 continued

CONSTANT IBM	-3.21 **	-3.11 **
	(1.14)	(1.11)
DEDAPPL IBM	1.45 **	1.40 **
	(0.58)	(0.58)
DUMMULTI IBM	-2.09 **	-2.16 **
	(0.56)	(0.56)
DUMARMY IBM	-1.22	-1.38 *
	(0.85)	(0.82)
DUMAIRFORCE I	-2.97 **	-3.16 **
	(1.11)	(1.09)
DUMNAVY IBM	-1.10	-1.07
	(0.88)	(0.87)
DUMTCA IBM	-0.24	-0.51
	(0.88)	(0.87)
SUMCPU IBM	0.01	-0.01
	(0.04)	(0.04)
SIZE IBM	1.06 **	1.11 **
	(0.17)	(0.17)
CONSTANT UNI	-2.50 *	-2.04 *
	(1.31)	(1.24)
DEDAPPL UNI	1.70 **	1.42 **
	(0.66)	(0.62)
DUMMULTI UNI	0.64	0.61
	(0.61)	(0.57)
DUMARMY UNI	-1.94 *	-1.57
	(1.02)	(0.99)
DUMAIRFORCE U	0.32	-0.04
	(1.10)	(1.08)
DUMNAVY UNI	-0.88	-1.06
	(1.06)	(1.03)
DUMTCA UNI	0.39	0.46
	(1.02)	(0.99)
SUMCPU UNI	0.04	0.02
	(0.04)	(0.04)
SIZE UNI	0.50 **	0.42 **
	(0.21)	(0.20)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Note: Sample 1 excludes acquisitions or incumbents labelled GE or RCA. Sample 4 relabels all GE and RCA acquisitions and incumbents as Honeywell and Univac.

Table 9

Coefficient Estimates for Unconstrained Experiment with IBM 360/370 Dummy
(Standard Errors in Parentheses)

	Sample 1	Sample 4
NUMBER BUR ACQUISITIONS	93	95
NUMBER CDC ACQUISITIONS	32	32
NUMBER HON ACQUISITIONS	106	137
NUMBER IBM ACQUISITIONS	230	233
NUMBER UNI ACQUISITIONS	98	116
LOGLIKELIHOOD	-422.641	-493.569
NUMBER OF OBSERVATIONS	559	613
Characteristic of choice		
INVEST	0.008	0.006
	(0.013)	(0.01)
MINAGE	-0.18 **	-0.053
	(0.089)	(0.067)
COMPCAP	0.02	0.058
	(0.05)	(0.046)
INCUMBSYS	2.84 **	2.53 **
	(0.55)	(0.45)
INCEQUIP	0.80 **	0.43
	(0.32)	(0.27)
PERCENTSYS	-1.14	0.94
	(1.26)	(1.15)
Factors affecting IBM only		
INVEST IBM	-0.02	-0.016
	(0.015)	(0.015)
COMPCAP IBM	-0.02	-0.064
	(0.05)	(0.056)
MINAGE IBM	0.27	0.14
	(0.11)	(0.09)
INCUMBSYS IBM	-3.31 **	-2.93 **
	(0.73)	(0.64)
IBM 360/370 INCUMBENT	2.36 **	2.27 **
	(0.36)	(0.35)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Sample defined at the end of the table.

Table 9 continued

Factors affecting vendors differently		
CONSTANT CDC	-8.81	-7.94 **
	(1.93)	(1.89)
DEDAPPL CDC	1.09	1.30
	(1.21)	(1.17)
DUMMULTI CDC	-1.41 *	-1.35 *
	(0.80)	(0.77)
DUMARMY CDC	-1.94 *	-2.16 **
	(1.05)	(1.03)
DUMAIRFORCE C	-2.69 *	-3.10 **
	(1.48)	(1.46)
DUMNAVY CDC	-2.26 *	-2.54 **
	(1.22)	(1.21)
DUMTCA CDC	-2.40 **	-2.63 **
	(1.11)	(1.09)
SUMCPU CDC	0.02	0.03
	(0.09)	(0.09)
SIZE CDC	2.00 **	1.85 **
	(0.32)	(0.32)
CONSTANT HON	-4.85 **	-4.57 **
	(1.24)	(1.18)
DEDAPPL HON	0.20	0.35
	(0.75)	(0.70)
DUMMULTI HON	-0.78	-0.95 *
	(0.59)	(0.57)
DUMARMY HON	-0.55	-0.63
	(0.92)	(0.86)
DUMAIRFORCE H	-1.38	-1.93 *
	(1.16)	(1.12)
DUMNAVY HON	-0.12	-0.23
	(0.94)	(0.91)
DUMTCA HON	-0.01	-0.25
	(0.95)	(0.91)
SUMCPU HON	-0.03	-0.04
	(0.05)	(0.05)
SIZE HON	1.29 **	1.29 **
	(0.20)	(0.19)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Sample defined at the end of the table.

Table 9 continued

CONSTANT IBM	-2.84 ** (1.17)	-2.73 ** (1.13)
DEDAPPL IBM	1.22 ** (0.59)	1.23 ** (0.59)
DUMMULTI IBM	-2.34 ** (0.59)	-2.34 ** (0.57)
DUMARMY IBM	-0.82 (0.87)	-1.01 (0.85)
DUMAIRFORCE I	-3.18 ** (1.13)	-3.53 ** (1.11)
DUMNAVY IBM	-0.90 (0.90)	-0.85 (0.89)
DUMTCA IBM	-0.06 (0.90)	-0.35 (0.88)
SUMCPU IBM	-0.01 (0.04)	-0.01 (0.04)
SIZE IBM	0.93 ** (0.18)	0.97 ** (0.17)
CONSTANT UNI	-2.29 * (1.33)	-1.83 (1.25)
DEDAPPL UNI	1.41 ** (0.65)	1.20 ** (0.63)
DUMMULTI UNI	0.64 (0.61)	0.63 (0.58)
DUMARMY UNI	-1.81 * (1.03)	-1.50 (0.99)
DUMAIRFORCE U	0.28 (1.09)	-0.18 (1.08)
DUMNAVY UNI	-0.96 (1.06)	-1.15 (1.04)
DUMTCA UNI	0.32 (1.02)	0.39 (1.00)
SUMCPU UNI	0.03 (0.04)	0.01 (0.04)
SIZE UNI	0.45 ** (0.21)	0.37 * (0.20)

* T-statistic greater than 1.64
** T-statistic greater than 1.96

Note: Sample 1 excludes acquistions or incumbents labelled GE or RCA. Sample 4 relabels all GE and RCA acquisitions and incumbents as Honeywell and Univac.

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