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Computers, compatibility, and economic choice

Greenstein, Shane Mitchell, Ph.D.

Stanford University, 1989

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COMPUTERS, COMPATIBILITY, AND ECONOMIC CHOICE

A DISSERTATION

SUBMITTED TO THE DEPARTMENT OF ECONOMICS

AND THE COMMITTEE ON GRADUATE STUDIES

OF STANFORD UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

By

Shane Mitchell Greenstein

June 1989

I certify that I have read this dissertation and that in my opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Abstract

These essays contribute to our understanding of the economic consequences of incompatibilities and switching costs in the mainframe computer market in the 1970s.

The first essay examines the micro-economics of interface manipulation, i.e. designing the interface between two products to enhance the profits accruing to the designing firm. It explores how a dominant system designer can gain competitive advantages through interface manipulation. It also examines whether there is analytical substance to notions of "leveraging" -- i.e. the use of monopoly power in one component market to gain monopoly power in a complementary component market.

The second essay examines the relevance of switching costs for Federal mainframe acquisitions. It focuses on how conflicts between agencies (making acquisitions) and committees (assigned to oversee the procurement system) lead to difficulties in coordinating decisions pertaining to switching costs estimation, system use and vendor selection. These factors accentuated or de-emphasized the "lock-in" that resulted from switching costs. The essay argues that an appropriate understanding of the process of "lock-in" must account for decision-making that is not coordinated over time, as occurred in the case examined here.

The third essay examines the observed relationship between an agency's vendor selection and its previous experience with a vendor. It explores whether the extent of an agency's previous experience with an

incumbent predicts the choice of a mainframe vendor by a government agency. The essay also focuses on why IBM seems to gain fewer advantages from incumbency than does its rivals. The essay strongly suggests that the compatible upgrades available for older generations of equipment are important factors in vendor choice.

The final essay measures the economic determinants of an agency's choice between sole-sourcing and competitive procedures when making mainframe acquisitions. The essay demonstrates how economic models of bidding can provide structure for econometric models of an incumbent's advantage in bidding for government contracts to supply commercial mainframe computers. The analysis shows that factors other than an incumbent's advantage, particularly differences in potential competition across markets, account for much of the observed differences in bidding behavior.

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Edward Steinmueller, Geoff Rothwell and Josh Rosenbloom have patiently listened to my ideas over the years, read previous drafts of this work, and provided copious remarks. I could not have done this work without them. Tom Downes, David Green, Valerie Suslow, Steve Tomlinson, Michael Topper, Ann Velenchik, and Joel Waldfogel have also provided critical remarks at crucial points in this work's development. In addition, there are improvements to this work that can be directly attributed to the inspired observations of Luis Cabral, Greg Clark, Sarah Lane, Greg Rosston, Tom Prusa, Tom MaCurdy, Mike Riordan, Nate Rosenberg, and Frank Wolak. Every student should be so fortunate to have a set of editors as generous as these. Relly Weiner and Ann Robinson solved more problems than I can recall, for which I am grateful. And in all these years Steve Finacom and Marvin Theimer have always been available with an attentive ear and sympathetic remark.

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Introduction

The relevance of incompatibilities to economic decision-making cannot be understood in isolation of many of the other structural conditions of a product market. Many of these interactions cannot be anticipated. This research uses the computer industry and the computer market to provide concrete examples for expanding our understanding of economic decision-making when incompatibilities are relevant to those decisions.

The research contained in this dissertation has been divided into four essays. Each essay can be read on its own or as part of a whole. Together they form an empirical study of the role of incompatibilities and switching costs in economic decision making.

The first essay deals with the micro-economics of interface manipulation, i.e. the design of the interface between two products to enhance the profits accruing to the firm controlling the design. It explores how a dominant system designer and supplier can gain competitive advantages through interface manipulation. It also examines whether there is analytical substance to notions of "leveraging" -- i.e. the use of monopoly power in one component market to gain monopoly power in a complementary component market.

The second essay examines the role of switching costs in Federal mainframe acquisitions. It especially focuses on how conflicts between agencies (making acquisitions) and committees (assigned to oversee the procurement system) lead to difficulties in coordinating decisions pertaining to switching costs estimation, system use and vendor selection. This essay highlights how these additional factors accentuated or de-emphasized the extent of "lock-in" over time that resulted from switching costs.

The third essay examines the observed intertemporal relationship between an agency's vendor selection and its previous experience with a vendor. It explores whether the choice of a mainframe vendor by a government agency can be predicted by the extent of an agency's previous experience with the incumbent. The essay also focuses on why IBM seems to gain fewer advantages from incumbency than does its rivals.

The fourth and final essay attempts to measure the economic determinants of an agency's choice between sole-sourcing and competitive procedures when making mainframe acquisitions. The paper uses the structure of simple theoretical models of bidding behavior to shape an econometric estimation of unobserved bidding behavior. This analysis attempts to shed empirical light on the importance of several economic factors, including the importance of an incumbent's advantages, the value of procurement, the potential supply of commercial systems in different segments of the mainframe market, and whether a Federal agency's office had experience with IBM.

On the whole, these essays modify significantly our understanding of the consequences of incompatibilities and switching costs in the mainframe computer market in the 1970s. The first essays questions whether these incompatibilities arise in a benign way or can be generated in a way to bring advantages to the designing firm. The second essay questions whether economist's present understanding of the process of "lock-in" is appropriate for a market where decision-making need not have been coordinated over time, as occurred in the case study examined. The third essay shows that an agency's vendor choice is empirically predicted by the presence but not the extent of a buyer's investment with an incumbent. These estimates strongly suggest that decision-making was influenced by the compatible upgrades available for older generations of equipment. The final essay demonstrates how economic models of bidding can provide structure for econometric models of an incumbent's advantage in bidding for government contracts. The analysis shows that factors other than an incumbent's advantage, particularly differences in potential competition across markets, account for much of the observed differences in bidding behavior.

<u>CREATING ECONOMIC ADVANTAGE BY SETTING COMPATIBILITY STANDARDS: CAN "PHYSICAL TIE-INS" EXTEND MONOPOLY POWER?</u>

"IBM's installed base of customers... and its subsequent control over system's architecture, coupled with it power to develop unilateral and arbitrary internal standards while using its power to forestall the development of industry standards, serves to preclude the development of viable competitors for its customers." -- Jack Biddle, Computer Communications Industry Association, 1977.

"If IBM was able to change the interface between the CPU and the storage devices to render the competitive machine useless, or was able to change the physical arrangements of various pieces to increase the difficulty of attaching competitive devices, it could achieve at least a patial tie and limit the competitive impact of storgage entrants..." -- Gerald Brock, 1987.

<u>I. INTRODUCTION</u>

Can an integrated systems supplier <u>significantly</u> increase his competitive advantage by means of manipulative interface redesign? Does altering interfaces "physically tie-in" customers of two products to the same supplier, as some antitrust suits have alleged? When is "tying" via interface manipulation possible?

Analysts have correctly approached these issues with some skepticism. Most arguments alleging interface manipulation, such those quoted above, have not analytically outlined the behavior that underlies interface manipulation, nor identified the circumstances favoring such actions. In addition, some analysts suggest that these cases resemble other cases of contract tie-ins; but if that were the correct analysis, there is a well-known body of economic analysis showing that bundling and tie-ins should be interpreted as devices facilitating price discrimination. Most economists agree that the welfare effects of such actions are generally ambiguous.

If another vision of the market for integrated system such as computers is more appropriate, then it must be made clear why the existing body of analysis of bundling is inappropriate. A new analysis should explain when the standard economic analysis makes appropriate assumptions and when it does not. A new analysis must also demonstrate both how interface manipulation benefits a system designer, and why system and component competition or a demand for components compatible with previous generations do not limit such behavior. A new analysis should also make sense of the quotes listed above. Why is interface manipulation found -- or suspected -- frequently in some industries, such as computers, but not in others? Finally, a new analysis should make clear what we have to observe to confirm that manipulation occurred in practice. This paper contributes a model and analysis which does all these things.

The goal of this paper is to develop a model in which physical tie-ins enhance monopoly power. Section 2 highlights important features of several cases of alleged "physical tie-ins" and argues that the standard approach to "tie-ins" or bundling is inadequate for those cases. The standard analysis crucially assumes that entry occurs instantaneously, which will be innappropriate for the cases examined. Moreover, it does not model the endogeneity of the design decision, nor does it capture any sense in which rivalry between a system designer and imitator affects the design decision. Sections 3 and 4 develops a simple and stylized model that incorporates within the standard bundling analysis these competitive factors. Incorporating these factors significantly alters the analysis and often reverses the conclusions drawn from the standard analysis.

The new model focuses on a system designer's decision when choosing amongst alternative interfaces. A system producer faces imitation in a compatible peripheral component market and designs the component interface between both complementary components. The system designer can influence the costs of imitation when he chooses among alternative designs for his product. The model focuses on the system designer's incentives to manipulate compatibility between the products and on observable reasons why market forces may or may not restrict interface manipulation.

The analysis shows that if a system supplier has proprietary rights over an interface between his component and others, and if he introduces (or redesigns) a complementary component that cannot be instantaneously imitated, then he always has an incentive to shape product designs to a rival's disadvantage -- in this case, change the interface between his monopolized component and the complementary component. This redesign is a means to retain the temporary profits he derives when facing fewer or more costly competitors.

This model has several important results:

-- The model provides one operational definition of what "controlling" standards means. By no means is this the last word on modelling this activity, but at least it serves as a benchmark. The model serves as a useful reference point for analysis, because it provides a language for organizing issue, it identifies assumptions necessary for formulating a stylized model, and it identifies market features essential to observed outcomes. As a consequence, the analysis predicts when interface manipulation is most likely to succeed, what circumstances limit interface manipulation, and what observable occurrences ought to accompany interface manipulation -- something which previous analysis had not clearly stated. The analysis also give a more precise understanding of when interface manipulation is socially wasteful and when it is not.

-- The model allows us to more precisely discuss some contentious issues about the constraints facing designers and imitators. This leads to new insights about dominant firm advantages in markets for technically interrelated goods and the incentives to produce and control essential system components. The last sections of the paper argue that there is some analytical substance to the much criticized notion of "leveraging", or using monopoly in one market to gain advantages in another market. It suggests a novel interpretation of the returns to being a monopolist in cases when leveraging is possible.[1] It points out that such concepts should be used carefully, especially when discussing technical changes in systems and the legal protection of system components that become standards.

Several of the issues discussed in this paper can be found in previous work. Its central argument sheds light on the appropriate analysis of competition in markets made up of systems of compatible components (Jordan 1975, Ordover and Willig 1981, Stockdale 1980, Bower 1986, Adams and Brock 1983, Braunstein and White 1985). Another related field is the growing literature on interface standardization (see David 1987, Farrell and Saloner 1986 for references), where little work has been done on the circumstances in which a standard can be manipulated for the competitive advantage of the designer. Close issues also arise in the investigations of converter technologies (David and Bunn 1988), when no "ex post" converter can be cheaply installed. The outline of the argument will ultimately extend the spirit, though not the same model, of "raising a rival's costs" (Krattenmaker and Salop 1986, Salop and Sheffman 1986) to the circumstances in these cases. What differs is the means by which a firm excludes rivals from a market. This grows out of the focus here on the exclusion of rivals from the complementary product market rather than home market. Finally, this work is also in the spirit of recent examinations of the plausibility of "foreclosure" through strategic use of bundling (Whinston 1987). However, this paper emphasizes dynamic rather than static strategies and moreover, the actual cases of physical tie-ins provide a context for examining many concrete implications of the behavior.

II. EXAMPLES AND ISSUES

Not surprisingly, some of the best known allegation of compatibility manipulation have arisen in the context of antitrust cases. These have collectively been labelled as cases of "physical tie-ins". Here follows a brief summary of three antitrust cases and some of the related contentious issues:

__Automobiles:__[2] In the early 60s, an independent producer of radios for automobiles sued Ford Motor Company over design alterations in the dashboard of several models that allegedly made installing radios supplied by independent dealers relatively more costly. Old designs had "knock out plates" in the dashboard that could easily be removed at the factory or dealer for radios supplied by Ford or the independent radio suppliers. The new designs required replacing a part of the dashboard in order to install the radio. Ford refused to sell to its dealers the newly designed dashboards without radios (which could accommodate independently supplied radios), ostensibly because such cars were "unfinished" products. One central legal issue involved whether Ford's design alterations could be construed to be a "tie-in" between car and radios, which were per se' illegal at the time.

__Cameras:__[3] In the mid 70s Kodak was accused by Berkey Photo, a rival camera producer and film processor, of manipulating for its own advantage photographic formats in the home photography market. The case arose out of Kodak's quite profitable product innovation, the 110 pocket camera with Kodacolor II, to which competitors in the camera and processing market, such as Berkey, could not respond without considerable delay. One central issue concerned whether Kodak used it virtual monopoly in film and photographic paper to gain unfair advantages in complementary markets, such as cameras. Another central issue in the trial revolved around whether Kodak was subject to special restraints on its conduct (such as early product announcements of format changes), because it "set standards" in amateur photography.

Computers:[4] In the early 70s several IBM system component competitors sued IBM for system redesigns initiated by IBM which significantly altered the product designs and interfaces of the components. Evidence from the trials made apparent that IBM's pricing and design decisions frequently balanced the strategic impact alternative possible design decisions had on both future customer demand and expected imitator response. Because many design motives were bundled into the final product design decision, observers had difficulty disentangling product alterations that had had a "predatory intent" -- which was not well defined -- from permissible product alterations any system designer makes in technically active markets. As a result, when a mix of motives affected product designs, it was difficult to articulate unambiguous rules for what constituted a product design with an unreasonably restrictive impact on competition.[5]

These cases share several common features: (1) All design changes were initiated by large integrated firms which hurt single component suppliers who could not instantaneously switch to new formats. (2) Design and pricing of single components by the system suppliers were made with anticipation of its impact on component competition. Alteration in the compatibility of two components delayed the response of single component suppliers. (3) All events were analyzed in antitrust trials, a forum in which lawyers tried to fit square events into the round anti-trust concept of "tie-ins", a category for which there were already well-defined legal principles for evaluating appropriate market conduct. Tie-ins via contracts were (and still are) per se' illegal.[6]

These cases suggest several important questions: Do integrated systems suppliers have advantages over component imitators if they design the system? What observable circumstances are associated with compatibility manipulation? Why don't competitive market forces eliminate altogether the possibility for compatibility manipulation?

Since these examples are well-known and often scrutinized, one would think that these questions would have straightforward answers. Yet, there is no consensus among economists about the appropriate analytical approach. One relevant literature addresses the question "Do integrated firms have advantages if they set compatibility standards (Adams and Brock 1983, Braunstein and White 1985, Carlton and Klamer 1983, Fisher 1979, Katz & Shapiro 1983)?" Relevant issues in this literature concern whether system designers have advantages over single component producers, whether integrated system suppliers "set standards" and manipulate standards to their own benefit, and whether competition limits the returns to such behavior. Another line of inquiry asks whether product innovation is always beneficial or can be "predatory" in some sense (Stockdale 1979, Ordover and Willig 1981). A recent line of work has also theoretically examined the uses of bundling to achieve foreclosure in a complementary market (Whinston 1987).

A problem with these analyses is that (1) it often is difficult to give a useful operational definition to what "controlling standards" means, and (2) the models that have been proposed often do not capture all the important observable features common to the cases mentioned above. For example, several computer industry studies have analyzed the anti-trust issues of these compatibility manipulation episodes in the context of patterns of competitive behavior in the industry (Fisher, McGowan, Greenwood 1985, Brock 1975, McAdams 1982). There is no consensus among these economic observers about the appropriate model of behavior best suited for analyzing each situation. Nor is there a consensus about the relative importance of technical and structural conditions underlying compatibility manipulation.

Given this documented lack of consensus, there is a clear need for a reference point at the simplest structural level. This framework should organize issues provide a language for defining actions in operational ways, and establishe a framework for prediction.

III. INTEGRATED SYSTEMS, COMPONENT IMITATION, AND COMPETITION

Previous interpretations of "physical tie-ins" as a bundling decision forms the theoretical starting point. Bundling occurs when firms require that customers purchase two components together. This analytical approach reinterprets any bundling decision as a device by which a firm price discriminates among customers with different intensities of preference for two components. The already extensive analysis of the motives to use tie-ins, and the anti-trust trials themselves suggested that this type of analysis of market conduct might be relevant. This section begins to show how this usually is only part of the story.[7]

The standard analysis goes as follows: If the system supplier is a monopolist over two system components, X1 and X2, then his pricing decision can be represented as:

$$(1)\ \max_{P^1,P^2,P^B} \pi_M(P^1,P^2,P^B) = \{ X1(P^1,P^2,P^B)\cdot[P^1-c1] + X2(P^1,P^2,P^B)\cdot[P^2-c2] + XB(P^1,P^2,P^B)\cdot[P^B-c1-c2] \}^8,$$

where c1 and c2 are the costs of producing components X1 and X2 respectively, his capacity in each component is unlimited, and there are no joint economies or extra assembly costs for the bundle. $X1(P^1,P^2,P^B)$, $X2(P^1,P^2,P^B)$, $XB(P^1,P^2,P^B)$ represent market demands for X1, X2 and the bundle of both components, aggregating all customers of heterogenous tastes. Naturally, $\delta X1/\delta P^1 < 0$, $\delta X2/\delta P^2 < 0$, and $\delta XB/\delta P^B < 0$. X1 and X2 need not be complementary, i.e. $\delta X_i/\delta P^j < 0$, $i \neq j$, but it is difficult to imagine a situation where it were not so. XB is also a substitute for X1 and X2, i.e. $\delta XB/\delta P^i > 0$, $i = 1, 2$. For example, in the Ford case, X1 is an auto, X2 is a radio and XB is both.

Note that if the integrated supplier's X2 component is supplied competitively by the market then the integrated supplier's decision becomes

$$(2)\ \max_{P^1,P^B} \pi_I(P^1,P^B) = \{ X1(P^1,c2,P^B)\cdot[P^1-c1] + XB(P^1,c2,P^B)\cdot[P^B-c1-c2] \}.$$

Equations (1) and (2) can be used to analyze the incentives to bundle two components in a contract (or in a technically bundled system) as a means to price discriminate amongst buyers of different preference intensities. The insight highlights the ambiguity of welfare evaluations. The analysis then finishes by noting that there is no analytical basis for concluding that the monopolist in one good can "leverage" that into a monopoly in the complementary good. The analysis's one clear prediction is that $\pi_M > \pi_I$, i.e. imitation of one component always reduces aggregate profits, which has no legal implications.

While the above is appropriate for many cases of "tie-ins" by contracts, this approach is not appropriate for analysis of the alteration of design features to gain monopolies over components, because the manipulation of interfaces is not modelled. The standard approach is geared toward the analysis of contracts -- where the supplier presents a take-it-or-leave-it contract to the buyer. It already assumes the firm has a monopoly in two products. What that literature is about is how a dual monopolist prices both components, not how he obtains his monopolies -- which is the crux of the issues in physical tie-ins. It is also dissatisfying because it does not identify circumstances that limit or aid the possibilities for interface manipulation.

This paper models interface manipulation by extending the standard analysis in a simple and stylized way. What is missing from (1) and (2), but can be found in the examples sighted above, is a sense that intra-firm rivalry between integrated system designer and component imitator affects the design decision of the integrated supplier.

Brock does not seem to have a complicated model in mind, so it does not seem worthwhile to develop an excessively complex model. Suppose imitators who produce X2 produce exact duplicates of that component, but cannot do so instantaneously[9]. The imitators produce exact duplicates of X2 because inattention to minute detail can potentially render a component dysfunctional.[10] Duplicates cannot be made instantaneously because time and inputs are not perfect substitutes in product development or reverse engineering.[11] The crucial thing is that it takes time to produce that duplicate and they do not have much say over the many aspects of design. This is not implausible for the type of products markets discussed above.[12]

The following two traits describe the potential aggregate supply of imitations of X2: 1) Falling costs in the potential aggregate supply of imitations of X2 over time, approaching the marginal cost of the systems supplier; 2) And/Or increasing potential aggregate imitative capacity with time, approaching complete industry demand at competitive supply price; These are all satisfied, for example, by the general case of an upward sloping potential supply of imitation that falls over time for all quantities produced until it supplies the market at the lowest marginal costs possible.

Also assume that all potential imitator entry actually occurs and that pricing by imitators follows the system designer's pricing leadership, as one often finds in simple dominant firm/competitive fringe models. This assumption simplifies the analysis without sacrificing important insights.[13]

The supply of imitation can be represented by a simple supply schedule, $R(t,P^2)$, where the function R is differentiable and $\delta R/\delta t \geq 0$,

$\delta^2 R/\delta P^2 \geq 0$, $\delta^2 R/\delta t \delta P^2 \geq 0$, $R(t', c2) = \infty$ for some $t' < \infty$, and $R(0,c2) = R$, $0 \leq R$. Time 0 is the time of introduction of X2, and t' is the elapsed time after time 0 at which imitation of the system supplier's X2 component can completely meet the demand for that component.

Assume that consumers (of various tastes for both components) arrive at a steady rate to purchase an infinitely long-lived X1 and X2, and further assume, that all customers buy the goods in the same proportions (e.g. one of each). These assumptions simplify the analysis by effectively ruling out intertemporal substitution by buyers and implies that the demand for the two components are related at any point in time, but not over time. In other words, the market is composed of very impatient customers and it clears in each instance[14]. The system supplier's problem is then characterized as a generalization of equation (1) and (2) in the following manner:

$$(3) \quad \max_{P^1, P^2, P^B} \int_0^{\infty} e^{-rt} \pi(P^1, P^2, P^3)\, dt,$$

$$\text{where } \pi(P^1,P^2,P^B) = \{ X1(P^1,P^2,P^B) \cdot [P^1 - c1] + [X2(P^1,P^2,P^B) - R(t,P^2)] \cdot [P^2 - c2] + XB(P^1,P^2,P^B) \cdot [P^B - c1 - c2] \}.$$

Solving (3) yields a system of first order condition for P^1, P^2 and P^B for each t[15]. Denoting the optimized profit function as π^*, it can be readily shown that:

(4) $\delta\pi^*(t)/\delta t \leq 0$, i.e. equilibrium instantaneous profits fall over time and reach a minimum at $\pi^*(t')$.

(5) $\delta\pi^*(t)/\delta R \leq 0$ for all t, i.e. profits increase as the competitive response of imitators at time zero becomes smaller.[16]

Proposition (4) says that the introduction of X2 sets a spate of potential imitators in motion which the system supplier cannot eventually deter. As the aggregate capacity of these imitators increases with time as their aggregate costs decline, the system supplier faces an ever decreasing "residual" demand for X2. As his market power declines in X2, so too do his total profits from all the single component and bundle markets. This pattern continues until his potential output of X2 is completely matched by imitation. In a steady state he prices X2 at its competitive price, and his profits from production of X2 equal zero. This is not an unexpected result.

Proposition (5) says that the designer has an incentive to slow this imitative process down if he can by raising the costs of imitative supply or lowering aggregate capacity of imitators. If such actions have a cost, then he will take such action so long as the marginal expense of making imitators start at a worse point is less than the marginal profits it generates. This is a very simple insight, not unlike that found in the literature about "raising rival's costs"[17]. If an incumbent firm can affect the supply conditions of his rival firm, he may do so if it earns him sufficient profit. Yet, this simple idea has been missing from the discussion about physical tie-ins: a system designer should be able to affect the costs of imitation, in principle, when he chooses among alternative designs for his product in particular, when he chooses among alternative standards. This idea will be given a formal representation in the next section.

Though a large number of assumptions were needed for this model, any model of competition which satisfies (4) and (5) is sufficient for what follows. This encompasses many models of design and imitation.

IV. COMPATIBILITY AND COMPLEMENTARITY

All technically complementary components have two qualities which describe them: (a) their function and (b) the interface that determines their compatibility with the other component. Following David and Bunn (1988), the compliments X1 and X2 are compatible if the two components together permit attainment of maximal system performance levels in all relevant output dimensions. The reservation value placed on this system output, differs across individuals. "Compatibility" might be thought of as a single parameter, hidden inside each component. If each component has the same value, they are compatible. If a new generation of components is designed with a new parameter, then the old and new generations are incompatible. For convenience, we assume that there is no demand for systems composed of incompatible components.[18]

Note an important feature of the model of interface manipulation. It is essential that the system supplier have monopoly power over X1, and that he obtains the monopoly power by holding property rights over the design of some function the component performs and not from controlling the design of the interface. There are two reasons for this. If the designer only controls the interface then system competition with exact component duplicates using another interface eliminates any advantage to manipulating interfaces. Second, in the absence of monopoly power, the designer will have no incentive to manipulate interfaces, because to do so will yield him no extra returns. Gaining control over two complementary components allows him to price discriminate when he prices the bundled components together.

What does this look like in practice? Every time an interface is altered, a designer has several options on how to package two components together: He can (1) integrate them so that a single X2 component has no value unless bought in a package with X1, or (2) design X2 components so that they can be bought as a modular components and "snapped" into the X1 interface with various degrees of difficulty, or (3) integrate them using skills which the designer, but possibly not other firms, is well endowed. Of course, different interface designs will result in different degrees of difficulty of simple component imitation. For example, an "open architecture" and modular design -- which commits to not manipulation a design -- invites component imitation, while a "closed architecture" and integrated design makes single component imitation much more challenging.

This idea can be formalized, but only with a bit of awkwardness; yet we will learn something from the theoretical example. Suppose that any time the system supplier changes the interface parameter for any X1/X2 pair, he does so at an exogenously cost of F. Furthermore, let the imitation of the newly encoded X2 proceed in the way characterized above, with supply of imitations on a newly encoded X2 increasing over time after each time interfaces are changed. Call the length of time until the next interface manipulation t^*. In principle, t^* could be a vector of times between switches, but define the problem so that the time to switch will be the same between each manipulation (there will be no loss of generality). Also define I^* as the maximum obtainable profits after each interface change discounted to the present.

Based on the above discussion, at any point in time, call it t_n, the monopolist's forward looking decision to employ a new interface can then be written as:

$$(6)\ \text{MAX}\ [I^* - F,\ \int_{t_n}^{t^*} e^{-r(t-tn)} \cdot \pi(P^1,P^2,P^3)dt + [I^*-F] \cdot e^{-r(t^*-tn)}].$$

where the instantaneous profit function $\pi(P^1,P^2,P^B)$ is the same as in equation (3), and t^* becomes infinite if an optimal switch time never occurs. In equation (6) the monopolist chooses not to change interfaces until some time $(=t^*)$ because the right side is greater than the left. The problem repeats itself with each new interface manipulation.

The problem in (6) can be equally rewritten in a more convenient form with a new imitator function that explicitly cycles. Let this new function be $R(t,P^2,t^*)$ as defined below. The monopolist's problem can then be described as:

$$(7)\ I^* = \underset{P^1,P^2,P^B,t^*}{\text{Max}} \int_0^{\infty} e^{-rt} \cdot \pi(P^1,P^2,P^B)dt - \sum_{i=1}^{\infty} e^{-irt^*}F\ ,$$

$$\text{where } \pi(P^1,P^2,P^B) = \{\ X1(P^1,P^2,P^B) \cdot [P^1-c1] + [X2(P^1,P^2,P^B) - R(t,P^2,t^*)] \cdot [P^2-c2] + XB(P^1,P^2,P^B) \cdot [P^B-c1-c2]\ \},$$

where $R(t,P^2,t^*) = R(0,\ P2(0))$ when $n \cdot t^* = t$ for some integer n,
and $R(t,P^2,t^*) = R(t-nt^*,\ P2(t-nt^*))$, where $nt^* < t \le (n+1)t^*$.

Equation (7) captures all the important features of (6). I^* is the value of profits under optimal behavior, discounted from the time of introduction of a new interface (The appendix demonstrates that I^* is bounded from above). At each t^* length of time after introduction of a new interface the system supplier finds it optimal to introduce another new interface and set the aggregate supply of imitation back to $R(0,P^2(0))$. He restarts the imitation cycle at a cost of F. If t^* does not exist, the system supplier will introduce only one generation of pairs of X1 and X2.

With the model defined in (7), then the following must be true (proof in appendix):

Proposition 1: (a) If a t^* exists, $F > 0$, and $\pi(t)$ is continuous, then $0 < t^* \leq t'$, t^* is unique, and $\delta I^*/\delta F < 0$ in that range. That is, if it is optimal for the monopolist to change the interface, then he will always do so every t^* intervals of time, never after the moment that profits are driven to $\pi(t')$ -- the minimum guaranteed level -- and prices reach the competitive costs. Those total profits decline as the cost of switching increases.

(b) A necessary and sufficient condition for t^* to exist is

for $F \leq \int_0^{t'} e^{-rt}[\pi(t) - \pi(t')]\, dt$. Equality holds only if $t^*=t'$.

That is, the system supplier switches if and only if the cost of switching is no greater than the total discounted sum of instantaneous profits above the minimum guaranteed profits, measured for one generation from the time of peripheral introduction to complete imitation. He is indifferent between switching and not switching when switching just covers his costs.

The interpretation of proposition 1 is straightforward. After the introduction of a new X1/X2 pair, the profits of the firm begin to decline with time as an increasing number of imitators duplicate the new X2. At t^* the incremental loss of profits from allowing in new imitation plus the discounted forgone profits from introducing a new X1/X2 pair and starting the cycle again just outweighs the discounted expense of changing the interface. If it ever makes sense to change interfaces, then it must make sense do so before profits reach their minimum at t' because the net profits from changing are always positive.

So long as $\pi(t)$ is continuous and t^* exists, it can readily be shown that t^* is defined where

(8) $\pi(t^*) = r \cdot [I^* - F]$.

That is, the system supplier changes compatibility between components when the declining instantaneous profits from continuing with the old interface just equal the flow rate of future profits obtainable from switching to a new interface. Figure 1 illustrates the equilibrium.

Comparative statics are instructive. If each t^* was synonymous with technical change that boosted aggregate demand for the next generation, then the system designer will desire to bring those profits forward a little sooner, making the optimal switch time shorter. If the monopoly profits on the X1 component fall over time, but can be readjusted with a new improved generation, then interface manipulation also will occur sooner. If the life of the product was of finite length, then I^* would decline as one approached the terminal time. Since there would be no change in countervailing forces, this would make the optimal time to switch longer over time.[19]

In this model, the repeated expenditure of F (as well as the efforts of rivals to imitate new interfaces) is a social waste. The system supplier's incentives to alter interfaces diverge from social incentives because he does not internalize the effect of his design decision on his competitor's profits and his buyer's returns and moreover, he derives a return in the X2 market from facing little competition after the introduction of a new interface. It is as if the monopolist chooses to decide when and where the competitive race will begin each time, and having done so, fires the starting gun without warning. His competitors, scrambling to prepare for the event, will be scattered at best, and do not catch up to the system designer for some time.

Consumer welfare is obviously lowered by interface manipulation. However, total social welfare may not be lower in a regime with interface manipulation than in one where there is no manipulation and entry into the complementary market. Compare the situation where all component competitors are excluded with one where they are present and pricing competitively. The difference in social welfare between the two regimes depends on the degree (first, third) to which the dual monopolist successfully price descriminates among all different customers. In the case when a monopolist charges one price for X1, one price for X2 and only one price for a budngle X1 and X2 (third degree), pricing will exclude customers, producing (static) social waste, leaving everyone worse off -- relative to a case of free entry into the complementary market. Successfully charging each customer his reservation prices (first degree) will result in higher welfare total, as the dual monopolist captures all the rents and more customers are served. It is the in differences in quantities sold under different degrees of price discrimation which makes the static welfare evaluation ambigious.

In sum, since the system supplier of one component has market power, he also has proprietary rights over an interface between his component and others, and he can change that interface as often as he chooses. If he introduces complementary component that cannot be instantaneously imitated, then he always has an incentive to change the interface between his monopolized component and the complementary component as a means to retain the temporary profits he derives when facing fewer or more costly competitors. This simple model predicts that if an integrated system designer and supplier succeeds in this strategy, then he will maintain high profits from sales of X2 and market power in peripheral markets despite competition, whether he completely eliminates his imitative competition or not. It further predicts that one might expect to see periodic episodes of "compatibility" fights with imitators and complaints from them about needless interface changes. Perhaps, these complaints will be most common when standards sponsors "update" features of a standard.

V. BACKWARD COMPATIBILITY -- A LIMIT TO INTERFACE MANIPULATION?

Unlike the specification in equation (7), buyers for many systems of interrelated components -- such as cameras and computers -- do not purchase both components in the same proportions, nor all at once. This observation poses problems for the previous model. If both purchases are not bought contemporaneously, then past purchases will generate future demand for compatible components and possibly adversely affect the profitability of interface manipulation.[20] If the model presented in (7) and proposition 1 is relevant to systems other than cars and radios, it certainly must accommodate intertemporal purchasing of compatible components.

Capturing this effect requires an alteration of the specification of demand in the model of competition. We decompose into two groups aggregate demand for components of a particular generation of a system, new customers -- who continue to arrive at a constant rate, and old customers looking to purchase single components compatible with purchases of old generations. The system designer cannot discriminate between the two groups except to the extent that he can sell a bundle of both components to new customers. We specify the old customer's demand for compatible complementary components as $\alpha_i(t)\cdot Zi(P^i)$, where i = 1 or 2, and on the interval [0,t] the following holds: $\delta Zi/\delta P^i < 0$, $\delta\alpha/\delta t >$

0, $\delta^2\alpha/\delta t^2 < 0$, and α continuous. Also, $\delta\alpha/\delta t = 0$ for all $t > \bar{t}$. That is, Zi is an increasing function of time, reflecting the effects of past sales on the demand for the complementary component, but decreasing in contemporaneous price for Xi.[21]

Similar to (3), the system supplier's problem can represented as:

$$(9) \qquad \underset{P^1,P^2,P^B}{\text{Max}} \int_0^{\infty} e^{-rt}\pi(P^1,P^2,P^3)\ dt,$$

where $\pi(P^1,P^2,P^B) = \{\ [\alpha_1(t)\cdot Z1(P^1) + X1(P^1,P^2,P^B)]\cdot[P_1-c1] +$

$$[\ \alpha_2(t)\cdot Z2(P^2) + (X2(P^1,P^2,P^B)-R(t,P^2)]\cdot[P^2-c2] +$$

$$XB(P^1,P^2,P^B)\cdot[P^B-c1-c2]\ \}.$$

Two cases span the space of possible outcomes to equation (9), either $\alpha_1(t) = 0$ for all t, or $\alpha_2(t) = 0$ for all t. Proposition 1 already examined a situation in which both are zero. Using (9), the following holds:

Proposition 2: (a) If $\alpha_1 = 0$ and t' is reached, then for all $t \geq t'$, $\delta\pi^*(t')/\delta t = 0$, and there exists $\underline{t} \in [0, t']$, such that for $t > \underline{t}$, $\delta\pi^*(t)/\delta t \leq 0$. That is, if the installed base of X1 results in increasing demand for the imitated component, profits must decline with time after some point. Profits will not grow after complete competitive entry of X2 is achieved by imitators.

(b) If $\alpha_2 = 0$ and t' is reached, then for all $t \geq t'$, $\delta\pi^*(t)/\delta t \geq 0$, and for some $\underline{t} \geq t'$ $\delta\pi^*/\delta t = 0$ for all $t > \underline{t}$. $\delta\pi^*(t)/\delta t$ can be positive or negative in the range of $t \in [0,t']$. That is, if the installed base of

X2 results in increasing demand for the monopolized component, profits continue to grow even after full imitation, though it must eventually converge to a constant. Because installed base effects continually raise the profit level at full imitation, profits can increase or decrease over time prior to full imitation. Notice that this implies that $\pi(t')$ need no longer be the minimum instantaneous profit level.

Analogous to equation (7), the system designer's problem can then be represented as:

$$(10) \qquad \max_{P^1,P^2,P^B,t^*} \int_0^\infty e^{-rt}\pi(P^1,P^2,P^3)\,dt,$$

where $\pi(P^1,P^2,P^B) = \{ [\alpha_1(t)\cdot Z1(P^1) + X1(P^1,P^2,P^B)]\cdot[P_1-c1] + [\alpha_2(t)\cdot Z2(P^2) + (X2(P^1,P^2,P^B)-R(t,P^2,t^*)]\cdot[P^2-c2] + XB(P^1,P^2,P^B)\cdot[P^B-c1-c2] \}.$

Will compatibility manipulation still occur? What effect does this installed base effect have on incentives to manipulate interfaces? Using equation (10) the following must be true:

Proposition 3: (a) If $\alpha_1 = 0$, then $0 < F \leq \int_0^{t'} e^{-rt}[\pi(t) - \pi(t')]dt$ is necessary and sufficient for a unique t^* to exist and is unique in the range $0 < t \leq t'$. That is, if the installed base of X1 results in increasing demand for the imitated component, the optimal time for switching interfaces may still exist if and only if bounds on F are met. Indeed, because $\pi(t)$ is higher for all t, the bounds on F are higher than in the absence of the installed base effect.

(b) If $\alpha_2 = 0$, then several outcomes are possible:

(i) If t^* exists, it exists in the range $(0,t']$. That is, if a switch occurs, it occurs before imitation completely takes place.

(ii) If $r(I^{**} - F) \geq \pi(t)$, where I^{**} is defined as the profits if switching takes place, then $0 < F \leq \int_0^{t'} e^{-rt}[\pi(t) - \min_t[\pi(t)]]dt$

is necessary and sufficient for the existence of t^*. That is, if the market tends to a steady state where the system designer's instantaneous profits are less than the flow rate profits in the new interface regime, then a sufficiently low cost of switching is a necessary and sufficient condition for the optimality of interface manipulation. This cost constraint can be lower or higher than the same condition in proposition 1, because $\pi(t)$ will be higher for all ranges in $(0,t')$, but $\text{Min}[\pi(t)]$ -- the minimum guaranteed profit level -- will be higher.

(iii) If $r(I^{**}-F) < \pi(t)$, then $0 < F \leq \int_0^{t'} e^{-rt}[\pi(t) - \min_t[\pi(t)]]dt$

is a necessary but not sufficient condition for the existence of t^*. A sufficient condition is that $\int_{t_n}^{\infty} e^{-rt}\pi(t)\, dt > (I^{**}-F)$, where t_n is measured from the first point at which $\pi(t) = (I^{**}-F)$. That is, if the instantaneous profits rates tend to a level greater than the flow rate of profits in the next regime, then the bounds on F are not sufficient to guarantee an interface change. A sufficient guarantee is that the total sum of discounted future profits with the present interface measured from the point at which t^* would exist in the absence of a "backward compatibility effect" -- the effect of past sales on future sales of complementary components -- be less than the total discounted profits with the new interface. Figure 2 illustrates this backward compatibility effect.

Proposition 3 highlights aspects of the process that were not readily apparent. Backward compatibility affects the interface decision through changes in the minimum profit level achievable, through changes in instantaneous profits at any point in time, and also through growth in the minimum guaranteed profits after full imitation occurs. First note that the rise in instantaneous profits before full imitation of X2 may change the timing of interface decisions, but not its eventual occurrence so long as the minimum profit level remains unchanged (proposition 3a). Though he may temporarily benefit, eventually the system designer does not profit from increasing the demand for a fully imitated component. Also note that whether an installed base of components affects the eventual occurrence of interface manipulation or not depends solely on how past demand for the imitated component affects the demand for the monopolized component.

The second thing to note is that backward compatibility prevents interface manipulation only if growth in demand for monopolized components is too great after full imitation occurs (proposition 3biii).

This implies that if we observe no growth in demand for the monopolized component after full imitation of its complementary component, then we can infer that the interface switching did not occur because it was too costly to redesign (proposition 1b, 3a, 3bii). It also implies that if we project large growth in demand for a complementary component and small redesign costs, but do not observe interface change, then we might conjecture that the designer did not think that the profits from staying with the present configuration exceeded future additional profits from interface manipulation. The latter relation occurs either because actual supply of imitation grows too quickly to make manipulation very profitable, or future sales are very profitable due to backward compatibility. Thus, where backward compatibility effects are weaker, as (a) when the imitated components are less durable or become obsolete faster, or (b) imitators are slower to respond, an integrated systems designer is more likely to manipulate interfaces to his benefit.

Proposition (3) is also consistent with one insight that was apparent prior to the analysis -- why we may observe an integrated designer with market power over key components accepting standardization of interfaces between complementary components he designs and those that are supplied competitively (Indeed, he may encourage it through open architecture, etc). When the integrated systems designer receives no monopoly profits for an existing system component that increases demand for his monopolized complementary component, he has no incentive to manipulate existing interfaces and every incentive to remain backward compatible with those competitively supplied components. In other words, a system designer may internalize the "positive externality" that an existing network of complementary components has on future demand for his monopolized components by designing components compatible with the existing installed base or potential supply of complements. In markets where capabilities are technically diffuse, one should expect the designer to open up his interfaces to encourage the entry of complementary components to enhance the value of his monopoly. Hence, it is reasonable that Kodak could manipulate interfaces in one branch of the photography market (110, 126, and the "home" market), but find it unprofitable to do so in the high quality end (135), where the installed base of cameras with that format was very large and where innovative products using the 135 cameras were being introduced each year.

VI. INTERPRETING INTERFACE MANIPULATION AND BACKWARD COMPATIBILITY

The foregoing results can be directly applied in the cases motivating this inquiry. For instance, our findings settles an old and tedious argument in the computer industry about whether component imitators and incumbents are equally "constrained" by backward compatibility. The argument remained unsettled principally because both sides of this argument were able to cite different aspects of IBM's product designs and interface changes as evidence in favor of their interpretation of IBM's actions.[22] Using the above analysis, we can operationally define the two arguments and illustrate their limits.

The designer and imitator do not face symmetric situations. The two rival firms are identically constrained only if both rivals introduce monopolized components whose demand is a function of the same compatible components purchased in the past. In general, the two situations are different because the player's goals are different in each. Backward compatibility constrains the integrated systems supplier's new product designs because he collects monopoly rents, but backward compatibility does not constrain the component imitator who is more concerned with making his imitation compatible with the system designer's product.

The outcome of this debate should not turn on the general assertions about market conditions facing all entrants. It should depend on whether it is proper to interpret competitive component entry as (a) competition among innovator and imitator or (b) competition among equally capable producers of differentiated products, both of whom are producing additions to an existing system.

The above interpretation cannot immediately settle the argument when interface changes and technical advance occur at the same time. Over time the ability of an integrated systems designer such as IBM to manipulate interfaces to its advantage may be eroded by the durable investments of its customers. Hence, it only becomes profitable for IBM to manipulate interfaces if interface change is accompanied by significant boosts in demand -- say, due to a technical advance embodied in the new product -- that induces old customers to scrap an old system and become new customers for the new generation. In other words, if one thought that an interface allegation had been designed deliberately for its competitive value, one would expect it to be accompanied by technical advance in a key component in order for it to succeed in markets where system designers are constrained by backward compatibility. Of course, these prediction are observationally difficult to distinguish from legitimate technical advances in system design which necessitate interface change. Thus, using the same evidence, one side can see "predatory product innovation" where another sees advance, especially when observers are unable to clearly allocate the importance of various incentives on the actual design chosen.

Though the issues particular to the IBM case will probably remain unresolved, the analysis does suggest a way of working around the ambiguity of distinguishing manipulative market actions from legitimate design change (important for both the IBM and Kodak cases). The analysis suggests a novel conceptual understanding of the incentives to obtain monopoly power with innovation in markets for interrelated components. The heart of this novel approach involves a reinterpretation of the value of technical innovation.[23] Because the simple model in this paper nested bundling options in its demand structure as a special case, it suggested that the returns to system innovation are linked to two aspects: (1) "a derived demand return", i.e. a return for the function the component performs; (2) "a leveraging return", i.e. a return for the design implementation within a system of components, a design choice that accounts for its impact on competitors (additional rents from some advantage in the X2 market). The heart of the interpretive problem in the Ford, Kodak, and IBM cases is to identify these two separate effects. Thus, the proper question for identifying compatibility manipulation should concern whether one also observes actions that have no direct relationship to the "derived demand" for that innovation.

The argument implies that markets where imitators are slow and backward compatibility is not very binding, an integrated system designer could continue, in principle, to "multiply" monopoly power across a whole array of related systems products, through generations of technical improvements and despite various component imitators. In technologically advancing fields with many complementary components, leadership in one central component can potentially mushroom into leadership in product design of the system. Such leadership in design could aid a firm in gaining rents in a large array of components within a complex system long after an initial patent race for control over the design of an essential-and-difficult-to-imitate component[24].

Because the returns to innovation in that component can be "multiplied" across components, one expects to find that the competition to gain an unassailable monopoly in a crucial component will be translated back to action preceding market introduction of the innovation, such as the research and development stage. This implies that since research on the central component partly proxies for returns on other parts of the system, the research funds expended for an unassailable lead in areas of central technical importance will be far greater than the returns that research on one component alone could justify, those returns being composed of both "derived demand returns" and "leveraging returns"[25].

In effect, this vision recasts the Schumpeterian connection alleged between the need for risky innovation and the desire to obtain monopoly power. Coincident with innovation on a system, interface designs are altered -- without openly appearing to damage old customers -- in order to extract rents on non-monopolized complementary components. Costly (and risky) innovation is the justification for lack of fidelity to customers using old technical designs. In other words, the main component monopolist innovates in the system to keep imitators at bay -- at the (private and social) cost of altering interfaces to slow down imitation. It is the monopolist who is creatively destroying features of his own old system.

Placing interface manipulation in the context of a dynamic research and development race raises another set of welfare ambiguities. Economists have long recognized that the innovator's returns under monopoly act as a incentive to firms to do more research. However, recent research has shown how difficult it is for firms to appropriate returns to their innovations[26]. In such a world, it may be welfare-enhancing over the long run to raise innovator's returns (through manipulation) to make up for the insufficient incentives they receive otherwise. Though true in principle, such a calculation is difficult to make, as it depends on the monopolist's price-discriminating abilities and the appropriability conditions prevailing in the market place for the main component -- which varies greatly by product and time period.

VII. RECONSIDERING LEVERAGING, "PHYSICAL TIE-INS" AND POLICY

Courts have worried in the past that patent law should limit "leveraging", i.e. using the monopoly power in one market as a means to monopolize other markets, and have tried to confine a patent owner's returns to innovation to those he receives only from his monopoly on inventing X1 (See Bowman 1973 for examples). Since Stigler's (1967) and Ward Bowman's (1957) analysis of leveraging, the economic analysis of contract tie-ins and bundling has ridiculed the court's worries, correctly arguing that, if all firms are equally capable of competing, returns to innovation are restricted to a what has been labeled here as a "derived demand return". That analysis essentially shows that it is not the case that what passes for "leveraging" in the courts increases the number of monopolies under a patent holder's control. Rather, at most, these tie-ins serve as devices by which the patent holder can increase profits through price discrimination.

In his book on antitrust law, Posner (1976) further identified two glaring weaknesses in the court's use of leveraging notions: (1) the leverage theories did not demonstrate that a monopoly in another product is a consequence of a tie-in; and (2) the leverage theories did not explain why it was profitable for the seller of the monopolized good to use the tie-in as a leveraging device. Once again, in a long run setting where all firms are equally capable of competing, this criticism is valid.

The above criticisms are not validly extended to cases of "physical tie-ins". They are flawed by their assumption that long run entry will occur in the short run, and by their neglect of the privately profitable temporary advantages that interface manipulation may yield a system designer. The foregoing model meets both Bowman's and Posner's objections to the older leveraging examples by defining "leveraging" in a short run operational setting. When imitation in complementary component markets is not instantaneous, under simple circumstances a system supplier temporarily excludes competition in complementary markets and potentially multiplies his monopoly in one component into repeated temporary or permanent market power in another.

This is not arguing that the "leveraging" argument has been used properly in the past, but that it could be more sensibly used in the future if done carefully. In the foregoing analysis I have shown: (1) how designers may obtain the ability to price discriminate in two component markets is more central to these cases and both monopoly power in one component and integration in both are essential to that story; (2) that courts should not just assume that all aspects of technical change are socially beneficial, particularly when it involves altering system interfaces; (3) that increasing the legal protection of property rights of product components that become industry standards, such as system software, has potentially unanticipated welfare sonsequences, especially if this allows an integrated system supplier to control the design of standards system interface, as Menell's (1987) argument correctly suggests. However, I have also argued that such an argument is incomplete without specifying the circumstances necessary for such action to succeed -- such as the importance of a monopoly in one signficant component, or the absence of demand for backward compatible components, specifying a link between the standard and the speed of imitation.

If courts still want to limit leveraging, despite some of the welfare ambiguities noted, the line of analytics that have been developed also suggests proper legal limitations for producer conduct in cases involving "physical tie-ins". The guiding principle is a simple one: Where possible, the courts should remove the ability of the integrated system's designer to use his design advantage in complementary markets, i.e. eliminate the incentives for leveraging, without impinging on his ability to get returns to innovating in his primary market.

Applications to the cases already mentioned will illustrate the principle (and most of its difficulties). In the Ford case, the courts should have required Ford to sell automobiles <u>without radios</u> with dashboards that could accommodate radios, essentially removing their leveraging tool without hurting their ability to innovate with new design changes. In the Kodak case, the same principle would require Kodak to sell unformatted rolls of film to other camera makers who wanted to introduce innovative formats. Indeed, the appeal court ruling in the Berkey cases appeared receptive to requiring such an action though none was requested by the plaintives.[27]

The difficulty with both of the above solutions is, of course, in the determination of a "fair Price" for unformatted film and a car without radio and the enforcement of it, once determined. If not monitored closely, Ford or Kodak can easily vertically price squeeze their component imitator by pricing their unformatted goods too high.

The suits against IBM also demonstrate difficulties with the application of this principle. In those cases, simultaneous interface and technical changes resulted in greater demand for a IBM's product, both because the new system of products was technically superior to previous generations -- especially for those who valued upward compatible system components, and because component imitators took a long time in scrambling to respond. In the absence of a clear technical alternative to the one chosen by a designer it was often impossible for courts to properly scrutinize every aspect of a product design and judge which design features hurt rivals and were unnecessarily restrictive or determine which features included new functions that lead to higher demand for the new product generation. In short, even if the central issue should concern which design aspects or market conduct had no bearing on the returns to innovation, it is not evident that there is a proper restriction of design conduct if large technical advances at a systems level plausibly lead to significant interface alterations.

Are there any other applications of these principles in complex markets such as these? Requiring product announcements in advance of interface change is the one other method of removing advantages system designers such as IBM gain from using its monopoly power over components to unilaterally hurt component imitators. This takes away part of the short run advantages from interface change, reducing "leveraging returns", though also the "derived demand return" to some extent. Indeed, the common market has essentially done this by requiring IBM to announce all major system changes with a six month lead time.[28]

VIII. SUMMARY

This paper argued that the standard anti-trust analysis of bundling and tie-ins led to an incomplete understanding of the important features in a case of "physical tie-ins". As a contribution towards more thorough understanding, this paper has developed and analyzed a simple model of a market in which a monopolist on one component controls a complementary component market through manipulation of interfaces. The model serves as a useful reference point for analysis, because it provides a language for organizing issues, it identifies assumptions necessary for formulating a stylized model, and it identifies market features essential to observed outcomes. The analysis has provided an operational definition of "leveraging" and "interface manipulation", and organized an approach to understanding this occurrence. It has argued that it can be socially wasteful, but has noted several ambiguities with this analysis.

The analysis most plausibly applies to a systems producer and designer with some market power in one component who easily controls the compatibility between complementary components through design changes. The paper argued that interface manipulation is most likely in markets made up of systems of technically complex components, where purchases of past generations of components do not greatly restrict the probability of designing an incompatible present generation. The paper showed that interface manipulation is most likely in markets where past generations of competitively supplied components do not lead to much future demand for complementary components for which the designer receives monopoly rents. If "leveraging" is not possible, then standardization of interfaces may result because backward compatibility is too constraining on designer behavior.

The analysis has several predictions about observable features of markets where interface manipulation and leveraging occur. One should expect to find intense competition for control of critical components in future systems if doing so allows a firm to design interface features that significantly slow rivals. In such cases, one should expect to find complaints about monopolist's needless periodic redesign of component interfaces, and one should expect to find the monopolist of a central component earning persistent high profits on peripheral component and maintaining market power in these markets in spite of competition in those peripheral markets. Lastly, one should expect the products to be those that do not induce much demand for complementary components far into the future. When applying these predictions, one can usefully distinguish between returns linked to the function the product performs and returns linked to design implementations made in anticipation of imitator response.

As illustration of the potential value of these insights, some old arguments about IBM's competitive advantages as a system designer were also discussed. The analysis also had potential applications to similar cases in several product markets: cameras and film formats change, car dashboards and car radios, hardware and software, or any two components where technical complementarity requires the manufacturer to consciously design the components to work together.

Future work should explore the effects of designer strategies on the demand for components and the effects of interface change on the demand for substitute systems. It should also explore how sensitive the analysis is to intertemporal substitution by less impatient consumers in the market. It should also try to understand the restrictions compatibility places on incremental innovations by designers of heterogenous products and designers of products that are partially compatible. It could show how system competition and network effects influence the success of manipulation. Finally, future analysis could also incorporate a role for third-party marketing of gateways technologies between otherwise incompatible systems. An analysis of all these issue is too involved for this introductory investigation.

Figure 1

The Costs and Benefits of Interface Manipulations Over Time

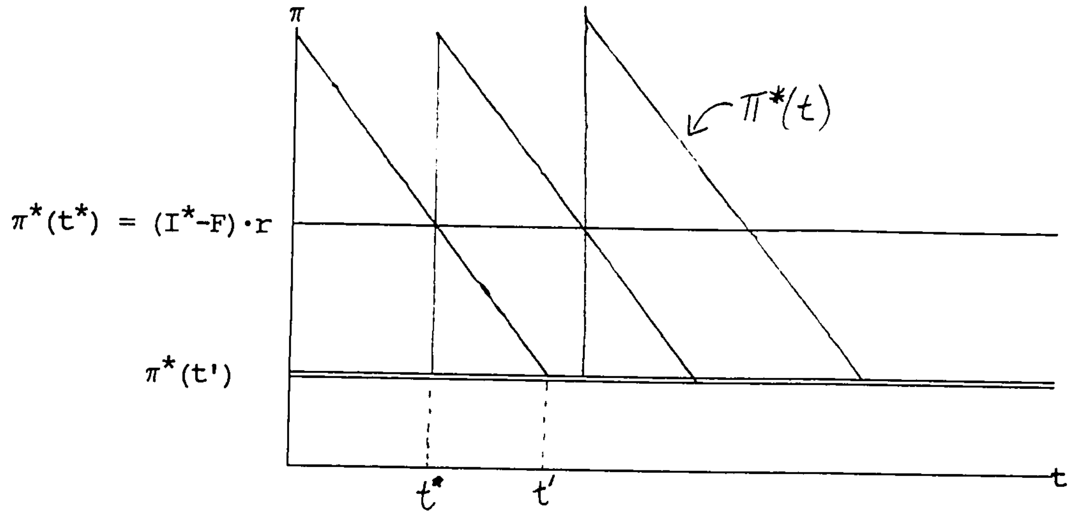
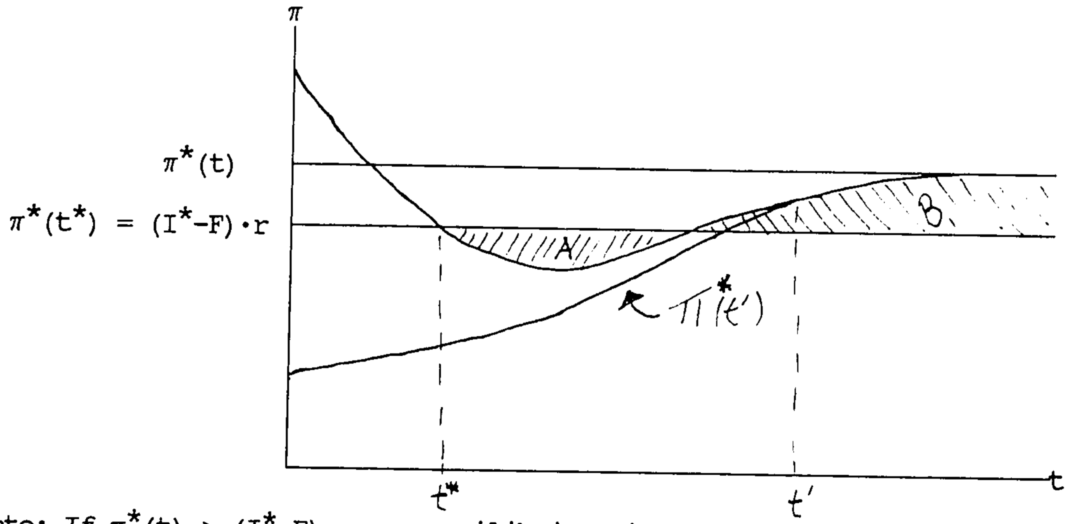


Figure 2

Interface Manipulation with a Demand for Backward Compatibility



Note: If $\pi^*(t) > (I^*-F)\cdot r$, an equilibrium will not exist if the discounted value of A + B > 0.

Endnotes

1. Scholars employing economic analysis have almost uniformly and rightly criticized this concept in the context of patent law, in which it has arisen. See, for example, the much used texts by Blair and Kaserman 1985, and Posner 1975, all following the classic studies by Bowman 1957, and Bowman 1973.

2. Automatic Radio Manufacturing Co. v. Ford Motor Co., 242 F. Supp. 852, (D. Mass.), 1965, 272 F. Supp. 744 (D. Mass. 1967) aff'd, 390 F. 2d 113 (1rst Cir) cert. denied, 391 U.S. 914 (1968).

3. Berkey Photo, Inc. v. Eastman Kodak Co. 457 F Supp. 404 (1978), 603 F. 2d. 263 (2d Cir 1979), petition for certiorari docketed, No 70-427 (U.S. Sept. 14, 1979).

4. Telex Corporation v. IBM, 367 F. Supp 258 (1973), 510 F2d 895 (1975). Memorex v. IBM, 458 F. Supp. 423 (1978) 636 F 2d. 1188 (1980). Transamerica Computer Co. v. IBM, 481 F. supp 965 (1979), especially pages 1002-1008 for a discussion of some of the legal issues concerning product design.

5. For conflicting economic interpretation of the cases, see McAdams, pp. 263-276, Brock, pp. 114-132, and Fisher et al., Chapter 8.

6. See Bowman (1973) or Posner (1976) for summaries of representative cases and the relevant laws, such as the Clayton Act (1914).

7. For a representative review of recent literature and motivations for using tie-ins other that price discrimination, see Craswell 1982, Pittman 1985, Slawson 1985, Blair and Kaserman 1985, Posner 1975, Bowman 1957, and Bowman 1973. The classic articles on bundling are Stigler 1962, Adams and Yellen 1975, and Schmalensee 1983. For a novel approach to bundling problems, see Phillips 1981. Whinston (1987) takes an approach which is in the same spirit as this paper. He examines the feasibility of foreclosure in the context of a bundling argument. However, his departure concerns the strategic consequences of dismissing constant marginal costs, while this paper focuses on the ease of entry over time.

8. For obvious reasons, this and all subsequent maximization problems are subject to the conditions that $P^1 + P^2 \geq P^B$, $P^1 \leq P^B$, and $P^2 \leq P^B$. See Adams and Yellen for a graphical representation.

9. Some studies have explored the possible behavior of imitation (Mansfield, Schwartz, and Wagner 1981, Kamien and Schwartz 1982, Levin 1985), usually suggesting that such firms are ubiquitous and have the descriptive features used below.

10. That this is a central concern of imitators is illustrated in Telex v. IBM, and Memorex v. IBM. See McAdams, pages 263-276, for an account that emphasizes plug-compatible producer's concerns, and strongly suggests the above restrictions. Also see Brock, 114-132 for a review of IBM's strategies that took advantage of this feature. The imitators feared "mid-life" product upgrades from IBM which would be incompatible with the imitations. In contrast, Fisher et al. chapter 8 argue that most of the changes were technically determined, so the emphasis on compatibility manipulation in other accounts is misplaced. See also footnote 14.

11. Brooks (1972) had such an idea in mind when he tried to dispel the myth of the "man-month" in software production. Increasing the number of men in product development does not necessarily lead to sooner delivery, i.e. diminishing or negative returns set in quickly because of coordination problems, thus limiting how quickly products could be developed. Other reasons for this lag will be discussed below. It need not be long. Mansfield et al. found that 60% of the products they surveyed met imitative competition within four years. Brock's discussion of IBM's analysis of imitative behavior also explicitly recognizes this constraint.

12. The simplest type of an imitation technology which is not instantaneous has imitating firms waiting for a fixed time spell between commitment to produce and the beginning of production. Supply of imitation at the aggregate level changes (increases) over time. Response time across firms will differ because capital commitments are needed to undertake production lines. Potential imitating firms have heterogeneous capabilities and advantages in imitating quickly and at low cost. Moreover, some firms are better able to shift production from one product to another because the imitation is closer to a product they already produce. New entrants naturally take longer. It also simply takes time to get new production processes organized without any "bugs" and get it working properly. Thus, at the introduction of X2 by the monopolist of X1 -- some imitators will be better positioned to begin production sooner than others. Over time, these capabilities will play themselves out, the better prepared imitators reaching market first until eventually the supply of X2 becomes completely competitive.

13. The assumption of passive fringe pricing behavior allows us to ignore feedback effects, thus ruling out limit pricing strategies. More complex pricing models could certainly give insight into the nature of competition, yet would add little to the purposes at hand. The existence of entry costs could accentuate the affect noted here by decelerating the rate of entry of new firms, but explicitly modelling such costs only adds the extra consideration that the profits of entry must cover the fixed costs of production. Clearly, entry is affected by the influence of the designer's behavior.

14. It is an open and theoretically difficult issue about whether the results are robust to an analysis of a market with customers with different time-preferences.

15. The conditions also guarantee that the optimal solution for any price to be charged at time t+δ, calculated at time t, will be the same optimal price charged at time t+δ. There is not time-inconsistency problem.

16. Not surprisingly, to show $\delta P2^*/\delta t < 0$ and $\delta X2^*/\delta t > 0$ is more involved. For example, it can be done for $Xi_{ii} < 0$ and $Xi_{jk} = 0$ for $i \neq j \neq k$ and close approximations. There are other less elegant ways, as well.

17. The idea is close in spirit, though it differs in market conduct it describes. In Krattenmaker and Salop (1986), for example, firms obtain monopoly power through practices, primarily arrangements with upstream suppliers, that place rivals at cost disadvantages sufficient to allow the dominant firm to raise price on its own product. In contrast, here firms rearrange the product in order to alter the ease with which rivals can enter the complementary component market. This excludes rivals and allows the dominant firm to raise the price on the complementary component, as well as the price on a bundle of its own product and the component. Rival's costs were raised, but by a different means than described in the original piece.

18. We will not explore the implications of "partial compatibility", as when some imitation of X2 does not perform all functions, like an IBM PC clone that only runs 98% of all IBM software. This is ruled out by the assumption of full imitation and that X2 is a homogenous good. Such a discussion would make the analysis an intractable introductory piece. Such goods must presumably be offered at a discount, but may be offered if the imitator cannot produce a full imitation fast enough to make entry profitable. Thus, to model this as an equilibrium outcome would involve a richer specification of imitator technology. See Berg 1988 for one analysis of "partial compatibility".

19. Thus, t^* has a unique length because this specification of the designer's problem is the same after each interface change, which is essentially a result of constant demand and the infinitely long-lived demand for the two components.

20. For example, since film is not very durable but cameras are, one might expect the demand for film of a particular format to be spread over time and be systematically related to past camera purchases. For the same reason, one might also expect demand for computer peripheral equipment with particular interfaces to be related to past purchases of compatible CPUs.

21. One may object that the above specification of old demand does not make future purchases an explicit function of past purchases. There are good reasons not to do this. Though it is generally worthwhile to consider how prices of one complementary component affect the demand for the other in the future, it is unnecessarily complicating for this model of compatibility manipulation. As illustration, consider what a general specification looks like. It demonstrates that the pricing of the integrated supplier not only accounts for the effects of prices on the profits derived from new and old customers, but also accounts for the

effects of contemporaneous prices on future growth in demand for complementary components, anticipating the future loss in residual demand in the X2 market. The only full specification of such demand functions to yield results in a form different from that which we get with the above are those in which the system designer chooses to take a price cut today in one complementary component as a means of generating later purchases. These type of pricing paths have promotional and limit pricing strategies mixed into one. In sum, the general specification let's us know the optimal price path. However, we will see that knowing that path will simply not be necessary for what follows, and the above captures the first order effect of the growth of demand. As with equation (3), the above specification is assumed as a way of ruling out promotional and limit pricing strategies as well as eliminating unnecessary computation. Thus, we can focus on more central issues.

22. For example, see the vastly different interpretations by McAdams and Fisher in the pages already cited.

23. The interpretation is novel because it contrasts sharply with the traditional price-theoretic analysis of the value of a patented innovation, where that value is taken to be the monopoly rents from the derived demand for an innovation. See Bowman 1973 for such an exposition.

24. The observation is consistent with the argument that IBM's long-standing advantages in mainframe component market derives not from the CPU monopoly (which is slowly eroding under imitation), but rather in its monopoly over system software (which has proven extremely difficult to imitate). IBM's advantage in complementary markets may be linked to control over design of the interface between system software and component functions.

25. Indeed, there may also be another misallocation of research devoted to designing central components relative to designing peripheral components.

26. See Levin, May 1985, for example.

27. In the absence of contracting problems, if the returns to Kodak for its innovation in film were solely derived from the derived demand for the innovation, then it should not matter to Kodak who packages the film. Kodak's returns should be the same with an appropriate price. However, if use of ownership over film provides Kodak with leveraging rents by preventing alternative systems competition, then Kodak should not want to market its film to others in unformatted form. Thus, one arrives at the suggested remedy.

28. Similar requirements have also been made of ATT. See Besen and Saloner 1987, pg. 62.

Computer System Switching Costs and Organizational Response: The Federal Government Experience

> "In most cases new ADP (Automatic Data Processing) technology will require modifications in system configurations, telecommunications and especially software, that can become intricate, lengthy and difficult to resolve. Hence, beyond other considerations that may push managers towards limiting competition in their procurement... managers in both the public and private sectors tend to prefer new technology that is as compatible as possible with existing technology to minimize disruption in the conversion process."
>
> -- Office of Technology Assessment (1986), page 20.

> "When there is a significant investment in software and data, the cost, risk and delay of conversion to a new architecture will be undertaken only for software which has no migration path (no upward-compatible option), or when other 'requirements' dictate that decision."
>
> -- National Bureau of Standards (1983), page 177.

I. Introduction

A switching costs is a cost incurred as a consequence of a buyer switching between alternative suppliers of essentially the same product. Economists are concerned that such costs can greatly influence vendor conduct and market outcomes[1]. Large switching costs can be responsible for greater buyer reluctance to switch between suppliers, resulting in incumbent firm behavior that is less disciplined by potential entrants. Switching costs may also play a role in buyer and supplier choices among alternative technologies. Markets may "lock-in" into technical alternatives compatible with early technological leaders and "lock-out" incompatible alternatives. This may result in sub-optimal technology choice[2].

A few examples, such as nuclear power plant design (Cowan 1988), video cassette recorders (Rosenbloom 1989) and the typewriter keyboard (David 1985, 1986) have been used to illustrate the optimal strategies for purchasers and suppliers when switching costs are high. Most observers suspect that mainframe computers could also be added to this list. What tends to be common in these cases is that users make investments in systems of compatible components -- e.g hardware-software, VCR-Cassettes, and so on. Some past investments retain their value if the user purchases more compatible components but lose their value if they purchase incompatible components.

The theoretical literature on switching costs has largely focused on the role of foresighted buyer and supplier behavior, or its instruments in an intertemporal setting -- such as short and long term contracts. Researchers have correctly recognized the importance of coordinating behavior in the past with actions in the future. Sometimes the existing theory relies heavily on the assumption of intertemporal coordination and sometimes it explores the consequences of myopic behavior. Yet, without a case study of an actual product market, it is difficult to anticipate what kind of departure from coordinated intertemporal decision-making will actually occur in practice and what will be its consequences for the dynamic "lock-in" that occurs in a product market.

This paper contributes to remedying this oversight by carefully observing and describing the actual decision-making process of a mainframe computer buyer. This case study analyzes how several general economic factors which have not been highlighted by existing literature interfere with the coordination of decision-making over time. This paper argues that not only is the presumption of coordinated decision-making inappropriate for the case studied here, but that it also leads to an incorrect understanding of how switching costs shape mainframe vendor selection.

Three observations must precede a discussion of the general issue. First one must show that mainframe computers display features associated with products subject to switching costs. This is done in the first sections of the paper and is not difficult to do. After this link with previous literature is established, the paper discusses how several factors not emphasized by the literature also shape the role of switching costs in vendor selection. First, it is incorrect to assume that buyers knew the costs of switching vendors prior to doing so. Buyers made estimates that, in the case of mainframe computers, were often subject to large errors. In effect, the price of a non-incumbent's system has uncertainty associated with it. How estimates were made and how the risks of being wrong were allocated between buyer and seller had an important effect on market outcomes. Second, switching costs are not outside the control of buyer. It is not the case that vendors, through the design of their products, solely chose the relationship between product use and future switching costs. Instead, buyers could expend (fore-sighted) effort in an extensive number of ways in advance of a future acquisition that could significantly change the value of switching costs later. Incentives to take these actions depended on many factors in practice.

Both of the above observations take on added relevance when decision-making is not coordinated within the organization acquiring a new mainframe. The role of switching costs cannot be understood without understanding all the difficulties of coordinating decisions pertaining to vendor selection with decisions pertaining to computer system use and switching costs estimation.

To illustrate this last point and provide a basis for more general conclusions, this study analyzes the coordination (or absence of it) of decision making in the Federal government regarding mainframe selection and use. As was common for mainframe purchases throughout the country in the 1970s, in the federal bureaucracy large capital purchases like mainframe computers tended to be funded by someone other than those who eventually used the system. This separation of funding and use lead to "principle-agent" type conflicts in coordination between different government organizations. Oversight committees were likely to dislike agency decisions when agencies controlled and coordinated all the decisions pertaining to system use, switching costs estimation and vendor selection. Agencies also were likely to dislike the outcomes when oversight committees controlled some of the decisions, especially those pertaining to vendor selection. In the latter case agencies had incentives to alter their management decisions and alter their estimates of switching costs in order to influence vendor choice. Whether the agency or overseer has the upper hand in this conflict determined whether switching costs greatly influenced or hardly mattered for vendor-selection decisions and by extension, whether there was a strong or weak inter-temporal link in decision-making. In other words, the outcomes of "principal-agent" conflicts were very important factors in the process by which switching costs lead to "lock-in".

The experiences of federal agencies have several features that make it ideal for this kind of study: (1) This product market is well suited to the topic. As the paper will show, late in the 1970s many Federal agencies began to experience large expenses related to the conversion of their software programming from one mainframe architecture to another. These "switching costs" raised a number of unexpected problems when replacement acquisitions were ordered; (2) There is a lot of information about these conversions. A number of examples of conversion problems at the time were closely studied for their managerial lessons by several Federal oversight agencies (The Government Accounting Office (GAO), National Bureau of Standards (NBS), and the General Services Administration (GSA)[3]). These studies left a detailed and public record of the conditions surrounding a procurement, the internal mechanisms of decision making and the solutions attempted to problems. This record provides more concentrated information about the characteristics of conversion problems than could ever be found about similar private sector acquisitions; (3) The structure of the computer procurement process highlights how switching costs shape distinct stages of the vendor selection process. This will highlight how important (and difficult) it is to coordinate decisions within a short time period and by extension, over a long time period. Moreover, there are many apparent similarities between Federal acquisition procedures and private acquisition procedures. Hence, many of the lessons from this study may carry over to the corporate mainframe market.

II. Switching costs and mainframe computers in federal agencies

This section establishes that mainframe computers in the Federal government display many of the features usually associated with product choices subject to switching costs. This section's analysis takes a view of switching costs which focuses on the relationship between buyers and technical features of the product (as compared with features of the sellers of the product). As such, the discussion will not rely on technical or institutional features peculiar to the applications of general purpose computers by federal government agencies. In other words, it focuses on the use of commercial mainframes in applications in Federal agencies that are analogous to private use[4]. In any similar settings in private industry, switching costs could still arise. We are just fortunate in this case to have documentation of the economic concerns and actions taken in response to them.

In most models of buyer choice subject to switching costs, a buyer has made investments with a supplier that continue to have positive value if the same supplier is acquired again, but have no value if any other supplier is chosen. The motivating case is the replacement of an old and technically archaic system with a new advanced similar system. Some old equipment works with a new system from the incumbent suppler, but not with equipment from any other supplier. It is as if the non-incumbent supplier charges a price, P_{ni}, for his system and the buyer pays that price, while the incumbent charges $P_i - S$ for essentially the same system, where S is the value of the old equipment the buyer will continue to use with the new system.

The simplest theoretical representation of the influence of switching costs seems to describe the costs to switching mainframe vendors. Switching costs originate from: (a) site preparation, such as raising floors, installing cooling units and electrical and communication connections; (b) training personnel to use a new vendor's unique system features; (c) dual operation of systems while one is installed, tested, and brought up to an acceptable operational level; (d) disruption of operations while new hardware is installed; (e) re-optimizing new systems to unanticipated problems; and (f) the direct costs of software conversion if existing software was a component worth preserving. Most of these expenses are minimal if one stays with the same supplier when upgrading mainframe purchases, but dual operations, disruption, unanticipated needs, and especially software conversion can be substantial if a change between suppliers of incompatible technologies occurs[5].

IIa. Technical interrelatedness and incompatibility

Previous work has identified several technical features of products which result in switching expenses and indeed, these features can be found here. First, commercial computer systems display what Paul David (1975, 1985, 1986, 1987) has called **Technical interrelatedness**: (a) tasks require a multi-component system and (b) that set of components must be technically compatible in order to work together and achieve efficiency in system performance.

It is easy to illustrate each of the two aspects of technical interrelatedness with mainframe computers. An essential technical feature of general purpose computer systems is that they are composed of a variety of compatible components -- central processor unit(s), input-output devices, communication terminals, memory devices, and "software" -- the programming that directs a system's hardware to manipulate information in a desired predictable manner. Table 1 contains a listing of the number of these components for different types of commercially available general purpose computers in use by federal agencies in 1979, clearly demonstrating that a large number of a variety of components make up a typical commercially available general purpose system[6]. Table 2 illustrates that these components typically are supplied by the same firm. Though hardware equipment complimentarities are important, the most important technical complementarily for economic is not displayed -- the relationship between hardware and software.

Evidence of the compatibility requirement is also easy to find, especially in the extensive discussions of the cases when that requirement is not satisfied. This most commonly occurs when software from one system remains incompatible with the hardware of another system. Compatibility, however, is not a dichotomous variable, but rather, compatibility describes a condition which varies by degrees. Examples of incompatibility illustrate why this is so: (a) plug and socket do not necessarily fit together physically or if they do fit together, they may not identically translate electronic signals similarly; (b) system software, the code that translates user written code into machine commands, can be incompatible with hardware architectures other than on which it is written; (c) higher level software, usually embodying commands for a particular application, can be incompatible with particular system software implementations available on the new machines; (d) higher level software that is optimize for implementation on one machine architecture can lose significant performance characteristics if implemented on another system[7]; (e) data files written in a particular form may be unsuitable for specific hardware models[8].

Because of all these levels of technical interrelatedness, buyers faced discrete choices among systems when different vendor's systems displayed **incompatible interfaces.** Switching costs arose from changes from one incompatible systems to another, not from changes in suppliers, per se. However, because there tended to be a one-to-one association of suppliers with computer mainframe technical families in the 1970 and early 80s, with a few notable exceptions, these differences tended to be indistinguishable in practice[9]. In general, users could not "mix and match" components from different manufacturers. This feature of systems was frustrating to users and well-known[10].

IIb. Incumbent's advantages

With each vendor offering incompatible systems, two factors worked to an incumbent's advantage -- another focus of previous research. **Long lived assets** obviously give the incumbent an advantage. Different components depreciate at different rates, leaving, at any point in time, some components that could continue to be used in future systems and some which required immediate scrapping. For example, the median age of processors of commercially available general purpose systems in 1979 was 6 years (mean = 6.3, s.d. = 3.6)[11]. In addition, software and programming obviously does not physically fall apart, nor is previous training immediately forgotten[12]; Once operational, software and training are useful as long as the proper complementary components are in place. Hence, the non-incumbent need supply features which the incumbent need not.

Focusing on only length of life of assets paints a somewhat deceptive picture, however. More relevant is whether that old hardware, software or training continues to have value in use. The value in use varies across each situation, depending on the demand for services the system provided and the needs to reconfigure a system to provide different services. In cases where the applications have frequently changed, rewriting all system software can be an economic alternative. However, the interrelationship between the idiosyncracies of an application and the idiosyncracies of software often constrained a change in the application, which left the incumbent as the natural supplier of complementary components and hence, at an advantage.

A second factor contributing to an incumbent's advantage involves the time it took to correct conversion problems. It is a general feature of large conversions that many improvements in software on the incumbent machine -- improvements that were added over time and through much use and testing -- cannot be easily translated to a new machine, but in fact, must be reinvented through extensive testing and trial and error aimed at learning how to take advantage of the unique features of the new system. In addition, users could not usually anticipate all the implementation difficulties of achieving a desired "look and feel" in system performance. Agency's experiences confirm observations that a general property of software design is that no other input, even a very elastic supply of programmers, can substitute for the amount of time needed to refine software through trial and error.[13] As a consequence, users were often anticipating the choice of a relatively "quick" conversion to compatible system or a longer wait (as much as a year) to a new working system from a non-incumbent.

In sum, **the foregoing was generally consistent with existing understanding of the sources of switching costs.** The analysis indicated that demands for compatible components arose from the combination of (a) system functional features which were not standardized across suppliers, and (b) technically complementary between supplier's unique features and buyer's unique applications. It has been argued that in general, software was the a long-lived asset whose functional value was reduced, if not eliminated, when a switch between incompatible technologies was made. When software was unique to the application, users had few substitutes for this essential component other than completely recreating it. If an agency held a large stock of software written for applications which were to continue with the new equipment, then there existed strong demand for backward compatible products as a means to avoid costs associated with switching between incompatible systems.

III. Observing switching and its determinants

The existence of switching costs in principle does not demonstrate their relevance in fact over a wide-range of situations. Switching costs will be relatively larger in some situations and not others. Switching costs are relevant to situations where old hardware components, particularly processors, are to be replaced with new technical generations, because this situation requires that all the software on the old system be made compatible with the new system. Switching costs also influence supplier choice if existing systems and new systems must work together in the new configuration, or if the new system will employ any software developed on the old system. Switching costs, in the sense used above, are not relevant to vendor selection where old technologies have been orphaned -- e.g. no new upgrade is available. Incumbents no longer possess advantages because the old equipment is not upward compatible with any new generation. All potential vendors and the incumbent suffer the same disadvantages. However, an orphaned system's switching costs may influence other aspects of new system choice, such as the timing of an acquisition.

What is the quantitative evidence that the switching costs were a large problems in many cases? Despite a seeming abundance of quantitative data, this is difficult to assess because the relative influence of switching costs on buyer decisions are not easy to measure. The main observable consequence of switching costs -- repeated buyer choice of the same product -- may also be explained by persistent buyer preferences for the unique services provided by a vendor. Rarely does a set of micro-level data provide direct measures of either customer's preliminary switching costs, much less buyer preferences, that permit an observer to distinguish between their relative roles in accounting for temporal patterns of purchases. Econometricians have not found methods for solving this problem other than imposing arbitrary functional forms[14].

However, we do know from several studies done of federal agency conversions from one mainframe vendor to a competing vendor that total conversion costs could be large[15]. These studies found that the total switching costs between incompatible systems could range anywhere from 22% to 250% of the price of the acquisition of the new system, depending on management practices, software quality, and other uncertain factors. By another measure, these conversion costs were anywhere from 13 to 128 times the average monthly rental for the newly acquired system (or roughly 1 - 10 times the average yearly cost)[16]. These studies leave the impression that the "distribution" of switching costs is (naturally) bounded from below and (possibly) skewed heavily upward by especially costly unpredictable circumstances.

The lowest "conversion" expenses of all the cases was much less for a "conversion" than for an "upgrade" between machines from the compatible IBM system 360 and 370 families. All the system specific features of software implemented on the 360 were preserved in the upgrade to the larger 370 machine. It totalled 1% of price of acquisition and one half the costs of one month's average rental.

There are other reasons to think that conversion expenses in federal agencies may be large. The installed stock of commercial general purpose mainframes, as shown in Table 3 is quite large, often exceeding 2000 systems in any year[17]. Table 4 show that the number of new acquisitions per year is also high enough that if switching costs are a problem it is likely that the dollar value of this problem is large for the whole Federal government. Loyalty rates for a variety of firms have also been in line with private censuses loyalty rates[18]. As noted above, this cannot be unambiguous evidence of switching costs, but it is not inconsistent either. Finally, Table 5 lists the publications by Federal oversight agencies that dealt with problems related to switching costs. It is hard to imagine that this effort would be expended if switching costs were not a problem for a substantial number of Federal agencies.

IV. Two additional factors

The following section analyzes the uncertainty surrounding the estimation of switching costs and the extent to which switching costs are a function of user behavior. The latter sections show that if decision making within an organization is not coordinated then these factors will take on added importance. To emphasize that these factors are distinctive from organizational issues, the discussion will focus on aspects of commercial computer technology and will not rely on particular features of their use in the Federal government.

IVa. Uncertainty about switching costs

Previous work has recognized one source of uncertainty: buyers make their initial investment in a vendor's system without knowing who will have the best system for their needs in the future[19]. This is clearly a factor in vendor choice, though perhaps, less so in federal agencies where the choice is often done in a formal procurement process that cannot easily accommodate long-term expectations about industry trends[20].

The records of actual conversions demonstrate that many other sources of uncertainty are relevant to vendor choice. In particular, when buyers choose between incumbent and non-incumbent vendors they typically do not know with much certainty: (1) the future realized level of switching costs; (2) the overall feasibility of conversions; or (3) the likely length of conversions (in time). This section establishes that the majority of this uncertainty can be traced to unanticipated and unavoidable problems in fine tuning newly converted software.

There was substantial technical uncertainty surrounding the feasibility of doing conversion. It was difficult to "transport" software between incompatible systems, because software typically embodied features needed for a unique application in the agency and was technically complementary to the system on which it was developed. In practice software was written for a particular set of needs and for a fixed set of users trained to use it. As a consequence, software lost some (if not all) of its functional characteristics when implemented on alternative systems, even those that were technically more advanced, as measured by benchmark programs[21]. Hence, it was difficult to easily duplicate a former system's performance on another system.[22]

Idiosyncracies of a software programs resulted in the uncertainties surrounding conversions. Large conversion expenses were inherently difficult to estimate, even for experienced conversion experts. Software conversion costs did not follow a calculable algorithm based on a readily observable feature of the code, such as the number of lines. Unanticipated costs could often be traced to (a) poor documentation of earlier programs, (b) fragile code -- held together by "bubble gum and bobby-pins" -- which was difficult to get working again until a crucial bottleneck in the code was understood, and (c) "patchwork code" -- a program composed of unsystematic additions to the basic software program, the logic of which was hard to reconstruct years after the program's various creators had departed from the agency[23]. Any one of these characteristics made it difficult to retrace the operational logic underlying old programs. Many of these problems were difficult to anticipate until software conversion was underway or largely accomplished. Thus, agencies could anticipate that there would be problems during conversion, even if they could not anticipate what those problems would be.

There was little an agency could do to reduce that uncertainty. During a conversion agencies could either (1) invest in preserving old software on new machines, or (2) invest in reinventing their software on the new hardware. Either option was undesirable, because both were time-consuming and costly activities. In-house conversions usually took too long because the required number of programmers exceeded an agency's available staff, especially with large jobs. Moreover, old staff usually had little experience with conversion and misunderstood what was required. Programmer or user knowledge about software implementation, programming procedures, and use of the old system were not necessarily useful on a new system.[24] It was no better out of house: contracting out for conversion services could be quite difficult and expensive to do because performance standards were difficult to specify in a contract, especially when the output was idiosyncratic. Conversion experts also were difficult to find, because this type of problem was not common in private industry. Many that were found were undependable and agencies frequently had to use their own staff to refine the conversion programs for which they contracted.[25]

Not surprisingly, conversion costs could be greatly under-estimated if the agency's office was not very experienced with conversion, which they frequently weren't (since conversions occur infrequently at the same location). Conversions could also be greatly underestimated if the conversion work contained several unpredictable and largely intractable problems. Thus, reduction of the uncertainty surrounding conversions became the focus of many publications and efforts.[26] For example, since the early 1980s, the Office of Software Development in the GSA has housed experts in conversion problems, people schooled in the special tools required for these problems. There is also considerable documentation of oversight and advisory agencies trying to help agencies by providing aid in the form of expert advice, bibliographic material on conversion tools, and other managerial guidance material[27]. Ironically, these effort to extinguish the blaze are the best evidence that the blaze was large.

In sum, **buyers faced unavoidable uncertainty about a non-incumbent's product quality and eventual costs of installation.** Not only could switching costs be large but a non-incumbent's eventual "price" was subject to variance. To the extent that decision-makers incurred some of these costs and to the extent that they were risk-averse, this accentuated the advantage an incumbent vendor already possessed. Hence, how estimates of conversion were made and how the risks of being wrong were allocated between buyer and seller had an important effect on decision-making, behavior and outcomes.

IVb. Converter technologies and anticipatory actions

A second feature of switching costs in mainframe computers which has not been analyzed is the extent to which buyers control the level of future switching costs. In the most models of market subject to switching costs, buyers are assumed to make a vendor/technology choice, then use the product for some time and then make another vendor choice, where the later choice may be subject to switching costs. While this partially resembles the situations observed in Federal mainframes, as demonstrated above, it misses important links between the use of a system and the costs paid to switch later. These links have special significance when decisions by the user/manager of the system are not coordinated with decisions pertaining to the selection of the next system vendor.

That users influence the level of future switching costs to some extent is not too surprising, especially if decisions are coordinated over time. When decisions are coordinated buyers can spread switching costs over time in innocuous ways. After all, if a buyer can foresee with certainty that he will be staying with the same hardware vendor in the future, he will likely telescope that decision to the present by taking anticipatory actions. For example, buyers may purchase incremental peripheral equipment for existing systems or develop software that raises switching costs (were a switch to be made). Such actions are irrelevant if the next system upgrade is with a compatible vendor in any event.

In fact, the links between user and future switching costs are more complex than represented in the simple example above. Buyers can make extensive efforts to change future switching costs and those efforts are often related to decisions made daily. In the case of federal computer system use, these efforts included standardization of component parts, greater use of higher-level language programming, and efforts to achieve modularity of software and system design and structured programming. The implication of this observation will be that two users, starting with exactly the same system, could end up with substantially different switching costs if their day to day use and practices differed in deliberate ways.

The analysis of these activities can best be placed in the context of a discussion of "converter" technologies -- bridges between incompatible systems that free the buyer to use alternative system sub-components without necessitating investment in an entirely new system. It is now well-recognized that third parties can enter with technical "bridges" to system incompatibilities. Those converters result in systems that are complementary in various sub-components, thereby integrating systems a. various costs. Converters has received some attention because their introduction has (sometimes surprising) consequences for industry dynamics[28].

Instead of focusing on converters provided by third parties, this case highlights the role of converters provided by buyers. Here two types of converter technologies were important in mainframes -- **anticipatory** and **retrospective** converters. Retrospective converters are tools for easing the pain of conversions when they take place -- often provided by parties other than the buyer or system vendor. Anticipatory converters differ in that they are installed by the buyer prior to any definite decision to switch suppliers. For technical reasons explained below anticipatory actions regarding mainframe computers can only be taken prior to the decision to go through with a conversion.

Examples of tools for retrospective conversions can be found in the Office of Software Development in the GSA, as noted earlier. This office's existence all by itself already reveals the benefits from trying to ease conversions costs once a conversion-decision has been made. In addition, we know that bringing old software installed on new machines up to performance levels achieved on the old system took time and manpower, a cost agencies willingly incurred to save software. There was also an additional opportunity cost associated with taking programmers away from their efforts to improve the performance of existing programs.

Since retrospective conversions were costly yet desired, it would not be surprising to observe farsighted actions designed to reduce the costs of anticipated retrospective conversions, should that option be likely. Examples of attempts to use anticipatory converters are seen in the attempts to make all software **"transportable"** prior to any switch -- i.e. make it perform consistently when implemented on technically comparable (or improved) new systems possessing architectures (or system software) incompatible with the one on which the software was originally developed.

Attempts occurred in both government-wide programs and at the level of an agency's office. Some government wide programs that tried to pass the costs of anticipatory conversions to vendors included: (a) attempts to standardize manufacturer implementations of higher level languages[29]; and (b) attempts to coordinate manufacturers to produce similar physical interfaces[30]. Other efforts aimed to share the costs of anticipatory conversions among agencies, including (c) efforts to standardize software at different agencies on a few well-developed programs; (d) efforts to establish software pools, where agencies can swap well-developed programs developed on one manufacturers machine. Aside from eliminating redundancy, the latter two efforts attempted to make basic software available to all agencies, no matter who the hardware manufacturer was[31]. Still other government-wide efforts attempted to change agency programming. These were connected with (e) attempts to standardize all programming in higher level languages; and (f) attempts to provide advisory material on the need for "documented, modular programming" in higher level languages.

All these efforts, if followed, were designed to result in systems that were composed of interchangeable component parts. It all was supposed to make conversions a more routine procedure, eliminate some of the uncertainty about the magnitude of switching costs, and reduce some of the need for retrospective converters. In principle, code would perform on any manufacturer's system at any time, regardless of the one on which it originally was developed and when it was developed. This is precisely what we would expect an investment anticipating conversion problems would try to do.

Such anticipatory converters were costly to do and it may have required programmer cooperation at many agencies, which was not easily forthcoming for various reasons described below. Case studies of conversions in the mid 1970s make clear that ideal programming practices were generally not followed in the past and it was difficult to get programmers to worry about future switching costs. As a consequence, most agencies' stocks of software remained compatible with a limited set of available architectures at any point in time throughout the 1970s and early 1980s[32].

In sum, previous user management decisions influenced the costs of switching vendors when a switch was made. **Users who did not make efforts to install anticipatory converters faced higher switching costs than those who did.** Hence, it is important to understand the incentives of managers to account for the value of making these efforts if conversions are a likely option.

V. User decision-making and switching costs

This paper has explored several characteristics of switching costs. The technical sources of switching costs relate to the technical interrelatedness of system components and past investments by the buyer. The analysis also focused on how switching costs are estimated prior to an acquisition and on what actions are taken in advance of an acquisition to lower future switching costs. In sum, the analysis focused on three related buyer activities. These are (1) vendor (or technical family) selection, (2) estimates of future switching costs, and (3) efforts to reduce future switching costs.

The remainder of the analysis illustrates that when an organization does not coordinate decision-making in all three activities, related decisions are likely to be at cross purposes. The remainder of the paper focuses on three related questions that arise in the context of Federal acquisitions: **(1) Who makes the vendor choice and what incentives does he have to consider switching costs in his decision? (2) Who manages a computer system's day-to-day uses and what are his incentives to worry about future switching costs? (3) Who estimates switching costs and what are the incentives of the person doing the estimates?** This section highlights the existence and absence of coordination among decisions related to these activities.

The analysis argues that agencies and oversight committees conflict over vendor selection decisions due to the funding arrangements for large capital purchases such as mainframe computers. It argues that there were unavoidable conflicts over the estimation of switching costs, and that agencies had incentives to manipulate those estimates to influence the vendor selection made by an oversight committee. It also argues that there were unavoidable conflicts concerning an agency's management of computer systems. Agencies had incentives to take (or not take) actions that influenced switching costs in the future, depending on how those actions influenced vendor selection and on who paid for switching costs. The overriding theme of this analysis is that **the role of switching costs can not be understood without understanding all the difficulties of coordinating decisions pertaining to computer system use, switching costs estimation, and vendor selection.** Thus, how the internal decision-making apparatus of the Federal government is coordinated will influence the intertemporal links in observed vendor choices.

Va. Responsibility for decisions and the procurement process

Since switching costs influence decision making at different points in the procurement process, it is useful to outline that process. Though every procurement is complex and varies, most tends to follow a set of stages[33]. In the first stage, an agency defines it needs and secures funding (i.e. secures a capital budget allocation) for its planned acquisition. Next agencies and industry representatives negotiate over fine points 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 for the lowest price is awarded the contract (Evaluation of competing proposals can differ in ways that will be described below). In the final stages, protests from losing bidders can follow and potentially start the process again somewhere in the middle.

Switching costs certainly influence the award process at the very end of the formal process. This occurs when non-incumbent vendors are required to explicitly meet in their bids the costs to the user of switching to the incompatible product.

There are a variety of bidding assessment procedures possible. Either (1) the 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), or (2) the vendors accept some responsibility for uncovered parts of switching costs, either up to the level estimated of using their own estimates.[34] In other words, the incumbent bids P_I and the buyer pays P_I, while the non-incumbent bids P_N plus some switching cost. Because of the difficulties and risks associated with outside contractors of conversion, agencies typically use the first procedure[35].

Adding a cost to every non-incumbent vendor's bid is distinct from an agency writing into bids technical requirements that constrain all bids to be compatible with existing equipment. Though the two activities may appear to result in similar outcomes because in each case the non-incumbent vendor incurs a cost in order to meet compatibility requirement, the two cases can have much different consequences. The latter action may blockade entry of non-incumbent vendors who might have bid if switching costs were estimated and added to non-incumbent vendor's bids (especially if the switching costs are under-estimated). In addition, the latter activity is more subject to protest by non-incumbent vendors, depending on the policies followed by oversight personnel at the time. At any rate, technical "bid-rigging" clearly occurs, though it is not clear how frequently it successfully occurs[36].

To organize the myriad of possibilities, let us first focus on an acquisition that is awarded through a formal process. In this case: (1) switching costs are explicitly estimated by someone within the government; and (2) agencies do the conversions themselves and add switching costs to all non-incumbent vendor's bids; (3) the agency is making the acquisition to replace an existing system, the case in which switching costs will be greatest in magnitude[37]; and (4) the acquisition is for only one site[38]. The addition of switching costs to all non-incumbent vendor's bids would seem to favor the incumbent outright. Yet, when the effects of switching costs on other stages is analyzed, as is done below, the overall effect is more difficult to assess.

Vb. Conflicts over awarding the winner of a bid

The first relevant observation concerns the assignment of responsibility for awarding the winner of a bid. Neither the agency nor the GSA, acting for the Congress, necessarily retains absolute control over the vendor selection. The typical procurement for a mainframe will be a mix of agency decision making subject to oversight approval. In principle, oversight committees can overturn the agency's decisions -- the Brooks Act (1965) gives GSA the right in principle to intervene in any procurement[39] (This is not typically done for acquisitions low in value). In other words, someone other than the eventual user could settle procedural disputes and even choose the winning system, or threaten to do so. To understand the conflicts in this process, it is useful to contrast a case where the agency awards the bid with one where the oversight committee awards the bid.

The vendor decision of an agency and an oversight committee are likely to differ. This is not surprising since computer systems are a large durable purchase that shapes agency projects and working conditions. Even if switching costs were zero, the budgeting process will produce a conflict over vendor choice between the agency making the acquisition and the oversight committees -- standing in for congress, who is funding the acquisition. The agency and the oversight committee will differ in their evaluation of the marginal value of expending funds for extra features of different vendor's systems. Each dollar of a budget has equal value to congress, while the marginal dollar value of a capital budget to an agency may be lower than the dollar value in the operating budget. The latter is more fungible and can serve many of the agency's objectives, while the former is ear-marked for the particular acquisition and the opportunity cost of expending funds on that use can be lower than those in the operating budget[40].

In addition, an agency's evaluation of the marginal value of a dollar spent from the operating budget need not be the same as congresses's evaluation of the marginal value of the dollar in the total budget. Congress assigns money to agencies in order to pay for agency tasks. Those who work with the agency may prioritize these tasks differently than the congress. Hence, the marginal value of features of a system to the agency will likely differ from the marginal value of those features to Congress.

Even if all switching costs could be precisely estimated, then the difference between an agency's and congresses's evaluation would still influence evaluation of the worth of expending money on switching between vendors. If all switching costs could be estimated, all vendors must cover them and the funds for this expense must come out of the capital budget. If agencies evaluate the marginal value of the operating budget at equal or lower values than the congress[41], then agencies would be more willing to switch than congress because they do not value as much the extra costs (covered by the capital budget) as the congress does. Thus, in a case where switching costs are estimated "with certainty" (or agencies are risk neutral), agencies may be more willing to switch than the oversight committee.

The conclusion to the above argument is interesting because it runs counter to the widely held belief that agency's unnecessarily favor incumbents. The analysis below will show that something more that just differences in budgeting is necessary to make sense of the widely-held view.

Vc. Uncertainty and switching costs estimates

Some switching costs are easily estimated and added to the costs in a formal bid and some are not. Those that can be easily estimated tend to involve concrete and physical compatibility requirements (e.g. plug and socket), where there are generally few surprises in the adaption of technologies. Call this part of switching costs S1. Those that cannot be easily incorporated into a formal proposal are usually associated with software conversion and retraining, are less tangible and more subjective, and are subject to many more errors and surprises during conversion. Call these switching costs S2. Any particular conversion is a combination of both S1 and S2. S2 can plausibly be high, since as shown above, a piece of software's idiosyncracies will produce problems, though it is never clear how costly they will be until the conversion is underway. In addition, since these estimates could be very subjective, formal rules could prohibit agencies from using their estimates in a formal evaluation of competing bids[42].

An unavoidable conflict between the overseer and the agency exists because some switching costs are unknown and their evaluation subjective, and they can be very difficult to incorporate into a formal bid, where they will influence vendor choice. Consider a case where S2 is much larger than S1, and S2 is a large fraction of the acquisition costs. In that case, no provision is made for covering S2 out of the capital budget.

If switching costs are difficult to incorporate into bids then agency and oversight committees could potentially reach different conclusions about the appropriate vendor. The allocation of switching costs between S1 and S2 will influence the vendor selection when the agency is assigned responsibility for the decision, but probably not greatly. The agency will implicitly add S2 to its own evaluation of a non-incumbent's bid and evaluation. Contrast that outcome with the situation when an oversight committee controls the awarding of bids, where S2 may not influence vendor choice. The oversight committee will only make the addition of S2 if it knows about these costs, which by the definition of the problem it does not. The evaluation of competing vendors would tend to favor switching (relative to an agency's decision), since vendor choice is only influenced by S1.

Another source of conflict arises over an agency's estimates of S1. In cases where the agency's decision is not subject to review, switching cost estimates matter to the extent that agencies allocated the costs (and risks) of switching to their capital budget rather than their operating budget. Holding the sum of S1+S2 constant, the switching costs will favor the incumbent less, the higher the percentage of those costs in S1. In cases where an oversight committee makes the vendor selection, the switching costs estimates favor the incumbent only to the extent that they are included in S1. Holding the sum S1+S2 constant, when the oversight agency makes a vendor choice, agencies will favor putting as much as possible into S1 where it will influence the vendor selection. Moreover, the larger S1 the greater the conversion expenses that will come out of a capital budget rather than an operating budget.

All these conflicts occur in the standard procurement -- when an agency makes a vendor selection and its selection is subject to review by the oversight committee. Conflicts arise when the agency chose the incumbent after considering many intangible switching costs but found it difficult to formally estimate them in an objective manner and communicate its estimates to the oversight committee. This will appear unfair to the overseer and potentially cause the agency many difficulties[43].

The conflict over estimates was heightened in a political environment in which the agency and overseer mistrusted each other's estimates. As shown, when the agency favors the incumbent it has incentives to increase S1 to include as much of S2 as possible. When it favors a non-incumbent it may have a similar incentive to minimize those costs. In contrast, the oversight committee has an incentive to be skeptical of an agency's (subjective) estimates, especially if the oversight personnel feel that the agency exaggerated S1 to favor an incumbent bidder because the agency was too lazy to search for alternatives or its programmers were over-emphasizing the effort needed to switch to get more money for the budget. In addition, an oversight committee might make an alternative estimate of switching costs if they could not understand the agency's subjective evaluation of the costs of switching or if they had a policy about what costs could legitimately be included in switching costs.

Not surprisingly, the estimates of switching costs became a point of contention between the agency and the oversight committee. A large part of developing an estimating procedure upon which both agencies and oversight committees could agree concerned who made those estimates -- whether it be the agency, the oversight committee or a third party. It is interesting to note the current resolution of this conflict resulted in the third option. Switching cost estimates today are made by personnel of the Office of Software Development, who use a systematic (and quantitative) estimation procedure. That estimate is used, whether it be right or wrong because it is systematic and verifiable, which is a virtue in an acrimonious environment[44].

In sum, for the majority of computer acquisitions in the 1970s the conflict between overseer/principal and agency altered in important ways the influence of switching costs on vendor choice. The absence of

coordination at any point in time lead to difficulties coordinating decisions over time, sometimes accentuating and sometimes de-emphasizing the tendency to "lock-in". This was manifest in various decisions with intertemporal consequences -- e.g. as the mix of long and short term contracts was determined and as estimates of economic costs were construed within the context of internal conflicts.

Vd. The reduction of future switching costs

We can now show how assignment of responsibility for vendor selection and switching cost estimates influences agency incentives to reduce future switching costs. First consider the case where vendor selection by an agency is not subject to review. In that case, the agency may very well be able to pass on much of the costs through its capital budget in the event of a switch. The agency has more incentives to save on future switching costs the more of the switching costs that come out the operating instead of the capital budget. Hence, if all switching costs were covered in the capital budget, the agency's incentives to lower future switching costs would be lower than congress would like them to be. If the agency must cover those costs out of its operating budget then its incentives to save a dollar in the future will depend on whether the agency's utility of a dollar is the same as congress', and on differences in discount rates, the degree of fore-sightedness and so on.

The situation is more complex when the assignment for the award is given to the oversight committee. Some part of switching costs will be passed into the capital budget and some part into the operating budget, depending on how those costs were estimated and passed onto the competing vendors. A foresighted agency will anticipate this estimation process and the influence of its actual switching costs on estimated costs. The agency will then be able to estimate how its actions (regarding future switching costs) influence the probability of the incumbent winning. This extra factor will mean that the agency's incentives to take effort to reduce switching costs will differ from congress's whenever the agency has some preference differences across incumbent and non-incumbent that the congress does not have[45]. As argued above, that is likely to happen often.

Given these "principal-agent" differences in incentives between oversight committees and agencies, there is a clear congressional interest in monitoring and standardizing programmer actions. Standardizing the proper anticipatory actions gives a regulatory agency like GSA a clear benchmark for determining the degree to which an agency is responsible for the magnitude of it own switching costs[46]. Moreover, the oversight agency needs to monitor an incumbent vendor's natural tendency to encourage programming practices that raise switching costs. Monitoring programming practices provides the information necessary to make these assessments. Indeed, this theme can be found throughout GAO publications[47]. Finally, some coordination efforts that benefit all agencies would have to be government wide since no single agency has the incentive to cover costs of doing them. Several such projects sponsored by NBS and GSA were mentioned earlier.

Ve. A Summary of the Analysis

The foregoing highlighted three questions: (1) How is the vendor selection made and who makes it?; (2) Who estimates switching costs?; (3) And how are future acquisitions coordinated with present programming practices? The overriding theme of the analysis was that the role of switching costs could not be understood without understanding all the difficulties of coordinating actions pertaining to each of those decisions.

The analysis clearly implies that, in a literal sense, models of foresighted coordinated behavior are inappropriate for understanding the role of switching costs in Federal acquisitions. By extension, the analysis also indicates several consequences of this new understanding: (1) If users choose their vendors and bear the costs of underestimating switching costs then the uncertainty in the costs of switching to non-incumbents will likely accentuate tendencies to "lock-in"; (2) Because management decision-making influences switching costs in the future, the differences in incentives of system managers to internalize future costs will accentuate or de-emphasize tendencies to "lock-in" to incumbents; (3) The conflict of goals and the absence of coordination between various government agencies at any point in time must necessarily lead to difficulties coordinating decisions over time. This too may accentuate or de-emphasize tendencies to "lock-in" -- e.g. as the mix of long and short term contracts is determined, as the links in intertemporal decision-making are altered, and as fundamental economic costs are construed within the context of internal conflicts.

In sum, not only are models of foresighted decision-making inappropriate in this case, but ignoring the additional factors highlighted above would lead to an incorrect understanding about the relevance of switching costs for vendor choice and the process by which switching costs lead to "lock-in".

The foregoing also has one other important implication. A complete theory of switching costs and intertemporal vendor choice in the Federal government must necessarily develop the role of several more factors. First, the bidding behavior of incumbent and non-incumbent vendors will react to the publicly known rules under which switching costs are estimated and the assignment of responsibility over the vendor choice. This makes it likely that some vendors will optimize their behavior to the rules rather than solely to the demands of agencies. Second, agencies may also distort their technical specifications to favor one or another vendor. If an agency anticipates that switching costs will not formally be accounted for in the evaluation of awards, then this is another means for agencies to influence bidding behavior. In practice this strategy is quite complex and its feasibility risky, since specifications are subject to protest and many factors influence the decisions on protests. It obviously occurs, though no government publication contains estimates of how often. Third, oversight committees and congress have several means to influence vendor choice which were not analyzed in the above framework -- including hearings over the nature of a procurement and holding up funding or delaying bureaucratic approval of related requests. Thus, when making decisions and taking actions, agencies and vendors must also anticipate all the contingent actions of the relevant oversight agencies and congressional committees. These observations imply the following: **who (overseer or an agency) has the upper hand in conflicts determines whether the importance of switching costs in vendor decision-making is accentuated or de-emphasized in practice.** It is not possible to tell what occurred most often throughout most of the 1970s without further investigation[48].

Vf. Coordination and vendor selection in general

The distinct stages of the federal procurement process for mainframe computer systems provided a favorable setting for highlighting the difficulties of coordinating different decisions at distinct stages. However, a question naturally arises concerning whether these lessons also apply to all commercial mainframe use in this time period. Its answer will illustrate factors that limit the generality of the argument.

Several factors will clearly continue to be relevant in evaluating the role of switching costs in mainframe computer selection: (1) Switching costs resulted from technical incompatibilities and asset durability, which should persist in computer use in private industry; (2) the technical reasons for uncertainty surrounding the estimation of switching costs will not change in private industry; and (3) the technical links between anticipatory converters and switching costs will not change in private industry; (4) It was not unusual in this time period for system users (or MIS departments) and the source of funding to be separate. However, what may differ is the diffusion of authority between different individuals within a private organization and the coordination mechanisms. In addition, private acquisitions may not employ a procurement process that follows such distinct and rigid stages.

Economists tend to think that budget considerations affect the incentives of workers in the public sector less than in the private. The absence of any structural incentives to realize future organization goals might lead to more myopic behavior by federal agencies than one would find in the private sector. Indeed, one might argue that a profit motive gives private firms an incentive to coordinate their decision-making across related decisions. Hence, an open issue concerns whether the diffusion of responsibility within large private organizations could influence the role of switching costs -- as found in the government -- or whether the profit motives motivated the "principal" to successfully coordinate decisions related to switching cost estimation and anticipatory converters. This latter issue is beyond the scope of this paper.

VI Summary of the paper

This paper investigated the Federal government's experience with converting from one commercial mainframe computer system vendor to another as a study in the economics of switching costs. The paper established that mainframe computer displayed features -- technical interrelatedness and durable components -- usually associated with product choice subject to switching costs. It described two more important characteristics of the product related to switching costs -- the uncertainty estimating switching costs and the degree to which the use of a system in the past determines switching costs in the future. The discussion highlighted the conflicts that arise over decisions pertaining to system management and switching costs estimation. These conflicts arise out of the different incentives of the agencies who make acquisitions and the oversight committees who fund them.

This paper argued that these additional factors not only made previous understanding of intertemporal coordination of buyer-behavior inappropriate, but lead to incorrect understanding of the relevance of switching costs for behavior leading to lock-in. First, how the estimates of switching costs were made and how the risks of being wrong were allocated between buyer and seller had an important effect on the incentives to choose an incumbent or not. Second, buyers could expend effort far in advance of a future acquisition that could significantly change the value of switching costs later, particularly if these efforts were made with some foresightedness about their influence on future vendor selection. Finally, if buyer-decisions pertaining to vendor selection were uncoordinated at any point in time, as was likely when there were "principle-agent" conflicts within an organization, they were also likely to be difficult to coordinated over time. It is unclear whether this will accentuate or de-emphasize tendencies to "lock-in".

This analysis leads to several new questions. Future work could explore whether principal-agent relationships theoretically accentuate or de-emphasize the influence of switching costs on vendor choice in private industry — e.g. whether some of coordination problems in federal bureaucracy can be overcome in organizations with a profit motive. Future work could also investigate optimal oversight behavior for acquisitions subject to switching costs that are difficult to estimate. In addition, future work could attempt to measure some of the economic factors underlying the observed vendor choice and loyalty rates in the Federal government for the light they shed on the relevance of switching costs for a wide number of cases.

Table 1.

Number of Components in Systems in 1979 Inventory
(Commercially Available General Purpose Systems only)

TYPE	SYSTEMS	MEDIAN	MEAN	ST.D.
CPU	2488	1	1.60	3.03
STORAGE	2488	8	15.8	23.6
INPUT/OUTPUT	2488	5	14.4	33.9
TERMINALS	2488	1	14.5	56.6
OTHER	2488	1	2.64	9.67

Source: ADP inventories 1979 and IDC General Purpose Surveys.

Note: Systems is the number of systems which have at least one component from this type was present. Mean is the mean number of components that appear in these sample of systems. Similarly for the median and standard deviation.

CPU stands for any central processing units.

Storage units stands for any of the following: Mag tape, core unit, drum unit, disk unit, misc. storage, multi-purpose control.

Input/Output stand for any of the following: Card reader and/or punch, papertape reader and/or punch, OCR unit, mag data recording unit, mag ink character recognition unit, data converter, media converter, plotter, printer, image handling unit, display unit, operator console, control for IO channels, misc. system IO controls.

Communications terminals stands for any of the following: Card terminal, mag tape terminal, papertape terminal, printer terminal, input console, multiplexor control, misc. terminals and related units.

Other stands for any of the following: EDPE (electronic data processing equipment), card punch, tape punch/verifier, sorter, collator, reproducer/gang punch, interpreter, misc. PCAM or EDPE and unknown.

Table 2.

Number of Components in Systems in 1979 Inventory by Manufacturer (Commercially Available General Purpose Systems)

Machine manufacturer same as system designer:

TYPE	SYSTEMS	MEDIAN	MEAN	ST.D.	PER
CPU	2476	1	1.33	1.21	99.5
STORAGE	2406	6	11.3	16.2	96.7
INPUT/OUTPUT	2410	5	12.0	27.4	96.8
TERMINALS	2382	1	10.2	41.6	95.7
OTHER	2427	1	2.27	8.85	97.5

Machine manufacturer differs from system designer:

TYPE	SYSTEMS	MEDIAN	MEAN	ST.D.	PER
CPU	155	1	4.55	9.72	0.62
STORAGE	953	2	12.9	23.2	38.3
INPUT/OUTPUT	746	2	9.23	30.9	30.0
TERMINALS	1647	1	7.95	44.0	66.2
OTHER	1962	1	1.47	3.77	78.8

Source: ADP inventories 1971-1979 and IDC General Purpose Surveys.

Note: **Systems** stands for the number of systems with at least one piece of equipment of the designated type and either made by or not made by the system designer.

Per is the percentage of systems with at least on machine of the designated type from the same or different manufacturer out of the total number of systems with any at all.

See above for remaining definitions.

Table 3

Stock of General Purpose Mainframe Systems.

MANU	71	72	73	74	75	76	77	78	79	83
TOTAL	3229	3053	3037	3860	2646	2544	2508	2565	2509	2395

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 federal owned or leased systems from external supplier.

RCA and GE systems retain their 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 somewhat.

Table 4

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

Manu	72	73	74	75	76	77	78	79	80-83	Total
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 check 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 5

<u>Oversight Reports Concerned with Conversion Problems: 1977 - 1986</u>

General Accounting Office Publications:

1977, "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.

General Services Administration Publications:

Office of Software Development and Information Technology:

1981, <u>Conversion Contracting Techniques Associated with Procurement of Replacement ADP hardware System</u>, GSA/FCSC-1/003, PB82-145079, NTIS, Sept, 1981.

1982, <u>Conversion Work Packages</u>, Report No. OSD/FCSC-82/002, July 1982.

1983, <u>Conversion Plan Outline</u>, Report No. FCSC-83-002, Jan. 83.

1983, <u>Software Conversion Lessons Learned, Volume I</u>, FCSC-83/003, 1983

1984, <u>Preparing Software Conversion Studies</u>, OIT-FCSC-84/001, 1984.

1986, <u>Conversion Cost Model (Version 4), Cost Model handbook</u>, May 30, 1986, OSDIT/FSMC-86/005

National Bureau of Standards Publications:

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

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

Endnotes

1. See Farrell (1987), Farrell and Shapiro (1988), (1989), Klemperer (1987a), (1987b), von Weizsacker (1984).

2. See Arthur (1983), (1987), Cowan (1987), David (1975) (1985), (1986).

3. Indeed, an extensive record exists. The most relevant studies for this paper include investigations on the problem from the Government Accounting Office (1977a, 1977b, 1980a, 1980b, 1981), the General Services Administration's Office of Software Development and Information Technology (1981, 1982, 1983a, 1983b, 1984, 1986), the National Bureau of Standards (1980a, 1980b, 1983), as well studies cited in the last two reports. A partial bibliography is produced in the references.

4. See Gray 1981 for a discussion of general purpose applications in the Federal government.

5. See the GAO 1980a, Appendix II, and the summary of that appendix. The typical conversion between compatible systems was represented by the IBM 360 and 370, which has low retraining and reconfiguration costs.

6. General purpose mainframe definitions are borrowed from Auerbach reports (1962-1975), Phister (1979), and especially the IDC General Purpose mainframe surveys published in the EDP Industry Reports (1974-1982), and Annual surveys of the industry (1983-1986). This choice excludes all minicomputers, small business computers, desktop systems, and systems sold primarily for dedicated applications, but does include large mainframes for applications which might be called "scientific". The source of definitions guarantees that the systems were widely diffused in the private market as well; hence, the phrase "commercially available". See Greenstein data appendix for a full definition.

7. This last trait can be partly due to the sophisticated programmer's tendency to use the most convenient features of a system when writing programs, features which need not be the same on other machines. One might expect manufacturers to encourage this programming practice as a means to raise switching costs.

8. NBS 1980.

9. The exceptions occurred with the IBM 360-compatible mainframe manufacturer Amdahl or the IBM 360 compatible RCA Spectra series. These constituted a small fraction of total sales through the early 1980s. See Table 4 for an idea of its magnitude.

10. Industry records frequently refer to the incompatibilities of the architecture and system software of the general purpose mainframes produced by IBM, Burroughs, Univac-Sperry, NCR, CDC, Honeywell, DEC and others (See Auerbach Reports, for example). A limited amount of CPU compatibility across firms did also exist (For example, the RCA 7000

series, IBM360-370 series, Amdahl and NAS all roughly fall into the same product family).

11. Of course, the average age at replacement is not the same as the expected age at replacement for all processors. In a growing population of processors, it would provide a lower bound. Only in a stationary population would the two coincide. Case studies typically talk about contracting for systems with expected lives of 6 to 8 years. See GAO 1981, for example.

12. There was an analogous phenomena in the typewriter keyboard case. David (1986) notes that the durable asset there was the memorization of keyboards by touch typist. Like software for the human mind, it was costly for some users to reprogram themselves.

13. See Brooks 1971, for a similar emphasis on the technological necessity of solving complex software design problems in sequence, rather than in parallel. Each sub-problem needs to base its approach on solutions to previous problems in the sequence.

14. See Heckman and Singer 1982 or Amemiya, page 348-54 for example.

15. The estimated and actual cost (mid-70s dollars) of software conversion alone were large: $1.5 million for software conversion at EPA, 531,000 lines of code converted for an estimated $950,000 at the Navy base in Norfolk, 125,000 lines of applications for an estimated $559,000 at the naval base in Jacksonville, 332 application programs for $486,000 was estimated at the Naval base in Pensacola but 291 programs eventually were converted for $4.5 million, 14 of 571 totally converted and many partially done at a cost of $3,4 million at the USDA in Kansas City, 571 application programs for $3.4 million, 296 programs estimated at $338,000 for the USDA in New Orleans, but which eventually came to several million, and $4.5 million for application software conversion at the VA. In contrast, the one compatible upgrade had software total conversion expenses of $13,900. These slightly overestimated net conversion costs, because even an upgrade with the same supplier will contain some switching costs, but underestimated switching costs by neglecting some non-pecuniary costs. See Appendix for a conversion costs component breakdown.

16. These are ball park estimates. The first set were computed by taking the very precise estimates of total conversion costs in the case studies and comparing them against the average system price, as listed in the IDC General purpose surveys for that year and 1981 for any earlier conversion (Purchase price estimates did not begin appearing until 1981 and most cases came from the late 70s). They came to 23%, 22%, 27%, 50%, 68%, 79%, 150%, 210%, and 250%. The second set were computed by comparing the same conversion estimates against the IDC average monthly rental for that system in the year of installation. These came to 13, 14, 32, 37, 46, 70, 72, 123, and 128 times the rental price. See appendix.

17. This is only commercial systems, or systems for which we can get information about their use in private industry. This excludes many but not all uses that are especially idiosyncratic to the government, commonly found in the Defense and Energy departments. See the appendix for a definition of commercial systems.

18. These choices are investigated more closely in the next chapter. For information on private censuses, see EDP Industry reports.

19. Only uncertainty about the next likely superior vendor has been modelled up until now. See Klemperer (1987) for one such model.

20. In addition, the time horizon for those expectations must be longer in agency use than in private industry. Federal system life are known to exceed private industry system life. See GSA 1987, 1988.

21. Examples of functional loss are numerous. GAO 1980a, reports a case of converting line for line a program that previously took three minutes that then took 45 minutes to operate on the new system. See GAO 1980a. It also reports a case where a program used to take 5 hours took 22 hours on a new system. It had to be completely rewritten to take advantage of features of the new system (and took only 3 hours when completed).

22. Strictly speaking, the application need not be a unique one, though all the examples I know typically do involve software which possess some unique features related to the application. Market supplied implementations of software on one system may also not easily transfer to another system. Suppliers of software then might absorb some switching costs if a large number of buyers switch systems. Thus, market supply of software does not eliminate switching costs, though it may spread the incidence of implicit burden between buyers and suppliers of peripheral components. David (1986) makes a similar point during his discussions about the reluctance of typing school instructors and the first touch-typists to memorize alternative (non-QWERTY) keyboards or coordinate their decisions.

23. GAO 1976, page 20-21 discusses this, often citing programs whose documentation quality was sacrificed for urgent needs of the past, or whose development was done in a patchwork and unsystematic fashion.

24. This last switching cost is typically incurred during "retraining" and does not include non-pecuniary costs such as morale or staff turnover. See GAO 1980a, page 44.

25. GAO 1980a, pages 49, 52, 51, 57, 61.

26. See GAO 1977b, GAO 1980a, GSA 1981, GSA 1982, GSA 1983a, GSA 1983b, and GSA 1984 for more information on the management and implementation of conversions and their cost components. Also see GSA 1986, for a well-developed attempt at a conversion cost algorithm, an attempt which demonstrates the inevitable complexity of doing the task in a thorough and complete manner.

27. See the NBS and OSD publications in the bibliography and the references cited within.

28. See David 1985, David 1986, David and Bunn 1987, Carlton and Klamer 1983, Farrell and Saloner 1988.

29. Despite attempts to the contrary, it appears to be common for even the fairly standardized higher level languages, such as Cobol, to get implemented in incompatible forms on different manufacturer's systems (Bob Dornan, private communication). There are a large number of FIPs publications devoted solely to this subject. See NBS 1977 for a review.

30. See NBS 1977, or any of a large number of FIPS (Federal Information Processing Standards) publications.

31. Not surprisingly, the latter two efforts have had trouble precisely because each agency tended to design and modify programs to its own unique needs, not internalizing whether another agency might want to copy it and then desire another configuration of some important element.

32. It is a puzzling that there exist no extensive discussions in public records of <u>hardware</u> solutions to system incompatibilities, e.g. what are sometimes known as translators. If it were economically viable in some situations, then one would have expected some discussion. Is this silence evidence that these were not viable or a function of the sample of problems examined by the writers in the 1970s? The sole exception is one reference to "emulation" -- imitation of one system's software by another system's. This discussion does not recommend that emulation be used as along-term solution to incompatibility problems, citing the inefficient use of hardware resources which results. It was only recommended when an essential database was embedded in an old system where conversion was difficult (See GAO 1980). Of course, there are a large number of attempts to standardize software, as seen in many FIPS publications. Some of this is anticipatory and most is not.

33. This account is based on GSA 1987, GAO 1980, appendix.

34. See appropriate OSD reports, including OSD 1981.

35. 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. In house conversions make a lot of sense. Since the establishment of the Office of Software Development, the GSA has as good an in-house expertise in conversion as probably could be found in the market. And in-house conversions will be sensitive to the needs of the agency. Moreover, outside conversion 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 expense associate with factors the outside conversion did improperly. These

expenses can potentially be high. See GAO 1981.

36. See GAO 1983 on benchmarking practices, for example.

37. This contrasts with two related decisions -- initial acquisition and capacity addition of a new system. 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 much be written for an incompatible system and cannot be borrowed from the old one. In a capacity addition, there is also the extra issue associated with loss of efficiency in joint-system performance as a consequence of the lack of integration of the systems. Though the discussion below will focus on an acquisition for replacement it is useful the keep in mind these alternatives cases.

38. GAO 1980, GSA 1983b, contain case studies of several replacement purchases. These leave the impression that most conversion are for one agency office at a time. See appendix to this paper for a summary.

39. The Brooks Act grants GSA the authority to monitor and approve any computer acquisition. GSA could go so far as to make the decision among competing vendors itself, though in many cases it did not and simply retained the right to review. See Werling (1983) for an extensive description, and GAO (1977), NBS (1977) and (1983).

40. Werling (1983) contains some interviews that suggest that this is not always the case, that some capital budgets are too small for the purchase and hence are binding.

41. Evaluated against some "numeriare".

42. See GAO 1980.

43. This is not an implausible scenario; there were many conflicts in the 1970s consistent with this model. See Werling's (1983) analysis about the inability of procurement to account for many intangibles.

44. Material to aid agencies in their conversions includes OSD (1981), (1982), (1983a), (1983b), (1984) and (1986). Ironically, a program written for an IBM PC is used to estimate conversion costs.

45. For example, if the agency favors the incumbent it may be the case that it will want to raise switching costs in order to increase the probability of getting the incumbent next time. Let the expected net benefits of the incumbent, evaluated by the agency, be $V_I(SI)$. Let the best non-incumbent be $V_N(SI)$. V_I and V_N are net of prices, which are determined in bids and are influenced by S1. Let $0 < P(S1) < 1$ be the probability of the oversight committee choosing the incumbent as a function of measured switching costs. Then the agency maximizes $V_I(S1) \cdot P(S1) + [\ 1 - P(S1)\ ] \cdot [\ V_N(S1) - S2\ ]$. The solution requires

$P(S1) \cdot [V_I' - V_N'] + V_N = - P'(S1) \cdot [V_I - V_N + S2]$. At equilibrium, the net gain in the probability of the incumbent winning is just offset by the net cost of changes in the net benefit that is altered by bidding behavior. If the overseer does not have same evaluation of the two bidders, which is not likely, the optimal amount of desired effort would not be the same. If the oversight agency does not observe S2, then it most certainly will be different.

46. See McCubbins, Noll, and Weingast (1988) on the use of procedures to monitor behavior.

47. For example, GAO (1977a), (1977b), (1977c), (1980b), (1983).

48. This topic will be further explored in the next chapter.

Did incumbents have advantages in Federal Agency Computer Procurement?

> "(An Agency's) right to determine its own (automatic data processing) requirements under the (Brooks) Act does not include the right to dictate a specific brand name of equipment as its requirement..."
>
> -- House report 94-1746 (1976), page 6.

I. Introduction.

The previous chapter argued that conflicts in goals and the absence of coordination in decision-making between government agencies was likely to interfere with coordination of decisions over time. Whether this procurement system accentuated or de-emphasized "lock-in" appeared to depend on who had the upper hand in the conflicts that occurred between the overseer and the agencies making an acquisition[1].

Though the previous chapter argued that the federal computer procurement system complicated the intertemporal relationship between vendor choices, it left open issues regarding how extensive these effects were for many actual vendor decisions in practice. There was only a brief discussion of the quantitative evidence of what actually transpired in a wide-number of acquisitions. And there was not much discussion of whether or not most actual vendor decisions, varying greatly in circumstances and goals, were consistent with behavior that produces "lock-in". This paper sheds light on these open questions by analyzing the observed relationship between previous user experience and the mainframe vendors selected by Federal agencies from 1972 through 1983.

The goal of the analysis is develop a means to empirically predict who of the five largest computer mainframe vendors an agency's office chose -- based on that agency's previous choice. The exercise will indicate something about the extent of the advantages for the incumbent which stemmed from the buyer's previous experiences with the vendor. The discussion in the paper focuses on what these measured "incumbency advantages" tell us about the degree to which agencies are "locked-in" to vendors and the degree to which agencies successfully influenced vendor selection.

Specifically, this paper develops in a multi-nomial logit model an estimate of the probability that a procurement would be won by an incumbent vendor. This probability is made a function of historical factors such as (a) the presence of a vendor at an agency's office and (b) measures of the extent of this presence. If switching costs are allowed to influence vendor choice both factors ought to positively predict future purchases from a vendor. In addition, if the same vendors repeatedly are able to satisfy a particular agency's needs and those needs or preferences cannot be measured, then previous purchases ought to also correlate with (the otherwise unmeasured) buyer satisfaction with a vendor. Of course, the latter factor will make it appear as if there is more "lock-in" then is due solely to switching costs. But under either interpretation, the extent of previous investment measures an incumbent's advantage.

As the paper will show, the remarkable thing about federal acquisitions of mainframe computers is that only the measure of an incumbent's presence significantly predicts future vendor choice. The extent of interaction does not predict future choice very well.

Moreover, the relationship between previous buyer experience and future choice differs across firms. IBM gets less of advantage from being an incumbent than its rivals. However, unlike previous research (Werling 1983), this paper uncovers evidence that limits the view that procurement was systematically biased against IBM. This new evidence shows that the Federal "bias" is probably as much a consequence of the incompatibilities in generations of IBM's product line, especially between the 1400 series and 360 family, and the government's large and extensive investment in IBM systems in the 1960s. The sum total of this evidence yields seemingly contradictory signals: The generally insignificant estimates related to the extent of investment suggest that switching costs do not influence vendor choice over a wide number of cases, while the differential treatment of sites with IBM 360/370 systems suggest the opposite. Hence, the evidence shapes in important ways the empirical interpretation of the influence of the procurement system on commercial mainframe procurement.

II. Vendor selection, Bureaucratic Conflict and Strategy

This section outlines the vendor selection process for mainframe computers. It shows that the relationship between previous user experience and future choice is complicated by the procurement process and its regulations.

Though every procurement is complex and varies, most tend to follow a set of stages[2]. In the first stage, an agency defines it needs and secures funding (i.e. secures a capital budget allocation) 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 for the lowest price is awarded the contract (Evaluation of competing proposals can differ in ways that will be elaborated below). In the final stages, protests from losing bidders can follow and potentially start the process again somewhere in the middle.

Incumbents should have an advantage in this process if switching costs are substantial[3]. Non-incumbent vendors are usually required to explicitly meet in their bids the costs of switching to the incompatible product. There are a variety of bidding assessment procedures possible. Ideally, either (1) the 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), or (2) the vendors accept some responsibility for uncovered parts of switching costs, either up to the level estimated or using their own estimates.[4] In other words, the incumbent bids P_I and the buyer pays P_I, while the non-incumbent bids P_N plus some switching cost. Because of the difficulties and risks associated with outside conversion contracts, agencies typically use the first procedure[5]. These procedures have changed over time and some of the important changes will be highlighted below.

Whether switching costs are relevant or not, there are inherent conflicts between an agency and congress over procurement[6]. This is not surprising since computer systems are a large purchase that shapes agency projects and working conditions. Another source of this conflict lies in the nature of budgeting and the assignment problem. Differences in incentives between agencies and overseer manifest themselves in different evaluations of competing vendor's bids. An agency weighs the characteristics of competing vendor's systems differently than the congress might like them to do. Because capital budgets are not fungible across projects, the value of the dollar within the capital budget need not correspond to the agency's operating budget. The marginal value of the dollar spent from the capital budget need not correspond to the congress's marginal valuation of the dollars spent by the agency. Moreover, congress assigns agencies tasks and duties to pursue, but those who work within the agency may prioritize these activities differently. 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 congress's[7].

Neither the agency nor the General Services Administration (GSA), acting for the congress, necessarily always "chooses" the vendor. The typical procurement for a mainframe will be a mix of agency decision-making subject to oversight approval. In principle, agencies can be spared any oversight (which is typical for acquisitions of low value), or the oversight committee or GSA could completely take over the evaluation procedures, as authorized under the Brooks Act (1965). In other words, someone other than the eventual user could settle procedural disputes and even choose the winning system, or threaten to do so.

Under these general arrangements for procurement, agencies and oversight committees can pursue a variety of strategies to achieve control over vendor selection. The relative value of pursuing any particular strategy will differ across situations. To understand the broad number of possibilities, it is useful to catalogue these strategies and describe their general feasibility. Agencies strategies include the following:

1. One strategy involves structuring a procurement request so that the agency controls the entire procurement process, vendor-selection included. This is typically accomplished by making procurement small in value, perhaps by breaking up a large acquisition. This is impossible to do for many large acquisitions.

2. Another strategy involves engineering a procurement so that it is sole-sourced. Sole-sourcing is a situation in which an agency avoids the latter parts of the competitive procurement process by designating one vendor as the "sole" provider of the system. This is more feasible with a procurement of small value[8], since oversight will not typically regulate them. Other arrangements with oversight committees can also justify sole-sourcing, as when there is no more than one obvious bidder on a procurement, or the agency has an "urgent" need and cannot afford to wait for a competitive bidding procedure to finish.[9]

3. If the agency is anticipating that the oversight committee will review the vendor selection decision, one means to justify choosing an

incumbent vendor involves exaggerating the costs of switching vendors[10]. After all, high switching costs justify choosing an incumbent vendor. This action alone is usually insufficient to assure that the incumbent vendor will be chosen. The strategy is too well-known and sometimes transparent. Moreover, in an acrimonious environment no such estimate would be trusted[11].

4. Another means for getting a desired vendor involves rigging the technical specifications on which bids are evaluated. This strategy can be manifested in several different ways. Benchmarks that competing vendors must pass can be tailored to one vendor's system[12]. Other aspects of the technical specifications can also be written in ways to favor one vendor[13]. This strategy is also risky since only the most subtle manipulation of specifications are not transparent to a knowledgeable observer and specifications can be subject to protest by losing bidders.

5. Another means for influencing decisions is very subtle. Agencies can manage their systems in anticipation of how management decisions influence vendor selection procedures in the future. Activities involving programming, for example, can raise or lower future switching costs, depending on the extent to which software is modular and structured and the extent to which software employs idiosyncratic features of a vendor's system[14].

Congress (and it oversight agencies) have an equally broad array of strategies that they can pursue. These include:

1. Oversight committees can take over the selection procedures altogether. After an agency has specified it needs, an oversight agency, the GSA here, could exercise it right to make the choice between competing vendor's systems. This might, for example, necessitate that the oversight committee personnel (GSA employees) estimate the costs of switching vendors and evaluate the merits of competing proposals.

2. Oversight agencies can monitor agency decisions as part of the approval process set up after the Brooks Act. Monitoring can be accomplished by several means, including: (a) Assigning a "watch dog" agency, such as the GAO, to investigate particular decisions pertaining to a procurement; (b) publicly investigating actions through hearings; (c) establishing procedures for decision-making in agencies and the basis for review of agency decisions[15]. Some forms of monitoring are more costly than others, especially those that required sufficiently trained technical personnel[16].

3. Congress can take actions designed to punish agencies for deviating from state guidelines, or at least, threaten to do so. Relevant actions include (a) public hearings designed to embarrass agency administrators, (b) direct intervention in funding requests, (c) delaying otherwise routine bureaucratic approval of an acquisition, or (d) ruling against an agency in a protest. The effectiveness of these strategies is difficult to gauge, since in practice a threat may be sufficient to

produce the desired outcome and these can be difficult to observe after the fact in government records.

In principle, the oversight agency's actions should not be designed to favor any particular bidder, though there is some reason to believe that non-incumbents may have been favored. This evidence comes from the debate over accounting for "soft numbers" -- e.g. conversion expenses, vendor reliability, future upgrade and support. To agencies, not accounting for soft numbers in a systematic way meant that strict GSA procedures were not systematically accounting for the long-term or short term costs of converting software from an old to a new manufacturer. Agencies saw this as a potentially costly oversight that resulted in "unnecessary switching"[17]. An well-known contrary opinion thought that accounting for switching costs too easily lead to restrictive competition[18].

In 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).

Given the complexity of the situation, **it is not possible to know in retrospect how much control agencies or oversight committees had over vendor choice.** Absolute control over vendor selection does not seem to lie with either "player" in the majority of cases. In practice, the oversight agency is not omnipotent, because it does not have sufficient number of personnel to effectively regulate all acquisitions[19]. Nor are agency actions rubber-stamped by the oversight committees. In any given case, agency and overseer's strategies could play themselves out in a variety of ways with a variety of outcomes.

III. A Catalogue of Outcomes

What are the consequences of present procurement procedures for the wide number of choices made over many years and in different situations? After all strategies and unobserved heterogeneity in experiences are considered, it is not clear how strong a relationship one should expect to find between previous investment and vendor choice. On the presumption that agencies tend to favor incumbents -- either due to switching costs or repeated buyer satisfaction with incumbents, one would expect a strong relationship between previous investment and future vendor choice **if agencies are generally successful in getting the systems they want.**

On the presumption that oversight rules tended to reduce the agency's ability to favor the incumbent, one would expect a weaker relationship between previous investment and future vendor choice. If GSA competitive procedures were more price-sensitive than an agency would be and focus only on necessary functions of the desired system, and weighed less the "soft numbers" -- i.e. intangible benefits of a system's vendor, such as future support, upgrades, and servicing reliability -- then **something closer to "bidding parity" might result**[20]. This outcome could be called a "levelled playing field"[21], where no incumbent had any strong advantage over its rivals.

Though it has not been stressed in this discussion so far, congressional intervention also allegedly influenced the enforcement of procedures. Though Brooks retained no formal veto (Petrillo 1982), it was widely believed that he closely monitored the GSA's actions from his position on the House Government Operations Committee, interfering with a procurement when he pleased (e.g. slowed down approval, held up funding). In particular, it was widely believed that he especially favored vendors other than IBM and that he more closely monitored a procurement when IBM was acquired, especially in an uncompetitive procurement.[22] As Werling said in his study:

> "Within the Federal (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." (pg. 262)

Hence, the cost to the agency's office of purchasing IBM equipment was raised, because of the extra procedural burden imposed on the acquisition of IBM equipment. On the presumption that IBM was systematically disfavored, then one would expect that **IBM was less able to take advantage of its incumbency position.**

The first and second hypotheses contrast the degree to which incumbent advantages such as switching costs have much of a role in any acquisition. The latter hypotheses implies, irrespective of the relevance of an incumbent's advantage in general, that IBM is at a systematic disadvantage. This paper aims to shed empirical light on these hypotheses. It will measure the relationship between a buyer's previous experience with an incumbent and his subsequent choice. It will also focus on measuring whether IBM is unique or not.

IV. An incumbent's advantage and incumbency

This section analyzes some of the basic trends in vendor choices of a newly reconstructed sample of federal system acquisitions from 1972 through 1983. It primarily investigates sales figures and "buyer loyalty rates". The analysis establishes that IBM's sales history with the Federal government is puzzling. Aggregate Federal sales and market share figures do not resemble private industry's. IBM is dominant in private industry, but not nearly so here. Moreover, an unusually high percentage of Federal agency offices who formerly used IBM make their next purchase from another vendor. This will motivate the more elaborate measurement exercise done later.

Recent estimates suggest that, with notable exceptions, a majority of government agencies use commercial mainframes for much the same tasks as their private industry counterparts.[23] To facilitate comparison between Federal agency computer system use and private industry computer system use, exceptions must be identified. The analysis below restricts attention 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[24]. 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 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.[25]

A history of computer system acquisitions was constructed by comparing successive years of federal inventories at agency offices[26]. This removed the effect of retirements, which are probably the least accurately recorded element in the inventory[27]. Table 2 presents the results of this effort. Those familiar with private sector trends from the period will find Federal Government sales figures surprising. IBM does not display dominant sales figures for this set of general purpose mainframe computer systems, a class of products it absolutely dominates in private industry! While IBM certainly is the largest supplier over the entire period, there are many years in which it is not the largest.

One other disagregate table demonstrates the uniqueness of the Federal 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% loyalty rates and all other vendors regularly displayed 60% to 80% in

International Data Corporation's (IDC) "Loyalty Surveys"[28]. What is observed here?

Table 3 compares sites with a single system vendor prior to acquisitions against their choice of vendor for the next acquisition. The table permits one to compare the loyalty rates of IBM and non-IBM vendors against trends in private industry.[29] **Incumbency tends to be good predictor of future choice.** Yet, what is striking about the table is that **IBM consistently does not have the highest loyalty rates.** In fact, the firm's sites come no where near their dominance in this time period in the private sector.

Without more information about Federal procurement, the three tables together are puzzling. Federal users made heavy investments with IBM in the 1960s, but not as much in the 1970s, while most private buyers continued to use IBM. **It is puzzling 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 in a later decade and a half.**

V. The structure behind the measurement

The statistical model presented below will attempt to be a more sophisticated version of the loyalty test in Table 3 -- more sophisticated in the sense that it will try to control for some of the variety of circumstances that influence vendor choice, but typically differ across buyers. This model will focus on the relationship between previous buyer experience and vendor choice and try to measure those factors that predict whether an agency will choose its market vendor.

Let alternative sellers be indexed by j and let i index the number of observed acquisitions. The first important assumption in the model is that all buyers associate some utility with each seller. That utility level takes the form of random utility model where $U_{ij} = u_{ij} + \epsilon_{ij}$, the components of which are specified below.

A random utility model offers a plausible and useful, if somewhat sweeping, representation of the mix of certainties and uncertainties of decision making in GSA-supervised bidding. It focuses on the broad patterns of reduced-form buyer decisions among competing alternatives. This serves the goals of the analysis well because u_{ij} can be made partly a function of an incumbent's advantages and partly a function of other measured market forces influencing the evaluation of vendors.

There are many possible sources of error. First, this random utility model abstracts from unknown bidding procedures and unobservable bureaucratic tug-of-wars, as well as the idiosyncracies of every application. Second, it also abstracts from distinctions between replacement acquisitions, expansions of existing systems, and initial acquisitions. Previous experience with a vendor influences vendor choice to different degrees in the three types of acquisitions. An acquisition to replace an existing system is the case in which switching costs will be greatest in magnitude. This contrasts with an initial acquisition and capacity addition of a new system. 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 much be written for an incompatible system and cannot be borrowed from the old one. In a capacity addition, there is also the extra issue associated with loss of efficiency in joint-system performance as a consequence of the lack of integration of the systems.

It is well known that if the random components are independent and distributed such that $\epsilon_{ij} = \exp(-\exp(-\epsilon_j))$, then the probability that a buyer will prefer j over all others must be a standard multinomial logit given by

$$(1) \quad Pr(j) = \exp(u_{ij})/[\Sigma_k \exp(u_{ik})],$$

where $\Sigma_j Pr(j) = 1$ by design (Amemiya, ch. 9). Once the u_{ij} are made a function of observable, the likelihood function for (1) is then given by

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

where Y_j is an indicator variable for the observed choice and where the functional form for u_{ij} is yet to be determined. Several remarks on the plausibility of ϵ_{ij} will be made below.

The model measures factors influencing the observed supplier choice with two different categories of measures. A vector of factors measuring heterogeneity in the extent of buyer-vendor interaction, which will proxy for an incumbent's advantages, are called X_{ij}. A vector of factors measuring heterogeneity in buyer characteristics and desired system features, are called Z_i. An incumbent's advantages will influence all suppliers in the same magnitude, while buyer characteristics will influence each vendor to different magnitudes. The variables measuring X_{ij} and Z_i are specified in the next section.

Under the above assumptions, the evaluation of a vendor is then

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

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. The discussion will generally focus on the signs of the estimates of β.

To complete the specification of the u_{ij} I make two important assumptions about its specification:

Assumption 1: The more a buyer has invested with one supplier in the past the more likely that buyer wanted 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, investing in those he prefers more. This could be because there are costs to switching to alternative vendors, for which there is abundant technical evidence[30], or because one particular vendor has always been the best at providing what the buyer needs, which is also plausible. In either event, incumbents are at an advantage, the extent of which is revealed by the extent of previous purchases of a buyer.

Assumption 2: Investments with supplier j do not affect the u_{ik} of 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 by assumption, the coefficient estimate on this X_{ij}, which is β, measures the relative weight in the buyer's preferences for a new system from vendor j. That coefficient should be positive. This second assumption is innocuous so long as competing vendors market incompatible systems, which is almost always so in the sample examined in the text. More will be said about this below.

With these two assumptions, it is operationally convenient to restrict attention to acquisitions by users who had systems from no more than a single vendor prior to the new acquisition. The advantage of this is that incumbent advantages can unambiguously be attributed to only one seller. For example, 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 was evaluating all suppliers prior to his observed choice, previous investment by a buyer with a vendor confers an extra advantage to the incumbent vendor. 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.

With the exception of IBM, all suppliers are assumed to be influenced in the same proportion by the same extent of previous experience. In order to focus on the distinctiveness of buyer-vendor relationships when IBM is the incumbent I make the following specification:

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

In effect, if an incumbent's advantages work for all suppliers but not IBM, then β will be positive but θ will not. The interpretations of the coefficients is summarized in Table 4. If a "levelled playing field" resulted from federal procurement procedures then the previous investment with firm j does not influence the probability of firm j winning a bid. That would result in estimated β and θ that are zero. If <u>incumbents are at an advantage</u> then we should observe $\beta > 0$. If IBM is at a disadvantage, then the link between previous investment and the probability of winning is not broken for any firm other than IBM. We should observe $\theta < 0$ in that case. If θ is zero then IBM is not distinctive.

Finally, since X_{ij} are dominated by measures of the demand side, one should also try to control for changes in the supply side over time or across different types of markets. In particular, the estimates should control for the likelihood a vendor will have an "off-the-shelf" system that is close to the needs of the buyer. A supply variable doing just this will be specified below.

VII. Measures and Weights

This section provides detail about the variables used to measure incumbent advantages 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.

VIIa. X_{ij}, Buyer-incumbent relationships and incumbent advantages

The X_{ij} should measure incumbency advantages, which we attribute to either switching costs or repeated revelation of buyer preference for a \particular supplier. Both are plausible, though I find it easier to discuss these variables as if they measured switching costs.

Switching costs are thought to arise because buyers are hesitant to invest in assets that are not technically complementary with their existing stock of equipment. It has been found in case studies that software conversion expenses, personnel retraining costs, and lost output during conversions, constitute the largest expenses.[31] Since these expenses generally cannot be measured (since they often are not realized) I propose to use several proxies for them. The coefficients on all these variables should be positive if they influence vendor choice. These are:

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 with new. This variable takes on the book value of owned equipment on site, adjusted for changing producer prices. This should proxy with the value of switching costs embedded in equipment, which most studies indicate can be quite important.

Years experience with a supplier: This variable equals the sum of the number of systems a buyer possesses, where each system is weighted by the total number years since the system has been possessed. This variable should proxy for the experience a user has with a supplier. It is often stated that a user is hesitant to switch to a non-incumbent after he has honed his skills with and collective knowledge about a particular supplier's equipment. In other words, this variable captures retraining costs.

Total Computing Capacity: The total number of commercially available general purpose systems on site weighted by the average system size measures something like the total computing capacity on site. I expect that the larger the capacity of the site, the greater the investment in system and applications software, and the less flexibility when buying replacements. This measure is highly correlated (.9) with the total number of systems on site.

Incumbency in providing a system: This variable indicates whether a seller has ever sold a system to a site before. Naturally, this constant is positively correlated with all the measures above, but differs in that it captures whether the act of being on location with a major commitment like a system is the advantage of incumbency (not the extent of investment as measured above). It will also capture unmeasured advantages to incumbency which are correlated across suppliers.

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

VIIIb. X_{ij} Vendor traits applied to all firms, not just incumbents

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, though less advantage than garnished from providing a system to a 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 composed of systems which principally compete against one another. These are designated by the numbers 2 through 7 in IDC's "General Purpose" mainframe system surveys[32]. 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.

There are several reasons why the coefficient on the number 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 the Federal buyers are using the systems for the same things private industry does. (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.

VIIc. Z_i. Buyer characteristics influencing the evaluation of vendors

I included the following variables to capture fundamental differences in types of buyers. Different types of buyers will evaluate each vendors product differently, and hence will influence a vendor's likelihood of winning a bid and their profitability of bidding. The coefficients on these variables are not the focus of the estimation, but it is important to specify these variables because: (1) One must try to control for some obvious differences in types of computer buyers and their requests; and (2) The coefficients are of some inherent interest because there exists no previous econometric work on computer vendor choice. I use the following:

Dedicated application (versus general management class): The government's inventory classifies systems by their application. 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. 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.

Some dedicated applications were so specialized that some suppliers ought to have more off the shelf alternatives than others. Thus, we would expect that demand for a dedicated applications should affect the probability of each supplier winning to different degrees.

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 were specialized configurations of computer equipment and different suppliers should be better providers of these than others.

Acquired system's size: Some sellers make better quality larger systems than smaller systems. The IDC system size rating proxies for this quality difference across firm which is not captured by the supply measurements.

Department of Defense: Dummies were included for each of the military branches to test a general perception that some suppliers specialized in the particular buyer needs of these departments. 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[33]. This variable correlates highly with the number of systems except at sites that have processors for tasks other than mainframe work. These sites contain more technically advanced personnel and tended to use many small processors for simple process control work, thus, having less need for commercially packaged software. Vendors with large system support may be less heavily favored at such sites.

VIII. 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 because of several factors. First, it includes acquisitions from sites where there was no system prior to the acquisition. These observations yield information about incumbent advantages when switching costs are low. Second, it excludes observations for several reasons. Not all the acquisitions at single-vendor sites could be coded with the supply variables. IDC only provides size estimates for most commercial general purpose mainframes, but not minicomputers -- even those performing mainframe-like general purpose functions. Since the data is unavailable, mini-computer acquisitions were excluded from the sample.

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. Also note that since all observations are comprised of purchases, we are also implicitly excluding 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.

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.

Acquisitions of systems designed by General Electric (GE) or RCA, or acquisitions at sites that solely contained GE and RCA systems presents 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 consequence, occasionally one finds "indecision" in the inventories involving whether GE-designed systems should be labelled as Honeywell, and likewise for RCA as Univac.

The econometrician is faced with a parallel 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 acquires continued to operate these divisions successfully post-acquisition (Fisher, McKie and Mancke, 1983). Such a move might then correctly capture a buyer purchasing Honeywell machine because of a previous investment with GE. Similarly for RCA and Univac.

To test for the (ir)relevance of this coding problem, I estimated equation (2) with 4 different samples: (1) An observation is 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 or acquired. In the latter case, GE is relabelled as a Honeywell purchase and RCA as a Univac Purchase. (3) A system is excluded if GE or RCA is 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 Purchases. (4) All RCA incumbents and purchases are relabelled as Univac, and all GE incumbents and purchases are relabelled as Honeywell and included.[34] In the tables of estimates, 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 if Amdahl and IBM were both included in the sample since the former's systems are virtually duplicates of the latter's. Fortunately, in this time period, Amdahl sales comprised such a minuscule portion of the sample, that this seems to be a small concern[35]. (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 14 acquisitions of this model series in the sample, six of which occurred at sites where IBM was incumbent. Of 11 sites where RCA was the incumbent, only two acquired systems from the IBM360 family. If this problem really is important for the estimates in practice as it is in principle, then it should show up in the estimates using different samples[36]. With a sample size of over 550, not many estimates are likely to change.

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 the four different samples. Below I summarize the results and in the next section I assess their implications for the different hypotheses about the role of procurement 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 possess some advantage in future acquisitions. As one would expect, experience with a system confers a larger advantage than experience with pieces of equipment.

In Table 7 the positive coefficient on the capacity variable provides moderate support 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[37].

We see from Table 8 that buyers who had an IBM system on site were not likely to procure an IBM system in their next purchase. The estimates in Table 8 also provide moderate evidence that extensive investment with IBM was a special handicap to IBM's sales. In particular, those with especially older systems were less likely to buy IBM again. Hence, the evidence supports the view that IBM does have less of an incumbent's advantage than its rivals.

The percentage of systems offered by a supplier in a market segment does not predict very well. This could partly be an artifact of the coding problems (counting formerly RCA and GE systems as Univac and

Honeywell may incorrectly indicate that Univac and Honeywell offer many systems) or the measure could be faulted for equally weighing all systems within a market segment when other factors probably better indicate a firm's advantage in a market segment.

In sum, the presence of an incumbent, but not the extent of that presence, provides the incumbent with an advantage. However, IBM did not share in those advantages as much as did the other major mainframe vendors.

Characteristics of the chooser: The coefficients of the influence of user characteristics are estimated relative to Burroughs, and there are few surprises. Procurement of off-the-shelf systems for non-general purpose use (dedicated applications) statistically "favors" Univac and IBM relative to Burroughs, but generally all the firms are not statistically far apart. Procurement of multi-processor systems disfavors IBM the most, which is consistent with the notion that we are likely to observe IBM at its most successful selling its 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. All of these results are not particularly 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 β and Θ 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 extent of investment with a single incumbent and the next system supplier chosen. IBM does not have as much of an incumbent's advantage as it rivals. What kind of interpretation do these estimates largely support?

Xa. Initial conclusions

What explains the significance of the incumbency variables? Two interpretations are possible. One obvious interpretation is that switching costs influence vendor choice, producing repeated selection of the incumbent by the buyer. The other is that heterogeneity in the suppliers and users could have lead decision makers to repeatedly prefer the same vendor's products for different types of needs. Different vendors repeatedly won procurement bids with the same types of buyers, though we cannot measure why with the variables in Z. This unobserved and correlated error shows up in the coefficient on the presence of an incumbent. The estimates cannot differentiate between the two contrasting interpretations.

Several other estimates modify the above conclusions. The general unimportance of each measure of the extent of an incumbent's advantage variables in Table 8 and the sign and limited importance of the extent of incumbency variables in Table 7, provides only moderate support for the role of switching costs in supplier choice. Thus, if one believes that the specification should have produced some significant results (as I did when constructing this experiment), then it easy to argue that procurement procedures "levelled the playing field". On the other hand, if one believed that switching costs did not tend to generally affect many choices in private industry in this time period, then it is easier to see these estimates as largely a reflection of market processes and not the procurement system at all.

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

Finally, the estimates in Table 8 are consistent with the view that IBM was systematically disadvantaged. Most of the estimates in Table 8 have their predicted sign, if not always significance. Moreover, the four additional variables are jointly significant at the 1% level. Hence, the estimates strongly suggest that incumbency was an advantage that IBM did not share in, especially at agency offices who had remained exclusively with IBM for a long time.

Xb. Accounting for product family

An alternative explanation for Table 8's results, particularly the SUMAGES (IBM) coefficient, emphasizes that it may just be an artifact of the sampling period and many government agency's extensive early investment in the IBM 1400 series in the 60s. That is, the age variables for IBM may be getting larger over time at sites with first and second generation mainframes, like the 1400 and 7000 series, and implicitly picking up that IBM's advantages were the same as all non-incumbents when old and not upwardly compatible IBM equipment was at an office's site[38].

To test this alternative hypothesis, the experiment in Table 8 was rerun using information about the incumbent IBM system as an additional element in X. The reports for sample 1 and sample 4 are reported in Table 9 (sample 2 and 3 do not look much different). Two dummy variables were tried: one which indicated when there was an incumbent system from the IBM 1400 series family 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 family on site (just over two thirds of all acquisitions where IBM was an incumbent). Just over 10% of all acquisitions where IBM was an incumbent had both. Only the estimates with 360/370 family dummy are reported because it was found that this specification was unambiguously superior to the alternatives[39].

The results have the same character in both 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, on net, having an IBM 360/370 as an incumbent system resulted in a situation where the incumbent's advantages were just below the advantages that any other manufacturer enjoyed on average[40]. In contrast, not having an IBM 360/370 as an incumbent system was a good predictor of not enjoying these advantages on average. In other words, when no system from the IBM 360/370 family is on site, IBM seems to face significant disadvantages as an incumbent.

This result significantly limits any interpretation of the relationship between an incumbent's advantage and repeat vendor choice. Perhaps the easiest interpretation for the estimates in Table 9 is the alternative suggested above by the significant SUMAGES variable in Table 8. In effect, agencies generally got what they wanted, even when switching costs were important. Thus, when an IBM 360/370 was on site agencies generally 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, a greater percentage of the time non-incumbent vendors, IBM's competitors, succeeded in winning the bid. Thus, the perceived IBM disadvantage in Table 8 (and elsewhere) is an artifact of the extensive government investment in 1400 series equipment in the 1960s, which did not translate into much of an advantage for IBM in the government mainframe computer market of the 1970s. In this view, the hypothesis that IBM was disadvantaged seems as much (if not more) a result of incompatibilities in generations of IBM's product line as the

disadvantage stemming from procurement procedures.

These results are also consistent with the view that government procurement procedures "levelled the playing field", but such an interpretation is quite limited by Table 9's estimates. If switching costs were not allowed to matter in large part, then the differences between sites that had IBM 360/370 family systems and those that had other IBM systems must 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 it. Moreover, the 1400 dummy **cannot** correlate with that need. Otherwise, there is no other way that incumbency with an IBM 360/370 can produce a significant positive coefficient. In this view, the hypothesis that IBM was disadvantaged by procurement procedures seems less harmful than previously suggested, particularly if procedural "biases" against IBM were most relevant when older generations of IBM equipment were on site.

One other interpretation reconciles these results with all the allegations about procedural bias against IBM. It is very possible that the allegations of bias accurately describes several prominent and well-known acquisitions. However, a reputation based on a few prominent cases need not correlate with the vast majority of acquisitions. In this view, IBM may have been disadvantaged, just not over a wide enough number of cases to affect the estimates very much on average. This may explain why in Tables 8 and 9 that IBM is still at a small disadvantage relative to other vendors (after all, the signs on the measures of the extent of investment with IBM are all negative, though small, and jointly significant). In other words, if the disadvantage to IBM operated solely through breaking the link between switching costs and repeat buyer choice then it was mostly effective in a few procurement cases and it does not seem to have been widely effective. This seems especially true in the situations where it should have had the most prominent impact, when the IBM 360/370 family systems were the incumbent systems.

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 IBM as much advantage as similar incumbency experience yielded IBM when the site had a 360/370 or as similar experience yielded other firms. Nevertheless, it makes a world of difference in the interpretation of that result if the distinctiveness resulted from regulation restricting incumbent advantages or from technical incompatibilities amongst IBM's systems. Most probably, it was a combination of both, though this experiment suggests that the latter factor may have dominated over the majority of cases.

Xc. Who had the Upper Hand?

Based on the evidence just presented, it is difficult to unambiguously infer whether agencies generally got the systems they wanted or whether the procurement system restricted the advantages pertaining to incumbency.

On the presumption that agencies favored incumbents and that that preference was correlated with the extent of investment with the incumbent, then the agencies appear to be quite 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 demonstrates that agencies were able to choose an incumbent supplier in situations where it was necessary.

If agency preferences were not correlated with the extent of investment with the incumbent, then it is difficult to infer how most internal conflicts played themselves out. 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 large. In such situations, IBM did not possess the advantage of an incumbent; (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 lead to switching costs that justified using the incumbent again.

In sum, 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 indicated that the switching costs were probably not widely important, while the latter two are consistent with the hypothesis that switching costs were. While these results did not settle all open issues, they severely limit one's interpretation of the consequences of oversight on computer procurement.

XI. Summary

This paper analyzed a newly reconstructed history of federal agency acquisitions of commercial general purpose mainframes. It investigated the empirical relationship between incumbent advantages and computer system vendor choice. It 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, provided an incumbent with an advantage. However, IBM did not share in those advantages as much as its rivals. Further estimates suggested, in contrast to previous conclusions (Werling 1983), 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 latter factors may have dominated.

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 explore statistically estimating coefficients associated with choice amongst incompatible system families, in addition to choice of suppliers. This might provide a test of the relevance of incumbent advantages due to switching between incompatible systems, rather than firms. It would be also interesting for future research to consider the costs and benefits of the Brooks Act in light of the interpretation put forward in this paper.

Table 1

System Supplier for Stock of General Purpose Systems in the 70s.

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 federal owned or leased systems from external supplier.

RCA and GE systems retain their 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 somewhat.

Table 2

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

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 check 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 formely GE and RCA systems.

Table 4

Summary of Coefficient Predictions Under Different Models

Category of Variable	Prediction	List of Variables
β, influence of choice characteristics	positive if switching costs are relevant	INVEST, SUMAGES, COMPCAP, INCUMBSYS, INCEQUIP, PERCENTSYS
θ, influence of IBM characteristics	negative if IBM is disadvantaged	INVEST IBM, SUMAGES IBM COMPCAP IBM, INCUMBSYS IBM
$\delta_j - \delta_0$, influence of buyer characterisitcs	will vary	DEDAPP, DUMMULTI, DUMAIRFAORCE, DUMNAVY, DUMARMY, DUMTCA, SUMCPU SIZE

The statistical model

(1) $\Pr(j) = \exp(u_{ij})/[\Sigma_k \exp(u_{ik})]$,

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

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

(4) If j is the incumbent, j ≠ 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.

The model estimates β, θ, and $(\delta_j - \delta_0)$, j = Burroughs, Control Data, Honeywell, IBM, and Univac, where Burroughs serves as choice 0.

Definitions of variables are given in Table 5.

Table 5
Exogneous 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
SUMAGES	Number of systems weighted by their age
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 offerred by vendor
Factors affecting IBM only	
INVEST IBM	Dollar investment in IBM
SUMAGES IBM	Number of IBM systems weighted by age
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
SUMAGES	12.08	21.42	0.00	114.00
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 2	Sample 3	Sample 4
NOBS	559	576	580	613
NUMBER BUR	93	93	95	95
NUMBER CDC	32	32	32	32
NUMBER HON	106	113	117	117
NUMBER IBM	230	230	233	233
NUMBER UNI	98	108	103	116
LOGLIKELIHOOD	-455.283	-500.214	-471.424	-528.071
Characteristics of Choice				
INVEST	-0.009*	-0.008	-0.010*	-0.008*
	(0.005)	(0.005)	(0.005)	(0.005)
COMPCAP	0.054**	0.05 **	0.06 **	0.054**
	(0.025)	(0.02)	(0.02)	(0.023)
SUMAGES	-0.001	-0.00	-0.002	-0.002
	(0.011)	(0.01)	(0.01)	(0.011)
INCUMBSYS	1.51 **	1.48 **	1.59 **	1.69 **
	(0.23)	(0.22)	(0.21)	(0.20)
INCEQUIP	1.20 **	1.04 **	1.09 **	0.83 **
	(0.26)	(0.25)	(0.25)	(0.23)
PERCENTSYS	-2.46 **	-1.23	-2.27 *	-0.45
	(1.22)	(1.15)	(1.20)	(1.12)
Factors affecting vendors differently				
CONSTANT CDC	-9.22 **	-8.90 **	-9.14 **	-8.68 **
	(1.84)	(1.82)	(1.84)	(1.82)
DEDAPPL CDC	1.25	1.22	1.27	1.31
	(1.16)	(1.13)	(1.16)	(1.12)
DUMMULTI CDC	-1.42 *	-1.47 **	-1.34 *	-1.45 **
	(0.74)	(0.73)	(0.74)	(0.72)
DUMARMY CDC	-2.39 **	-2.22 **	-2.56 **	-2.43 **
	(1.01)	(0.99)	(1.00)	(0.97)
DUMAIRFORCE C	-3.13 **	-3.28 **	-3.20 **	-3.44 **
	(1.49)	(1.47)	(1.48)	(1.46)
DUMNAVY CDC	-1.93 *	-1.90 *	-2.03 *	-2.08 *
	(1.09)	(1.07)	(1.09)	(1.06)
DUMTCA CDC	-2.30 **	-2.33 **	-2.38 **	-2.48 **
	(1.07)	(1.04)	(1.06)	(1.04)
SUMCPU CDC	0.08	0.07	0.08	0.08
	(0.05)	(0.05)	(0.05)	(0.05)
SIZE CDC	2.11 **	2.04 **	2.10 **	2.01 **
	(0.31)	(0.31)	(0.31)	(0.31)

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

Note: Samples 1, 2, 3 and 4 defined at the end of the table.

Table 7 continued

CONSTANT HON	-4.21 ** (1.16)	-4.31 ** (1.14)	-4.04 ** (1.13)	-3.97 ** (1.09)
DEDAPPL HON	0.42 (0.76)	0.54 (0.72)	0.37 (0.75)	0.53 (0.69)
DUMMULTI HON	-0.84 (0.56)	-0.95 * (0.55)	-0.84 (0.55)	-0.99 * (0.54)
DUMARMY HON	-1.07 (0.88)	-0.77 (0.86)	-1.22 (0.86)	-0.98 (0.82)
DUMAIRFORCE H	-1.62 (1.13)	-1.74 (1.11)	-1.76 * (1.12)	-2.04 * (1.09)
DUMNAVY HON	-0.04 (0.91)	-0.02 (0.89)	-0.19 (0.90)	-0.34 (0.87)
DUMTCA HON	-0.23 (0.92)	-0.21 (0.89)	-0.25 (0.90)	-0.35 (0.86)
SUMCPU HON	-0.007 (0.049)	-0.01 (0.05)	-0.01 (0.05)	-0.02 (0.05)
SIZE HON	1.24 ** (0.18)	1.24 ** (0.18)	1.23 ** (0.18)	1.23 ** (0.18)
CONSTANT IBM	-3.83 ** (1.09)	-3.93 ** (1.08)	-3.68 ** (1.07)	-3.87 ** (1.06)
DEDAPPL IBM	1.63 ** (0.59)	-1.55 ** (0.58)	1.63 ** (0.59)	1.57 ** (0.58)
DUMMULTI IBM	-2.16 ** (0.56)	-2.22 ** (0.55)	-2.06 ** (0.55)	-2.19 ** (0.55)
DUMARMY IBM	-1.34 (0.84)	-1.28 (0.82)	-1.46 * (0.83)	-1.46 * (0.81)
DUMAIRFORCE I	-3.02 ** (1.11)	-3.01 ** (1.09)	-3.11 ** (1.11)	-3.17 ** (1.09)
DUMNAVY IBM	-1.11 (0.88)	-1.02 (0.87)	-1.09 (0.87)	-1.03 (0.86)
DUMTCA IBM	-0.34 (0.83)	-0.43 (0.86)	-0.43 (0.87)	-0.58 (0.85)
SUMCPU IBM	-0.003 (0.042)	-0.00 (0.04)	-0.00 (0.04)	-0.00 (0.04)
SIZE IBM	1.05 ** (0.16)	1.08 ** (0.17)	1.03 ** (0.16)	1.10 ** (0.16)

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

Note: Samples 1, 2, 3 and 4 defined at the end of the table.

Table 7 continued

CONSTANT UNI	-2.48 *	-2.27 *	-2.20 *	-2.04 *
	(1.27)	(1.21)	(1.19)	(1.14)
DEDAPPL UNI	1.90 **	1.49 **	1.93 **	1.50 **
	(0.65)	(0.63)	(0.65)	(0.62)
DUMMULTI UNI	0.56	0.39	0.67	0.46
	(0.57)	(0.55)	(0.56)	(0.54)
DUMARMY UNI	-1.93 *	-1.35	-2.18 **	-1.67 *
	(0.99)	(0.94)	(0.94)	(0.90)
DUMAIRFORCE U	0.33	0.18	0.15	-0.05
	(1.07)	(1.04)	(1.04)	(1.00)
DUMNAVY UNI	-1.07	-0.84	-1.45	-1.23
	(1.04)	(1.00)	(1.01)	(0.96)
DUMTCA UNI	0.25	0.32	0.16	0.24
	(1.00)	(0.96)	(0.96)	(0.92)
SUMCPU UNI	0.05	0.03	0.05	0.03
	(0.04)	(0.04)	(0.04)	(0.04)
SIZE UNI	0.49 **	0.48 **	0.46 *	0.46 **
	(0.20)	(0.19)	(0.19)	(0.19)

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

Note: Sample 1 contains no acquisitions or incumbents labelled GE or RCA.

Sample 2 equals sample 1 plus all acquisitions from GE and RCA relabelled as Honeywell and Univac.

Sample 3 equals sample 1 plus all incumbents from GE and RCA relabelled as Honeywell and Univac.

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 2	Sample 3	Sample 4
NOBS	559	576	580	613
NUMBER BUR	93	93	95	95
NUMBER CDC	32	32	32	32
NUMBER HON	106	113	17	137
NUMBER IBM	230	230	233	233
NUMBER UNI	98	108	103	116
LOGLIKELIHOOD	-446.445	-491.305	-460.502	-515.797
Charcteristic of Choice				
INVEST	0.007	0.007	0.001	0.004
	(0.016)	(0.01)	(0.01)	(0.01)
COMPCAP	0.03	0.04	0.06	0.06
	(0.05)	(0.04)	(0.05)	(0.04)
SUMAGES	0.01	0.01	0.01	0.01
	(0.02)	(0.02)	(0.02)	(0.02)
INCUMBSYS	2.19 **	2.04 **	2.25 **	2.30 **
	(0.44)	(0.42)	(0.42)	(0.37)
INCEQUIP	0.77 **	0.66 **	0.64 **	0.41
	(0.31)	(0.29)	(0.30)	(0.27)
PERCENTSYS	-2.02 *	-0.78	-1.66	0.11
	(1.23)	(1.15)	(1.97)	(1.12)
Factors affecting IBM only				
INVEST IBM	-0.02	-0.02	-0.013	-0.016
	(0.02)	(0.01)	(0.017)	(0.016)
COMPCAP IBM	0.06	0.03	0.03	-0.01
	(0.06)	(0.06)	(0.06)	(0.58)
SUMAGES IBM	-0.05 *	-0.05 *	-0.06 *	-0.050*
	(0.03)	(0.03)	(0.03)	(0.028)
INCUMBSYS IBM	-1.09 *	-0.92 *	-1.18 **	-1.16 **
	(0.57)	(0.54)	(0.54)	(0.50)

* 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	-8.75 **	-8.46 **	-8.58 *	-8.19 **
	(1.87)	(1.85)	(1.87)	(1.86)
DEDAPPL CDC	1.47	1.48	1.55	1.62
	(1.20)	(1.17)	(1.19)	(1.16)
DUMMULTI CDC	-1.35 *	-1.39 *	-1.24	-1.34 *
	(0.79)	(0.77)	(0.78)	(0.77)
DUMARMY CDC	-2.37 **	-2.21 **	-2.51 **	-2.36 **
	(1.04)	(1.02)	(1.04)	(1.02)
DUMAIRFORCE C	-2.86 *	-2.97 **	-2.88 *	-3.05 **
	(1.48)	(1.46)	(1.47)	(1.46)
DUMNAVY CDC	-2.60 **	-2.53 **	-2.61 **	-2.61 **
	(1.22)	(1.20)	(1.22)	(1.20)
DUMICA CDC	-2.47 **	-2.45 **	-2.51 **	-2.56 **
	(1.10)	(1.07)	(1.09)	(1.07)
SUMCPU CDC	0.03	0.03	0.03	0.03
	(0.09)	(0.08)	(0.09)	(0.08)
SIZE CDC	2.04 **	1.97 **	2.00 **	1.91 **
	(0.31)	(0.31)	(0.31)	(0.32)
CONSTANT HON	-4.44 **	-4.56 **	-4.36 **	-4.38 **
	(1.20)	(1.18)	(1.19)	(1.15)
DEDAPPL HON	0.50	0.64	0.48	0.65
	(0.76)	(0.72)	(0.76)	(0.70)
DUMMULTI HON	-0.85	-0.97 *	-0.80	-0.97 *
	(0.58)	(0.57)	(0.57)	(0.56)
DUMARMY HON	-1.01	-0.71	-1.11	-0.83
	(0.90)	(0.87)	(0.89)	(0.85)
DUMAIRFORCE H	-1.58	-1.69	-1.65	-1.90 *
	(1.14)	(1.12)	(1.14)	(1.11)
DUMNAVY HON	0.11	-0.08	-0.19	-0.28
	(0.93)	(0.91)	(0.93)	(0.90)
DUMICA HON	-0.24	-0.20	-0.23	-0.29
	(0.93)	(0.91)	(0.93)	(0.89)
SUMCPU HON	-0.03	-0.04	-0.05	-0.05
	(0.06)	(0.06)	(0.06)	(0.06)
SIZE HON	1.29 **	1.30 **	1.28 **	1.29 **
	(0.19)	(0.19)	(0.18)	(0.19)

* 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	-3.05 **	-3.28 **	-2.82 **	-3.07 **
	(1.13)	(1.12)	(1.12)	(1.10)
DEDAPPL IBM	1.56 **	1.50 **	1.52 **	1.46 **
	(0.59)	(0.58)	(0.58)	(0.58)
DUMMULTI IBM	-2.21 **	-2.29 **	-2.07 **	-2.22 **
	(0.57)	(0.56)	(0.56)	(0.56)
DUMARMY IBM	-1.48 *	-1.40 *	-1.54 *	-1.49 *
	(0.84)	(0.82)	(0.83)	(0.82)
DUMAIRFORCE I	-3.26 **	-3.23 **	-3.27 **	-3.28 **
	(1.11)	(1.09)	(1.10)	(1.09)
DUMNAVY IBM	-1.27	-1.16	-1.19	-1.10
	(0.88)	(0.87)	(0.88)	(0.86)
DUMTCA IBM	-0.49	-0.53	-0.52	-0.60
	(0.88)	(0.86)	(0.87)	(0.86)
SUMCPU IBM	0.02	0.02	0.02	0.02
	(0.04)	(0.04)	(0.04)	(0.04)
SIZE IBM	1.07 **	1.12 *	1.04 **	-2.00 **
	(0.17)	(0.17)	(0.16)	(1.24)
CONSTANT UNI	-2.26 *	-2.14	-2.09	-2.00
	(1.32)	(1.27)	(1.29)	(1.24)
DEDAPPL UNI	1.79 **	1.39 **	1.86 **	1.45 **
	(0.66)	(0.64)	(0.66)	(0.63)
DUMMULTI UNI	0.67	0.48	0.83	0.62
	(0.60)	(0.57)	(0.60)	(0.57)
DUMARMY UNI	-2.01 *	-1.33	-2.16 **	-1.56
	(1.05)	(1.00)	(1.03)	(0.99)
DUMAIRFORCE U	0.28	0.16	1.38	0.05
	(1.12)	(1.09)	(1.08)	(1.08)
DUMNAVY UNI	-1.08	-0.78	-1.38	-1.08
	(1.08)	(1.04)	(1.08)	(1.04)
DUMTCA UNI	0.25	0.41	0.28	0.45
	(1.04)	(1.01)	(1.03)	(1.00)
SUMCPU UNI	0.04	0.03	0.04	0.02
	(0.04)	(0.04)	(0.04)	(0.04)
SIZE UNI	0.45 **	0.44 **	0.40 *	0.41 **
	(0.21)	(0.20)	(0.21)	(0.20)

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

Note: Sample 1 contains no acquisitions or incumbents labelled GE or RCA.

Sample 2 equals sample 1 plus all acquisitions from GE and RCA relabelled as Honeywell and Univac.

Sample 3 equals sample 1 plus all incumbents from GE and RCA relabelled as Honeywell and Univac.

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	-425.128	-494.374
NUMBER OF OBSERVATIONS	559	613
Characteristic of choice		
INVEST	0.007	0.004
	(0.016)	(0.01)
SUMAGES	0.009	0.010
	(0.019)	(0.018)
COMPCAP	0.03	0.06
	(0.05)	(0.05)
INCUMBSYS	2.14 **	2.28 **
	(0.45)	(0.37)
INCEQUIP	0.83 **	0.44
	(0.32)	(0.27)
PERCENTSYS	-1.24	0.91
	(1.27)	(1.16)
Factors affecting IBM only		
INVEST IBM	-0.02	-0.013
	(0.01)	(0.016)
COMPCAP IBM	0.01	-0.044
	(0.06)	(0.06)
SUMAGES IBM	-0.033	-0.031
	(0.029)	(0.028)
INCUMBSYS IBM	-2.16 **	-2.23 **
	(0.59)	(0.53)
IBM 360/370 INCUMBENT	2.17 **	2.08 **
	(0.35)	(0.33)

* 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	-8.44	-7.86 **
	(1.88)	(1.87)
DEDAPPL CDC	1.19	1.39
	(1.20)	(1.16)
DUMMULTI CDC	-1.48 *	-1.44 *
	(0.80)	(0.78)
DUMARMY CDC	-2.27 **	-2.26 **
	(1.05)	(1.02)
DUMAIRFORCE C	-3.01 **	-3.18 **
	(1.48)	(1.46)
DUMNAVY CDC	-2.76 **	-2.75 **
	(1.23)	(1.21)
DUMTCA CDC	-2.56 **	-2.67 **
	(1.10)	(1.08)
SUMCPU CDC	0.02	0.03
	(0.09)	(0.09)
SIZE CDC	1.99 **	1.86 **
	(0.32)	(0.33)
CONSTANT HON	-4.58 **	-4.55 **
	(1.22)	(1.17)
DEDAPPL HON	0.26	0.43
	(0.75)	(0.70)
DUMMULTI HON	-0.92	-1.02 *
	(0.59)	(0.57)
DUMARMY HON	-0.89	-0.72
	(0.91)	(0.86)
DUMAIRFORCE H	-1.68	-1.98 *
	(1.15)	(1.11)
DUMNAVY HON	-0.18	-0.33
	(0.94)	(0.90)
DUMTCA HON	-0.28	-0.33
	(0.94)	(0.90)
SUMCPU HON	-0.03	-0.05
	(0.06)	(0.06)
SIZE HON	1.31 **	1.31 **
	(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	-2.62 **	-2.64 **
	(1.16)	(1.12)
DEDAPPL IBM	1.29 **	1.24 **
	(0.59)	(0.58)
DUMMULTI IBM	-2.42 **	-2.36 **
	(0.59)	(0.57)
DUMARMY IBM	-1.19	-1.21
	(0.86)	(0.83)
DUMAIRFORCE I	-3.57 **	-3.53 **
	(1.13)	(1.11)
DUMNAVY IBM	-1.18	-0.99
	(0.90)	(0.87)
DUMTCA IBM	-0.37	-0.50
	(0.90)	(0.87)
SUMCPU IBM	-0.01	-0.01
	(0.04)	(0.04)
SIZE IBM	0.94 **	0.98 **
	(0.18)	(0.17)
CONSTANT UNI	-2.09	-1.86
	(1.34)	(1.25)
DEDAPPL UNI	1.54 **	1.26 **
	(0.65)	(0.63)
DUMMULTI UNI	0.66	0.63
	(0.61)	(0.58)
DUMARMY UNI	-1.89 *	-1.48
	(1.06)	(0.99)
DUMAIRFORCE U	0.25	-0.31
	(1.12)	(1.09)
DUMNAVY UNI	-1.17	-1.15
	(1.09)	(1.04)
DUMTCA UNI	0.21	0.41
	(1.04)	(1.00)
SUMCPU UNI	0.04	0.01
	(0.04)	(0.04)
SIZE UNI	0.40 *	0.36 *
	(0.21)	(0.21)

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

Note: Sample 1 contains no acquisitions or incumbents labelled GE or RCA.

Sample 4 relabels all GE and RCA acquisitions and incumbents as Honeywell and Univac.

Endnotes

1. In part, regulations that governed procurement of computer systems, i.e. the Brooks Act -- public law 89-306, enabled oversight agencies to supervise computer system acquisitions by Federal agencies. In practice, agencies could anticipate many oversight personnel's actions and had several means for favoring preferred vendors.

2. This account is based on GSA 1987, GAO 1980, appendix.

3. Switching costs are usually most relevant to a purchase of a system for replacement of an existing system.

4. See appropriate OSD reports, including OSD 1981.

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. In house conversions make a lot of sense. Since the establishment of the Office of Software Development, the GSA has as good an in-house expertise in conversion as probably could be found in the market. And in-house conversions will be sensitive to the needs of the agency. Moreover, outside conversion 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 expense associate with factors the outside conversion did improperly. These expenses can potentially be high. See GAO 1981.

6. For more detail see the previous chapter.

7. See the previous chapter for more discussion.

8. See NBS 1981 for an outline of these guidelines.

9. "Urgency" can be either real or artificial, so long as the GSA agrees to rush procurement procedures. If an agency has a computational need that must be immediately satisfied and cannot wait for a lengthy procurement process, then the GSA has been known to approve of immediate sole-sourcing. This is especially true if the agency promises to make the next acquisition competitive. Not surprisingly, agencies have been known to manufacture "urgent" needs in order to avoid using the procurement procedures (Complaints about this latter practice can be found in GAO 1976).

10. This point was developed in the previous chapter.

11. In the early part of the decade, the GSA settled on a system whereby switching costs were systematically estimated.

12. GAO 1983.

13. See Washington Post, 1/8/89, page 1, for example.

14. This point was elaborated on in the previous chapter.

15. See McCubbins, Noll, and Weingast 1987.

16. Evidence suggest that there were insufficient number of sufficiently trained personnel in GSA. See Werling (1983).

17. For an analysis of this debate, see Cabral and Greenstein, 1989.

18. 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 IBM360, 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."

19. See Werling for some related anecdotes.

20. Paul Werling (1983) wrote a thesis on the Brooks Act and argued that interpreting the Act in terms of it stated intentions misses important aspects of its implementation. Because GSA lacked sufficient personnel, the threat of GSA taking over every procurement was not often credible. Instead, GSA monitored agencies by imposing procedural requirements on all procurement and selectively enforcing those requirements. Werling argued that procedural requirements were largely forced on agencies reluctant to comply, and that they overwhelmed other agency sub-goals, irrespective of the impact on the economic efficiency of the outcome.

21. Bidding parity is a term borrowed from the theoretical literature on auctions. It describes situations where all bidders have qual probability of winning, either because the firms are identical or the auction is constructed in such a way as to disfavor the firm in a disadvantaged position.

22. Werling suggests that Brooks had a variety of reasons -- e.g. to promote industry competitiveness, IBM was undergoing an antitrust investigations, Brooks misinterpreted the idiosyncratic relationship between computer supplier and buyer as rigged bidding. One could probably imagine a few more sensible reasons for Brooks' behavior. See Werling, page 177, 262 and the discussion therein.

23. Chapter 4 statistics of NBS 1981.

24. 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 data appendix.

25. Government reports suggest, though they do not prove it conclusively, that it could partially be an artifact of increasing replacement of the many small IBM systems (first acquired in the early 60s) by larger systems made by IBM, amongst others. See NBS 1981, page 1-11, for similar estimates and a description of the trend away from smaller mainframes.

26. 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.

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

28. 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.

29. The test assumes that the federal acquisitions at different sites are independent, which is certainly not true. However, all attempted corrections did not alter any of the basic trends.

30. See the previous chapter for more detail.

31. For an overview, see the previous chapter.

32. 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.

33. Do not 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.

34. Note that this recoding will not affect the coding of the supply favorable. 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.

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

36. What this problem really points out is the difficulty of investigating incumbent firm 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.

37. For example, even if all the variables concurrently increased by one standard deviation a piece, 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.

38. One might not expect IBM to have an advantage at sites where it was an old incumbent, since upward-compatibility issues were much less compelling when switching from old IBM 1400 series and 7000 series computers to the larger 360/370 families.

39. For Sample 4, the log likelihood 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 LRT, for example).

40. 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 recorded as a negative (though not significantly), the sum of the estimates point to a slight diminished advantage for IBM when an IBM 360/370 is the incumbent system.

An Econometric Investigation of the Determinants of Procurement Procedures in Federal Mainframe Computer Acquisitions

I. Introduction

As in the previous chapter, this paper studies a newly constructed sample of commercial mainframe computer system acquisitions by federal agencies in the 1970s and early 1980s. However, this paper focuses on whether the contract for an acquisition was awarded through competitive procedures or through sole-sourcing -- contracting with a single bidder. Why do we observe sole-sourcing sometimes and competitive procedures other times for a similar class of products? How do we measure the relative importance of this choice's different determinants?

This paper advances our understanding by developing an econometric method for measuring the importance of the various economic determinants of procurement procedures. This method bridges many gaps between simple bidding models and econometric measurement. In particular, this paper develops an econometric structure for measuring an incumbent's advantage when an incumbent and his rivals bid for government contracts to supply commercial mainframe systems.

Using this method and the available data, the paper develops evidence for a new view of procurement procedure choice. The estimates show that at least several economic factors influenced the competitiveness of procurement. First, incumbents can have advantages in bidding -- which had been expected because switching costs can be quite high in this product market. However, other economic factors often were dominate. The extent of potential competition in a market segment influenced the choice of bidding procedures, as did the value of a requested procurement. As in the previous chapter, the possible effects of oversight on procurement of large value will also be highlighted, especially regarding the distinctiveness of IBM. The evidence will suggest that this is either a market where many firms offered close substitutes for IBM products, resulting in more competitive bidding, or that the Federal procurement process placed IBM at special disadvantages.

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 (1987), the econometric analysis retains the structure of behavioral models of latent discrete decisions. In this case, the discrete decision concerns an agency's choice of procedures in anticipation of a computer vendor's decision on whether or not to bid. However, the situation here requires that we employ a different class of models than did Bresnahan and Reiss; This paper uses simple bidding models as a means to shape the econometric measurement of the economic determinants of procurement procedures[1].

The paper confronts issues similar to those found in Berry (1987) and Lane (1987). As in both of those papers, this analysis is concerned with measuring the influence of a vendor's previous experiences on the ease and profitability of subsequent actions. But here the data is rich enough to permit us to measure several dimensions of experience including an incumbent's advantages across product space, supply costs, and experience with buyers. In addition, here the form of the incumbent's advantage drives the modelling strategy. Because only the behavior of the bidder who wins the bid is observed, this empirical model recovers information about the unobserved decisions of bidders who lost competitive bids.

This paper studies computer procurement not only because it is interesting in its own right, but also to inform economist's understanding of the micro-economic forces influencing the private commercial market[2]. The latter motivation is relevant in this case because the available information about federal procurement will support a more detailed analysis than could be done with public information about private acquisitions.

The paper first reviews some basic economic factors behind Federal computer procurement. Then it develops a behavioral model of bidding, where the unobserved bidding behavior of incumbent and challenger vendors guides the econometric estimation. The model is then estimated on a sample of Federal computer system acquisitions from the 1970s and early 80s. The last section reviews and interprets the estimates.

II A Simple Model of Computer Procurement Procedure Choice

The procurement process for mainframe computers is typically broken into several phases[3]: (1) A phase in which the functional requirements of an agency's office are defined in terms of technical requirements and funds are committed by an agency to an acquisition; (2) A phase in which representatives from the agency's office and vendor representatives prepares for the final solicitation by clarifying benchmarks and requirements; (3) A phase in which bids are formally requested, evaluated and awarded.

Sole-sourcing is distinguished from competition in how an agency's office proceeds through phases (2) and (3). Competition means that agencies followed procedures designed to elicit a multiple number of bidder with proposals in phase (3). In contrast, sole-sourcing typically means that an agency's office negotiated a contract with a single vendor of choice. Sole-sourcing bypassed 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 make agencies aware of options they did not know about when they receive 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 for an acquisition, though there is some debate about how much agencies care about this price savings when the acquisitions is funded from congressional capital funds. Sole-sourcing results in speedier delivery of systems -- it skips phases (2) and (3) and potentially avoiding protests and challenges that delay delivery, outcomes which participants in the process emphasize. Sole-sourcing also gives the agency absolute control over vendor choice, which is valued when competitive procedures are subject to significant oversight scrutiny and the oversight committee considered making the decision themselves.

If agencies completely controlled the choice of procurement procedures and could anticipate bidder reactions to written specifications, agencies would choose sole-sourcing when only one vendor could profitably bid on an agency's technical requirements. In such a case, there is nothing gained by using competitive procedures. Of course, the net gains to sole-sourcing diminishes when more than one vendor could profitably bid.

Two factors influence the number of (anticipated) bidders on a procurement. The supply of "off-the-shelf" alternatives for different types of requests will influence expected bidder profitability and hence, behavior. The supply of alternatives will differ depending on the type of system requested. Second, agencies can manipulate technical specifications of a procurement to try to influence competitive bidding to favor one or another vendor[4]. These technical specifications will influence the expected profitability of bidding and hence, the number of bidders. If agencies completely controlled the procurement process, one can view sole-sourcing as a case where procedures have been manipulated so that only one vendor could profitably bid.

Several departures from the above model occur because procurement is subject to oversight. Under the Brooks Act (1965), the General Services Administration (GSA) holds the right to approve of all procedures used to acquire mainframe computers, as well as rule on protests. It is widely believed that GSA discourages the use of sole-sourcing, resulting in the use of competitive procedures more often. It is also widely believed that GSA limits an agency's ability to manipulate specifications. More will be said about this later.

III A Simple Econometric Exercise

If the number of anticipated bidders distinguishes sole-sourcing from competition, the economic forces influencing bidding behavior should predict the choice of procedures.

To gain insight into the influence of economic forces 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 was 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 which resembled private industry applications of mainframes, 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 data available reveals something about an agency office's purchase history prior to this acquisition. This was supplanted 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 were sole-sourced.[8]

I will restrict attention to the 221 acquisitions in the sample that occurred at sites that had no more than one incumbent vendor[9] (41 of those were sole-sourced). This was done primarily because it results in a sample where the incumbent can be identified, which is essential for the second model analyzed below. This restriction is convenient to impose now because it allows us to compare estimates from a simple probit with estimates from a complex model that requires the restriction. It also had the secondary benefit of eliminating many multi-vendor users in the Department of Energy and Defense, leaving the 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 (IBM, Sperry-Univac, Honeywell, Burroughs, and Control Data Corporation) it is possible to get from private censuses a reasonably good idea of state of the private market for these commercial mainframes.

Using this data, I estimated a probit of competition versus sole-sourcing, using the simplest possible econometric experiment. Implicit in the statistical experiment is a behavioral model that assumes, as in phase (1) above, that buyers first write technical specifications which reflect the office's preferences between types of systems and which may or may not favor incumbent vendors. Vendors then commit to bidding, as in phase (2), anticipating a bidding game to supply an alternative, as in phase (3). Bidding costs the supplier some fixed costs, which is subsumed in the expected profits of the seller and will be parameterized later.

When choosing procurement procedures, agencies anticipate vendor's decisions to bid[11]. Bidding follows the rule:

$$(1) \quad \text{Bid if } E\pi^* > 0, \quad \text{Do not bid if } E\pi^* \leq 0,$$

where $E\pi^*$ are the expected profits, broadly interpreted as the net gains to bidding less marginal costs. $E\pi^*$ will vary depending on who bids and how many vendors bid and is assumed to be a function of characteristics of the market, incumbent advantages and costs of supplying bids.

The two observed endogenous outcomes, competition and sole-sourcing, are interpreted as procurement with one bidder and procurement with many. As outlined below, the entry of a second bidder is a function of characteristics of the vendors for systems like the one acquired and as a function of the characteristics of the type of system requested. This should provide insight into several of the simple economic forces at work.

The endogenous variable is one if the acquisition was competitive (second entrant) and zero if it is sole-sourced. The following was estimated:

$$(1) \quad \text{Prob(COMPETITION)} = \Phi(\beta_Z Z),$$

where β_Z is a vector of coefficients and Z equals a vector made up of a constant, DEDAP, INCUMBENT, SYSTEMS, SIZE, NETWORK, and IBMINC, defined below. Φ is a cumulative normal distribution function. In effect, the model assumes that the expected profits from bidding of the second entrant are normally distributed. The variables simply index when a sufficient threshold is met for a second bidder to profitably bid.

The definitions, means, variances, minimums and maximums for the variables used are presented in Tables 1 and 2. Brief definition and justifications for their use are as follows:

The number of different types of systems available (SYSTEMS): From 1976 to 1983, International data corporation (IDC) classified general purpose computer systems into six categories according to market size groupings, each group composed of systems which principally compete against one another. These are designated by the numbers 2 through 7 in IDC's "General Purpose" mainframe system surveys[12]. From each IDC survey I counted in each size category the number of vendors who offered at least one system and the total number of systems offered by each vendor. The results from this counting are shown in Table 3.[13]

This variable measures two related notions about potential supply in a market. First, a larger number of vendors per size category should predict a greater probability that one vendor bidding 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; it too should predict a greater probability of observing more than one vendor bidding. Because 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), only the systems variable was used.

Note that using the variables above 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.

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[14]. 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 activities.

Some dedicated applications were so specialized that only a few suppliers should 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[15]. If fixed costs to bidding deter vendors from bidding and firms face different fixed costs, then the larger the value of the procurement, the more likely one would expect that more vendors will bid. We have 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.[16]

The likelihood that success in one sale influences another (NETWORK): We have no direct measure of whether bidding at one agency's office influences bidding for another office's acquisitions, but we do know something about the acquisition history of similar offices in an agency. 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 acquisition. 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.[17] Measuring the acquisitions at related sites should capture to some extent how vendor bidding at one site influenced acquisitions at related sites[18].

IBM is an incumbent (IBMINC): This variable takes on the value 1 when IBM is the incumbent system vendor at a site. It captures the notion found in other work that even when controlling for all other effects, IBM seemed to be at a disadvantage[19]. The disadvantage to IBM stemmed either from the selective enforcement of procurement rules or from the increased entry in the 1970s of competitors to IBM. Approximately 40% 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%).

Competition when there is no incumbent (INCUMBENT): There is a reasonable concern that the behavior of the second entrant against another entrant may differ between the situation in which there is an incumbent who did not bid and one in which there was not an incumbent. I account for this with a dummy variable that is one when there is an incumbent and zero otherwise.

The results from estimation are presented in Table 4. They have three basic descriptive characteristics: (1) As the proxies for a valuable procurement get larger (SIZE and NETWORK), either because the system is larger or more than one system was likely involved, the probability of competition increases. A one standard deviation increase in SIZE increases the probability index by 0.582 and in NETWORK by 0.547; (2) Proxies for the ease with which vendors can quickly supply alternatives in the short run (SYSTEMS and DEDAP) predict as expected. A one standard deviation increase in SYSTEMS increases the index by 0.23. DEDAP decreases the index by 0.32; (3) Acquisitions at sites where IBM was an incumbent tend to make competitive bids in their next acquisition. IBMINC increases it by 0.57.[20]

In sum, the estimates say: how a procurement is structured (large or small value) and what kind of potential supply is readily available (thin supply or not) influences the observed competitiveness of the acquisitions (second bidder or not). There is also something unique about sites that previously used IBM. These estimates are largely consistent with the view that economic forces lie behind the choice of competitive procedures.

Unfortunately, the estimates are not entirely satisfying. They do not address how an office's preferences influence vendor bidding. If the buyer-vendor relationship influences procedure choice, incumbents should have advantages. Accounting for that advantage could alter the magnitude of effects measured above and hence, our understanding of the relative importance of the economic factors measured.

There is good reason to suspect that this is an important factor[21]. It is thought that incumbent vendors can 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. Case studies have also shown that incumbents are at advantages because buyers incur costs when switching between suppliers -- on things such as software conversion expenses, personnel retraining costs, and investment in technically complementary assets[22]. All such factors work to the incumbent's advantage, especially if agencies value incumbents for these conveniences[23].

In order to account for the importance of the buyer-vendor relationship we must distinguish between sole-sourcing with an incumbent and sole-sourcing with a non-incumbent and a competitive procurement. A buyer's previous investment with a vendor will influence each outcome in different directions. Clearly, a more extensive model than a probit is appropriate.

IV A Behavioral model with incumbent's advantages

All possible observed outcomes and the their frequency are represented in figure 1. When there is an incumbent four outcomes are possible: (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 when there is not an incumbent vendor: (SNI) There was no incumbent system vendor at a site[24] and the new acquisition was sole-sourced; (CNI) There was no incumbent vendor at the site and the new acquisition was acquired in a competitive bidding process.

What factors lead to the outcomes in Figure 1? The goal of developing the model below is to illustrate what economic behavior is sufficient for producing sole-sourcing or competition with an incumbent or challenger. This will shape the econometric model of how an incumbent's advantages interact with other economic determinants of sole-sourcing or competition in practice.

Consider first a model of bidding behavior when an incumbent system supplier exists. Solving this model requires knowing the profits of the incumbent and challenger vendors under different bidding situations -- when the incumbent bids and when he does not, and when no challenger bids, when one challenger bids and when two challengers bid. These situations are represented in figure 2. Profit functions with superscripts I and C index incumbent or challenger. Numbers index different situations. In principle, these profits are functions of characteristics of bidders and agency's manipulation of specifications.

Under five assumptions about the bidding game, three function will determine equilibrium outcomes in Figure 2. First, incumbents move first and act in accordance with a sub-game perfect equilibrium. This assumption is tantamount 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 challenger's action[25].

Second, assume that either $\pi^{I}1$ is positive or $\pi^{C}4$ is positive or both are positive. This is tantamount to incorporating one constraint the data imposes on the experiment: In a sample of acquisitions, it must be the case that at least one vendor, either an incumbent or challenger, can profitably bid on a procurement.

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: $\pi^{C}2 \leq \pi^{C}4$, $\pi^{C}3 \leq \pi^{C}5$, $\pi^{I}1 \geq \pi^{I}2 \geq \pi^{I}3$, $\pi^{C}2 \leq \pi^{C}3$, and $\pi^{C}4 \geq \pi^{C}5$. This simply imposes a constraint that any sensible model of bidding would have as implications[26].

Finally, assume that weak challengers cannot make an otherwise profitable incumbent unprofitable. This is tantamount to assuming that the inequalities $\pi^{I}2 < 0$, $\pi^{I}1 > 0$, and $\pi^{C}2 < 0$ cannot all hold at the same time. It is convenient to set the probability of this unlikely event to zero[27].

Figure 3 lists the conditions sufficient to result in an equilibrium in Figure 2 (and in one of the 6 outcomes in Figure 1). Appendix A has more detail. Despite the myriad possibilities, three profit functions are sufficient to determine a unique equilibrium in figure 1. 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 is a straightforward extension of the model implicit in the probit estimated earlier. If an incumbent bids, whether we observe competition or not depends on a challenger's profitability of bidding. If the incumbent does not bid, then competition is a function of whether a second non-incumbent can profitably bid. Of course, whether an incumbent bids or not is also endogenous.

V Econometric model

The analysis next develops an econometric model. The analysis above closely guides the form of this econometric model.

The profit functions are never observed directly, though one expects, as in the probit above, that profits are a function of characteristics of the system influencing the profitability of bidding, 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. 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.

If follows from equation (2) that

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

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.

What are the relationships of these three index functions and observed outcomes? There are two distinct cases: when there is an incumbent supplier and when there is none. When there is at least one incumbent at a site, four discrete outcomes are possible. Define four mutually exclusive endogenous variables corresponding to figures 1 and

2:

(3) SI = 1 if the incumbent is the only bidder (1 in figure 2),
SC = 1 if a challenger is the only bidder (4 in figure 2),
CI = 1 if the incumbent vendor is chosen in a competitive bid,
CC = 1 if a challenger vendor is chosen in a competitive bid,

where C and D together are situations 2, 3 or 5 in figure 2.

Two more mutually exclusive outcomes are possible when there is not an incumbent. These are defined as:

SNI = 1 if a single supplier is observed,
CNI = 1 if competition is observed.

Under the behavioral model outlined above, the probability for each event becomes:

$$
\begin{aligned}
P(SI) &= P(1) &&= [\ P(f^1 > \epsilon 1,\ f^2 < \epsilon 2)\ ],\\
P(SC) &= P(4) &&= [\ P(f^1 < \epsilon 1,\ f^5 < \epsilon 5)\ ],\\
P(CI,\ CC) &= P(2,3,\text{ or }5) &&= [\ P(f^1 > \epsilon 1, f^2 > \epsilon 2) + P(f^1 < \epsilon 1, f^5 > \epsilon 5)\ ],\\
P(SNI) &= P(5') &&= [\ P(f^5 < \epsilon 5,\ \text{cond. on no incumbunts})\ ]\\
P(CNI) &= 1 - P(5'),
\end{aligned}
$$

where P(·) represents the probability of an event, as labelled in figures 1 and 2, and P(· , ·) represents the joint probability of two events, as labelled in figure 2. The profit functions are replaced by their appropriate index measures as defined in equations (1) and (2) and all competitive outcomes are aggregated for convenience.

Letting YSI through YCNI be dummies which index the events SI through CNI, the loglikelihood for the competitiveness of an acquisition can be written as

$$LL(4) = YSI*\log[P(SI)] + YSC*\log[P(SC)] + (YCI + YCC)*\log[P(CI \text{ or } CC)] + YSNI*\log[P(SNI)] + YCNI*\log[P(CNI)]. \quad (4)$$

Naturally, the loglikelihood for an entire sample of acquisitions is the sum of all the individual loglikelihoods. It will be useful to rewrite equation (4) as

$$LL(5) = YSI*\log[P(SI)] + YSC*\log[P(SC)] + YCI*\log[P(CI \text{ or } CC)*DD] + YCC*\log[P(CI \text{ or } CC)*(1-DD)] + YSNI*\log[P(SNI)] + YCNI*\log[P(CNI)], \quad (5)$$

where DD is the probability of an incumbent winning, contingent on observing any competition. For DD which are constant across all estimates, the estimated coefficients in equations (4) and (5) should not differ, only the sum of the loglikelihood values will. LL(5) will be more convenient to estimate for certain tests explained below.

An alternative means of distinguishing between outcomes (CI) and (CC) is less arbitrary than the method in equation (5). The previous discussion tells us 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. Therefore, let

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

where PP is the probability that the incumbent both bids and wins if he profitably would bid against one challenger. This specification tries to take advantage of the extra information contained in outcome (CI), that an incumbent bid. Using the above, the new loglikelihood is

$$\text{(6)} \quad LL(6) = YSI*\log[P(SI)] + YSC*\log[P(SC)] + YCI*\log[P(CI)] + YCC*\log[P(CC)] + YSNI*\log[P(SNI)] + YCNI*\log[P(CNI)].$$

If the theoretical restrictions reasonably capture firm behavior, equation (6) ought to perform better than equation (5). A "test" of this hypothesis lets the probability of competitive outcomes be specified as:

$$P(CI) = [\, P(f^1 > \epsilon 1,\ f^2 > \epsilon 2)*(PP') + P(f^1 < \epsilon 1,\ f^5 > \epsilon 5)*DD' \,],$$
$$P(CC) = [\, P(f^1 > \epsilon 1,\ f^2 > \epsilon 2)*(1 - PP') + P(f^1 < \epsilon 1,\ f^5 > \epsilon 5)*(1-DD') \,],$$

where the above are substituted into equation (6), call it equation (7). If, after estimating (7), we can accept the hypothesis H:DD' = PP' and reject the hypothesis H:DD' = 0, then we have evidence that equation (5) explains the data as well as equation (6). If we accept and reject the reverse, then we have evidence that equation (6) is superior to equation (5).

To make estimation easier, I will assume that PP = Φ(PPP), DD = Φ(DDD), PP' = Φ(PPP') and DD' = Φ(DDD') where Φ is a normal C.D.F.

VI Measures and Weights of exogenous variables

This section defines the data used for W, X, and Z. A summary of the variables below and their predicted sign in the market model is included in Table 1. A table of the means, standard deviations, minimums, maximums and selected correlations is included in Table 2.

VIa. Characteristics of challengers and incumbents

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

Number of competitor's systems (COMPSYS): Similar to SYSTEMS, the number of systems offered by non-incumbents in the market segment of the purchase were assigned to each observation[28]. It is called COMPSYS and is included in f^5 and f^2 as W_C. In principle, it should 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 a count of the number systems offered by the incumbent in this market segment. This represents W_I. At any point in time and 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, W_I should also be included in f^2, since it should influence an incumbent's profits.

Constructing W_I and W_C 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 both were acquired, respectively by Honeywell and Sperry-Univac. It seems improper to treat GE separately from Honeywell and similarly for RCA, since the sales operations were merged. It also seems implausible 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.[29] I would be concerned only if the 3 sets of estimates differed sharply (They will not -- see appendix B).

VII b. Characteristics of requested system

These variables, labelled as Z, index whether an incumbent or challenger found it more profitable to bid on the type of procurement. DEDAP, SIZE, and NETWORK are included and were already defined above. One more variable is:

Competition when there is no incumbent (NOINCUMBENT): The fact that there was no mainframe incumbent may indicate some information contained in the knowledge that an incumbent was on site. This dummy variable is one when there is no incumbent and zero otherwise. If the estimated coefficient is zero then perhaps the fears were unfounded. This variable only appears in f^5 and only in 26 cases.

VIb. Incumbency advantages and challenger disadvantages

An incumbent's advantages can be measured when the sample only includes acquisitions by users who had systems from no more than a single vendor prior to the new acquisition. This helps identify the influence of the incumbent's advantages on the challenger and incumbent, since it is clear who the incumbent is. All measured advantages are labelled as X.

A buyer's previous investment with a vendor is a plausible and useful proxy for an incumbent's advantages because incumbent's advantages generally are not directly observed (and are often not realized) and a buyer tends to invest more extensively in a vendor he prefers. Thus, if X_i is a measure of the observed stock of equipment a buyer possesses from vendor i before acquiring a new computer system, then this stock of equipment gives an estimate of the buyer's preference for supplier i or the costs of switching to a supplier other than i. Hence, if $[X_i - X_j]$ measures the relative advantage of incumbent i over challenger j, then X_i is the only information needed since X_j is zero at single incumbent sites.

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): The greater a site's commitment to an existing stock of equipment, the more difficulty the site potentially faces when replacing old equipment with new. 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 EXPERIENCE2): This variable equals the average age of systems a buyer possesses. Since there are only a few system at most sites, this variable usually equals the age of the system. It should proxy for the experience a user has with a supplier. It is often stated that a user is hesitant to switch to a non-incumbent after he has honed his skills with and collective knowledge about a particular supplier's equipment. In other words, this variable captures retraining costs. However, it is also often stated that the value of experience with a supplier depreciates rapidly after systems become especially old. Hence, a squared term was included to test for this effect. The first coefficient should be opposite the sign of the second.

Total Computing Capacity (CAPACITY): The total number of commercially available general purpose systems on site weighted by the average system size measures something like 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)[30].

IBM is an incumbent (IBMINC): This is defined as above.

VII The specification of the index functions

To summarize, WI includes INCUMBSYS; WC includes COMPSYS; Z includes DEDAP, NETWORK, SIZE, and NOINCUMB; X includes INVEST, CAPACITY, EXPERIENCE, EXPERIENCE2, and IBMINC[31]. 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:

$$(8) \quad f^5(W,Z) = \beta 5 + \beta_{WC}*W_C + \beta_Z*Z,$$

where W_C and Z are COMPSYS, DEDAP, SIZE, NETWORK, and NOINCUMB. There is no reason to expect this index of challenger behavior to be a function of incumbent advantages.

The index for 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, which I parameterize with the vector X. f^2 is specified as follows:

$$(9) \quad f^2(W,Z,X) = \beta 2 + \beta'_{WI}*W_I + \Gamma*[\beta_{WC}*WC + \beta_Z*Z] + \beta_X*X,$$

where $\Gamma > 0$ is some proportionality factor, and where β_X*X indexes the change in the likelihood when a challenger competes against an incumbent. W_I includes INCSYS. The factors in W_C 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 (see below), 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 are especially important deterrents to challenger bidding. X includes INVEST, CAPACITY, EXPERIENCE, EXPERIENCE2, and IBMINC.

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

$$(10)\quad f^1(W,Z,X) = \beta 1 + \beta_{WI}*WI + \tau*[\beta'_{WC}*W_C + \beta_Z*Z - \beta_X*X],$$

where $\tau > 0$ is another proportionality factor and WI includes INCSYS. Though τ 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. Notice that an alternative for equation (10) could be

$$(10')\quad f^1(W,Z,X) = \beta 1 + \beta_{WI}*WI + \tau*[\beta'_{WC}*W_C + \beta_Z*Z] - \Omega[\beta_X*X],$$

where $\Omega > 0$ and $\tau > 0$ are different factors of proportionality.

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 (8), (9), and (10) become

$$(11)\quad f^{5'}(W,Z) = [\beta 5 + \beta_{WC}*WC + \beta_Z*Z]/\sigma 5,$$
$$(12)\quad f^{2'}(W,Z,X) = [\beta 2 + \Gamma*(\beta_{WI}*WI + \beta_{WC}*W_C + \beta_Z*Z) + \beta_X*X]/\sigma 2, \text{ and}$$
$$(13)\quad f^{1'}(W,Z,X) = [\beta 1 + \beta_{WI}*WI + \tau*(\beta'_{WC}*W_C + \beta_Z*Z - \beta_X*X)]/\sigma 1,$$

where the errors are now $\mu1 = \epsilon1/\sigma1$, $\mu2 = \epsilon2/\sigma2$, and $\mu5 = \epsilon5/\sigma5$, which are all standard normal variables with mean zero and variance equal to one, under the assumption that $\epsilon1$, $\epsilon2$, and $\epsilon5$ are distributed normally.

Equations (11), (12), and (13) imply that the functional form forms for $f^{1\prime}$, $f^{2\prime}$, and $f^{5\prime}$. These will be:

$$(14)\quad f^{5\prime}(W,Z) = \theta5 + \theta_{WC}*WC + \theta_Z*Z,$$
$$(15)\quad f^{2\prime}(W,Z,X) = \theta2 + [\theta_{WC}*WC + \theta_{'}W_I*W_I + \theta_Z*Z]*\delta + \theta_X*X, \text{ and}$$
$$(16)\quad f^{1\prime}(W,Z,X) = \theta1 + \theta_{WI}*WI + [(\theta_{'}WC_*W_C + \theta_Z*Z)*\delta - \theta_X*X]*\alpha,$$

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 $\alpha = (\tau*\sigma2)/\sigma1$. Clearly δ and α must be positive. If equation (10) is replaced by (10') then (16) becomes

$$(16')\quad f^{1\prime}(W,Z,X) = \theta1 + \theta_{WI}*WI + (\theta_{'}W_C*W_C + \theta_Z*Z)*\alpha - (\theta_X*X)*\cap,$$

where every definition is the same except $\alpha = (\tau*\sigma5)/\sigma1$ and $\cap = (\Gamma*\sigma2/\sigma1)$. In sum, we estimate $\theta5$, $\theta2$, $\theta1$, θWC, θWI, θZ, θX, δ, α and sometimes $\cap$.

Notice that 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. Hence, we will only estimate indexes on the probability of bidding, where those indexes include factors thought to influence the profitability of bidding.

Initially I will assume that $\epsilon1$ and $\epsilon2$ are uncorrelated, and $\epsilon1$ and

$\epsilon 5$ are uncorrelated. The loglikelihoods of (5), (6) and (7) can accommodate arbitrary correlation between $\epsilon 2$ and $\epsilon 5$, which is subsumed in the specification of δ. Under the above assumptions, the probabilities of each event becomes:

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

for LL(5). Φ is a cumulative standard normal function. For LL(6) we have:

$$
\begin{aligned}
P(CI) &= [\ \Phi(f^{1\prime} > \mu 1)*\Phi(f^{2\prime} > \mu 2)*\Phi(PPP)\ ],\\
P(CC) &= [\ \Phi(f^{1\prime} > \mu 1)*\Phi(f^{2\prime} > \mu 2)*\Phi(-PPP))+\Phi(f^{1\prime} < \mu 1)*\Phi(f^{5\prime} > \mu 5)\ ]
\end{aligned}
$$

and a similar transformation was used for LL(7).

VIII Estimation Results

This section describes and interprets the results of the estimation. The discussion will emphasize several themes, some of which parallel the results in Table 3. These themes are: (1) Procurement of larger value induced more bidding; (2) The short run supply of alternatives in different segments of the mainframe market influenced the competitiveness of procurement across market segments; (3) The extent of experience a buyer has had with a vendor did influence the likelihood of sole-sourcing with that incumbent, but other market forces

dominated in most of this sample; (4) A very good predictor of a competitive procurement is whether a Federal agency's office had experience with IBM. These results support the argument that several economic factors determine the observed competitiveness of acquisitions.

Below I describe the estimates for LL(6) for equations (14), (15), and (16) from Table (5) (column 2) and Table 6. Table 5 uses the sample that treats GE and Honeywell as merged and RCA and Univac as merged. Table 6 displays estimated derivatives for a site with mean values of all continuous exogenous variables. Both tables display estimates where θ'_{WI} and θ'_{WC} were constrained to zero[32]. The analysis will not differ greatly for other specifications (See appendix B). The first two sub-sections describe the results and the next section interprets them.

VIIa Characteristics of the Coefficient estimates

Characteristics of the market segment of the purchase: DEDAP, NETWORK, and SIZE are all of the expected sign and reasonable magnitudes, mirroring their estimates in Table 3. Tables 5 and 6 says 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). Calculations show that a change of this magnitude increases $\Phi(f^{5'})$ by .026, $\Phi(f^{2'})$ by .03, and $\Phi(f^{1'})$ by .08. Turning DEDAP on or off decreases the probability of IBM bidding by .11, but 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 the dummy could often be easily swamped by other forces.

The availability of alternatives: One surprising result was that the estimates for coefficients in INCSYS in the challenger's equation and COMPSYS in the incumbent's equation were not jointly significant[33]. Only the point estimates for INCSYS in the incumbent's equation and COMPSYS in the challenger's equation are of the expected sign and jointly significant. For the estimates in Tables 5 and 6, 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. Just under three more systems offered by challengers leads to a .011 increase in $\Phi(f^{5\prime})$, a .012 increase in $\Phi(f^{2\prime})$, and an .037 increase in $\Phi(f^{1\prime})$ when IBM is not an incumbent.

An incumbent's advantages and a challenger's disadvantages: EXPERIENCE, EXPERIENCE2, 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 max), when its effect is quite large. 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. CAPACITY must exceed its range to really have a large impact. I have found that these results are insensitive to including or excluding variables in X. I conclude that INVEST is the best representative of an incumbent's advantage[34].

The probability of winning: The second column of Table 5 contains an estimate of the probability of the incumbent bidding and winning if the incumbent could profitably bid against a challenger. The estimate of PPP = .61 translates into a probability of 72.9% of bidding and winning. This point estimate means that of the 52 cases where a challenger won a competitive procurement, approximately 40 (or 76%) were competition between incumbent and challenger. The other 12 were competition between challenger and challenger, as when an incumbent would not bid against one or many challengers.

These results justify distinguishing between situations when incumbents bid and when they do not because they show how several paths plausibly lead to turnover in system suppliers for mainframe computers at Federal offices. Competitive procurement favored incumbents on average 3 to 1, but did not lock out all challengers, at least not in this sample of procurement. And while incumbents did not bid on every procurement, they did bid on most. The above estimates indicate that incumbent suppliers did not bid on approximately 11% of all procurement, which was enough to result in 22 acquisitions going to challengers (10 sole sourced with non-incumbents plus the 12 estimated from above into 195). The high percentage of challengers who were sole-sourced when the incumbent did not bid suggests that the acquisitions may have something that only the incumbent could not provide and only one non-incumbent firm could provide.

VIIb. The relative ranking of influences

Tables 7 contains calculations designed to identify which variable were relatively most important for determining outcomes. It shows how much the probability of the outcome would change if each continuous exogenous variable changed by one standard deviation, while holding the others constant at their mean values. Table 7 also contains changes in probabilities from turning the dummy variable on and off.

Table 7 demonstrates the relative importance of the value of the procurement for other sales. 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 over 0.071 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 0.103 when IBM is not an incumbent and 0.48 when it is not. The absolute magnitude of both of these shifts exceeds the shifts from any other category of variables overall.

Now consider COMPSYS and INCSYS. 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 observing IBM win 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 roughly 2 or more firms on average), increases the probability of competition by .11. This seems to be a large amount when you consider that a high percentage of acquisitions were already competitive. It is surprising that potential competition had any effect at all. This seems to be a small amount when you consider that entry into this market is quite expensive. In other words, if a policy-maker entertained the idea that vendors ought to be subsidized in the mainframe industry in order to produce more competition, then the gains from having 11 out of a hundred acquisitions more competitive would have to be large to justify the entry of two more competitors.

As expected, an increase in INVEST increases the probability of sole-sourcing with the incumbent by 0.101 when IBM is not the incumbent and 0.038 when IBM is incumbent. This later result offers evidence that INVEST influences outcomes when it is at levels other than its extremes. What INVEST seems to measure (that others do not) are the occasional sites that have extensive investments in miscellaneous equipment. However, notice that INVEST never swamps the effect of other variables.

EXPERIENCE and CAPACITY are not strong. Moving from of 3.4 to 6.0 takes EXPERIENCE from it maximum effect to a much more diminished one, but this does not shift any probability by very much in magnitude. It is no surprise that variation in CAPACITY has little effect, given the small coefficient estimates. Finally, other calculations show that in only 54% 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[35]. Thus, **incumbent's advantages can be important in diminishing competition; However, for a large number of cases they are not large in magnitude.**

The IBM incumbency variable, which is on for 40% 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 .174 and that an incumbent (IBM) will bid by .131, a relative change that few variables will match, except at extreme values. Altogether when IBM is the incumbent the probability of observing competition increases by .14. The above again demonstrates the uniqueness of Federal offices where IBM is an incumbent supplier.[36]

VIIc. Developing an overall interpretation

Tables 5, 6, and 7 revealed that the market processes underlying the outcomes are much more complex than the earlier estimates of a probit could represent. In addition, it is reassuring that all the conclusions drawn from the probit in Table 3 could also be drawn from the latter experiments. The next two sub-sections will summarize the interpretation.

The potential supply of alternative systems by competitors and by the incumbents rank as important variables. The estimates point toward the important role of differences in the potential supply across market segments and across time. These effects are not strong enough to swamp all other variables and do change in different circumstances. 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.

The general overall importance of the size of the procurement and the number of acquisitions occurring at related sites provides strong 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[37].

Of the measures of an incumbent's advantages, dollar investment, but not age 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 results solely from market factors, then it may be measuring potential competition that is missed by the other measures. That is, IBM tends to be in market segments where there is relatively more competition than other sectors of the mainframe market. Hence, IBM is at a competitive disadvantage.

The above interpretation draws a clearer picture of the economic forces 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, sometimes 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.

VIId. Supervision and Inferences from the estimates

To what extent is oversight systematically altering the magnitude of the estimates? Do these estimates tell us something about the commercial mainframe computer market in this time period?[38]

One concern is whether more valuable procurement is more competitive due to supervision. It is well-known that GSA follows guidelines that resulted in it more closely scrutinizing more valuable procurement[39]. 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 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[40].

This interpretation has consequences for recommendations from these measurements. If fixed costs were solely behind the result that more valuable procurement was more competitive, then this work would recommend that agencies bundle purchases together to get more competitive procurement. If supervision produced the outcome, then agencies had incentives to unbundle acquisitions in order to avoid supervision.

Supervision may also partially explain why an incumbent's advantages did not much influence the results in this sample -- even though several departures from cost minimization in federal experience should favor incumbents more than in an ideal profit-maximizing private firm[41]. In particular, strict GSA competitive procedures were thought to be more price sensitive than 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[42]. This reweighting of factors, if operative, could have induced more bidding from non-incumbent suppliers by diminishing the buyer's ability to manipulate vendor selection, no matter how much experience the vendor had with the buyer. It also could have limited an agency's offices from using sole-sourcing to insure that a system came from the desired vendor.

The performance of IBM also could represent some factors unique to the government and not shared by private buyers. Though 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). P. R. Werling made the argument in his thesis, which studied the implementation of the Brooks Act, that this intervention may have slanted oversight against IBM[43]. 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. Of course, these results can easily also be made consistent with the previous chapter's results[44].

VIII. Summary

The discussion in this paper analyzed how market forces influenced the competitiveness of computer system procurement in the Federal government. It developed an econometric model of procurement, where the unobserved bidding behavior of incumbent and challenger vendors guided the econometric structure. The modelling concentrated on measuring the influence of an incumbent's advantage on outcomes. The model was estimated on a sample of Federal computer system acquisitions in the 1970s and early 80s.

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 influence the likelihood of sole-sourcing with that incumbent. However, in many cases other market factors dominated. The **potential supply of alternatives** in different segments of the mainframe market influenced the competitiveness of procurement across market segments. In addition, **procurement of larger value** induced more bidding. The potential importance of several non-market factors was also analyzed, particularly the effect of oversight on procurement of large value.

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 where many competitors in the 1970s competed against IBM or the Federal procurement process placed IBM at special disadvantages.

The results point to a need to further understand the economic determinants of the supply of potential alternatives in different market segments across time and how it interacted with the value of an acquisition. They also point to a need to better understand the unique position of IBM as an incumbent vendor and how that shaped competition for the supply of systems to Federal agencies and private firms. It would also be interesting to evaluate the effectiveness of the Brooks Act in terms of its influence on the economic factors identified by the analysis as especially important.

Further work must verify that the substantive conclusions of this analysis remain unchanged when estimation accounts for the correlation in errors. Work could develop better measures of differences in the types of applications offices tend to do, expanding its analysis to multi-vendor sites, drawing out the importance of the vendor-user relationships in dimensions other than those explored here. It may also be possible to link these results to the prices paid by sites for their systems, if the price data in the inventories can be recovered.

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 and Challenger's Decisions

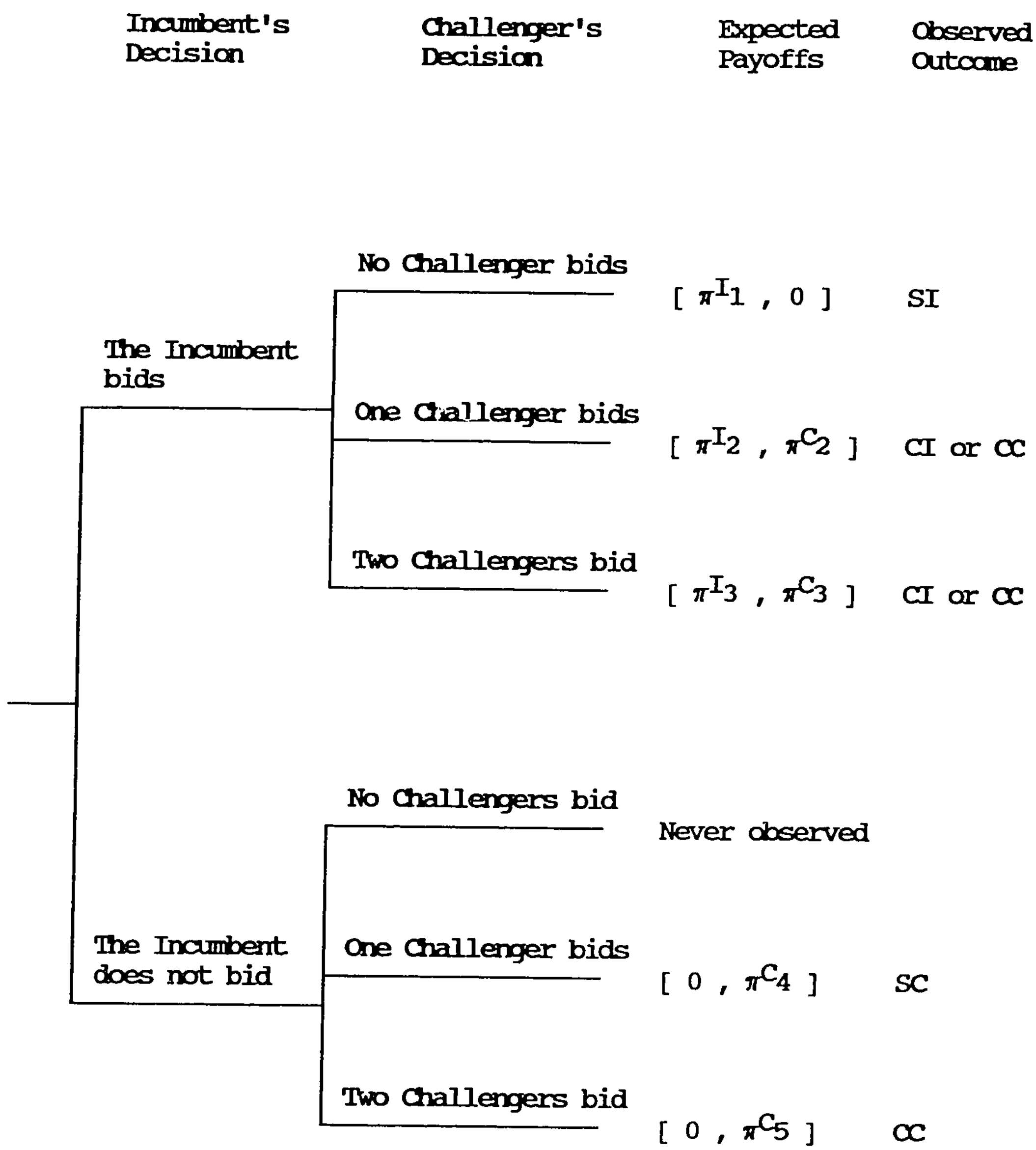


Figure 3

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

For the probit:

Abreviation	Variable Definition	Prediction
DEDAP	System requested for dedicated application	Negative
SYSTEMS	Number of system offerred in market segment	Positive
SIZE	Size of system acquired (2 to 7)	Positive
NETWORK	Number of systems acquired at related sites	Positive
IBMINC	IBM is an incumbent on site	Positive
INCUMBENT	Incumbent system supplier on site	None

For the model of bidding:

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.

Number of Vendors per Market Size Segment

Year

System Size	≤ 76	77	78	79	80	81	82	83
2	6	6	5	6	6	6	7	6
3	7	7	6	7	8	6	8	8
4	9	8	8	10	10	12	14	12
5	9	8	9	10	10	11	12	12
6	8	8	8	10	9	10	11	11
7	5	5	6	7	7	9	8	8

Number of Systems Offered per Market Size Segment

Year

System Size	≤ 76	77	78	79	80	81	82	83
2	21	20	20	24	24	25	24	23
3	35	35	34	37	40	42	45	50
4	46	50	61	57	68	74	84	92
5	42	42	38	41	55	57	59	71
6	34	32	35	39	43	47	46	58
7	24	23	23	31	33	37	45	57

Source: IDC General Purpose Surveys: 1/15/76, 12/3/76, 12/5/77, 2/23/79, 5/28/80, 6/26/81, 9/22/82, 1983 Yearbook.

Table 4

Probit: Competition as a Function of Market Characteristics

Number of Observations		221
Number Competitive		180
Loglikelihood		-93.3858
Constant		-0.94 (0.67)
Dedicated Application	(DEDAP)	-0.33 (0.31)
System in market segment	(SYSTEMS)	0.023** (0.011)
Size of acquisition	(SIZE)	0.12 (0.079)
Other systems acquired	(NETWORK)	0.11 ** (0.040)
IBM is an incumbent	(IBMINC)	0.57 ** (0.23)
Incumbent at office	(INCUMBENT)	-0.33 (0.33)

* t-statistic greater than 1.645
** t-statistic greater than 1.96

Table 5
Estimates of Equations (14), (15) & (16) for LL(5) and LL(6)
(Standard Errors in parenthesis)

	LL(5)	LL(6)
LOGLIKELIHOOD	-201.798	-198.529
NUMBER OF OBSERVATIONS	221	221
SINGLE BIDDER, INCUMBENT	26	26
SINGLE BIDDER, CHALLENGER	10	10
COMPETITION, INCUMBENT WINS	107	107
COMPETITION, CHALLENGER WINS	52	52
SINGLE BIDDER, NO INCUMBENT	5	5
COMPETITION, NO INCUMBENT	21	21
CONSTANT Θ5	0.03 (0.60)	-0.34 (0.55)
NUM COMPETITORS' SYSTEMS	0.008 (0.009)	0.011 (0.008)
PROCURE SIZE	0.053 (0.062)	0.078 (0.053)
NUM ACQUISITIONS IN NETWORK	0.026 (0.031)	0.033 (0.024)
DEDICATED APPLICATION	-0.10 (0.13)	-0.080 (0.097)
CONSTANT Θ2	-2.52 ** (1.08)	-2.46 ** (0.98)
IBM INCUMBENT	0.81 ** (0.24)	0.90 ** (0.26)
DOLLAR INVESTMENT	-0.011** (0.004)	-0.011** (0.004)
SUM EXPERIENCE	-0.22 * (0.13)	-0.21 (0.13)
SUM EXPERIENCE2	0.025* (0.013)	0.028* (0.015)
COMPUTER CAPACITY	0.009 (0.007)	0.007 (0.006)
CONSTANT Θ1	-4.06 ** (1.70)	-2.98 ** (3.47)
NUM INCUMBENT'S SYSTEMS	0.33 ** (0.16)	0.36 ** (0.14)
NO INCUMBENT VENDOR	0.22 (0.50)	0.32 (0.47)
DDD, P OF INCUMBENT WINNING	0.41 ** (0.10)	----- (-----)
PPP, P OF INCUMBENT WINNING	----- (-----)	0.61 ** (0.15)
DELTA = δ = $(\Gamma * \sigma5/\sigma2)$	5.90 (6.97)	3.91 (2.77)
ALPHA = α = $(\tau * \sigma2/\sigma1)$	1.86 ** (0.84)	1.26 ** (0.57)

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

Table 6

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.

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 A, B, C, and D. 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.

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].

Table 7

Probability Change From Standard Deviation Increase in Exog. Variables. Using Estimates of LL(6)

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. Only standard 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.

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 [$P(V=1) - P(V=0)$].

Endnotes

1. Economists have proposed a wide variety of models of procurement, principally focusing on how auctions work in theory. For a review of much recent work on auction and bidding theory, see McAfee and McMillan (1986), Anton and Yao (1988), or Demski, Sappington and Spiller (1988). Recent contributions in applied work on government procurement or auctions includes Hendricks and Porter (1988) on asymmetric information in oil lease auctions, and Lichtenberg (1988) on Research and Development and government procurement.

2. 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% 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.

3. This model is based on 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.

4. For example, see GAO 1983 on benchmarking practices their abuse. However, the Government Accounting Office would not speculate on how widespread their abuse was. Allegations of manipulation of specifications have also 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. 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 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 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 the text is the most common one. 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. An incumbent vendor is in this data set as a vendor that designed a system, as defined in the inventories, used by the site in the previous year. This definition assumes that there is a one-to-one association between "firm" and "product family", which is not true in general, but is permissible in this sample of data. The definition of a vendor will be made further.

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

11. The decision rule for deciding between vendors need not be fully specified. 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 where there are fixed costs to 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. 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.

13. The 1976 counts were applied to observations from earlier years.

14. Most special government designs and other customized systems have been eliminated from the sample.

15. See GAO report on benchmarking (1981) or testimonies in the Grace report on ADP/Office Automation (1983), for example.

16. 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 which come bundled together in a system.

17. Despite the looseness of this definition over time and across agencies, it seemed more sensible to count the number of system acquisitions in 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.

18. There are frequent complaints from the time 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.

19. 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 therein. Yet, Werling's argument remains largely untested because his quantitative evidence could be interpreted in many ways. See Greenstein (1988) for further analysis of this question.

20. Concerns about the correlation of errors across offices within the same "office command bureau" were allayed by estimating the probit with a sample of systems that randomly took no more that one acquisition from the same office command bureau in a given year. This eliminated 30% of the sample but did not change the qualitative results at all. Hence, the estimates appear insensitive to this potential problem.

21. This is a reasonable concern. See GAO 1977b or GAO 1980 on the influence of conversion expenses on the selection of new vendors. Economic theorists have also been interested in how "switching costs" could alter competitive behavior. Relevant papers include Farrell (1987), Farrell and Shapiro (1986) and (1987), and Klemperer (1986).

22. See GAO 1979, OSD 1983b or NBS 1980 for some of these case studies.

23. It is 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 often work to the advantage of incumbent system supplier.

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

25. The sequential move game is superior to a simultaneous move game for the application used below. 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.

26. Notice that the fourth assumption partially overlaps with the third assumption in that it rules out some games where asymmetric information in the incumbent's actions may influence the buyer's payoffs.

27. 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 appendix A.

28. Assuming exogeneity of the market segment will be warranted by the breadth of the IDC segments and the government system labels employed.

29. 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.

30. 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.

31. 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 DOD subagency such as the Army, Air Force, or Navy. Year of acquisition was also found to be uninformative when added to a specification where 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 is a minimal list.

32. 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% level. Attempts to constrain the proportional value of the estimates (as was done with B_X) also did not improve the estimation.

33. There did not seem to be sufficient data to significantly estimate the effects of rival's potential on profitability of another rival. Because both coefficients could not jointly pass a significance test they were set to zero.

34. As crude as a measure as it is, this probably works best because large values in INVEST, unlike any of the other measures, signal that a site has a vast amount of equipment.

35. This calculation was made by multiplying IBMINC, INVEST, EXPERIENCE, EXPERIENCE2 and CAPACITY by their respective coefficients and adding up for each sample observation.

36. Greenstein (1988) contains evidence that previous investment with an incumbent vendor was a better predictor of again choosing that incumbent when the incumbent was not IBM.

37. 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 for Federal agencies needed to meet more requirements to qualify for bidding than were found in private industry.

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

39. See NBS 1983, for example.

40. As the Grace Commission (1983) states: "The Government's (automatic data Processing) acquisition process indicates disproportionate concern with 'process accountability'". Werling (1983) strongly emphasizes how agencies could not understand the logic behind oversight process, especially when he focuses on how the Brooks Act was implemented. 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.

41. For example, it is widely believed that agency offices tend to value less one benefit of competition, lower prices for computer systems, than those who allocated the budget would like them to be. It is also widely believed that agency offices favor those vendors, typically the incumbent, that require the least use of an agency's discretionary budget. It is usually argued that after earmarked funds are spent on their assigned need, the recipient of those funds will frequently find a way to spend any extra funds, even on unnecessary purchases. Meanwhile, those who allocated the budget, like Congress, would rather that those funds be spent on some other need in some other agency. See McComb, Noll, and Wiengast (1987) for an analysis of some of the mechanisms used to monitor departures from desired behavior.

42. 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, see Cabral and Greenstein (1988).

43. Werling states on page 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

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page 177 and the surrounding discussion. Greenstein (1988) addresses the quantitative evidence using different methods.

44. However, unlike this 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.

Summary

This research used the computer industry and the computer market to provide concrete examples for expanding our understanding of the factors relevant to economic decision-making when incompatibilities lead to large switching costs. While it appears to be true from these essays that switching costs from incompatibilities could play an important role in determining economic outcomes, the effects of those costs could not be understood in isolation of many other structural conditions of a product market. A summary of the conclusions of each of the essays will make this general point apparent.

The first essay took several alleged instances of "physical tie-ins" as a reference point, and argued that economist's usual treatment of "tie-ins" and bundling is inappropriate for these cases. The essay proposed an alternative model. The model identified the circumstances under which interface manipulation yielded competitive advantages to an integrated system designer. It also focused on the limits placed on such behavior by the demand for "backward compatible" components. The model's implications were then examined for the light they shed on arguments about the plausibility of "leveraging" -- i.e. the use of monopoly power in one component market to gain monopoly power in a complementary component market. The essay concluded that the notion of leveraging can be given analytical substance, but emphasized that the concept should be used with some care.

The second essay investigated how several factors influenced the role of switching costs in vendor choice. It observed that buyers made estimates of switching costs that were often subject to large errors. How those estimates were made and how the risks of being wrong were allocated between buyer and seller had an important effect on the extent to which buyers favored incumbents. It also observed that users could expend (fore-sighted) effort in an extensive number of ways in advance of future acquisitions that could significantly change the level of switching costs later. The incentives for taking these actions differed from one circumstance to another. These observations took on added importance when decisions pertaining to computer system use, switching costs estimation and vendor selection were not coordinated. Hence, conflicts in goals between overseer and agency and an absence of coordination in decision-making at any point in time was likely to complicate the intertemporal links in decision-making over time. Ignoring these factors would lead to an incorrect understanding of the role of switching costs in vendor selection and how switching costs lead to "lock-in".

The third essay shed further light on our understanding of computer procurement by focusing on the observed relationship between vendor selection and previous user experience in a sample of commercial mainframe computer system acquisitions by federal agencies in the 1970s and early 1980s. It estimated in a multi-nomial logit model the probability that a procurement would be won by an incumbent vendor. This probability was made a function of historical factors such as (a) indications of vendor's interaction with a buyer and (b) measures of the extent of this interaction. The remarkable thing about federal acquisitions of mainframe computers is that only the indication of previous interaction significantly predicts future vendor choice. The extent of interaction does not predict future choice very well. Moreover, the relationship between previous buyer experience and future choice differs across firms. IBM gets less of advantage from being an incumbent than its rivals. Unlike previous research, however, this essay uncovered evidence that limits the view that procurement was systematically biased against IBM. This new evidence shows that this disadvantage is partially a consequence of the incompatibilities in generations of IBM's product line and the government's large and extensive investment in IBM systems in the 1960s. The sum total of this evidence significantly shapes the empirical interpretation of the effect of the computer procurement system on commercial mainframe procurement.

The final essay focused on measuring the economic determinants of an agency's choice between using sole-sourcing and competitive procedures when making acquisitions. It developed economic models of bidding that provide structure for econometric models of an incumbent's advantage in bidding for government contracts. This analysis shed light on the importance of several economic factors, including the value of procurement and the potential supply of commercial systems in different segments of the mainframe market. The analysis also illustrated that the extent of experience a buyer had with a vendor could have influenced the likelihood of sole-sourcing with that incumbent, but in most cases other economic factors dominated. Another good predictor of a competitive procurement is whether a Federal agency's office had experience with IBM. This either indicates that Federal Mainframe market contained many competitors who competed against IBM, or it indicates that Federal procurement processes placed IBM at special disadvantages.

On the whole, these essays modified significantly our understanding of the consequences of incompatibilities and switching costs in the mainframe computer market in the 1970s. The first essay questioned whether these incompatibilities arise in a benign way or can be generated to bring advantages to the designing firm. The second essay questioned whether economist's present understanding of the process of "lock-in" is appropriate for a market where decision-making need not have been coordinated over time, as occurred in the case studied here. The third essay showed that vendor choice is predicted by the presence but not the extent of a buyer's investment with an incumbent. These estimates strongly suggest that decision-making was influenced by the compatible upgrades available for older generations of equipment. The final essay demonstrates how economic models of bidding can provide structure for econometric models of an incumbent's advantage in bidding for government contracts. The analysis showed that market factors other than an incumbent's advantage, particularly differences in potential competition across markets, accounted for much of the observed differences in bidding behavior.

While these results suggest that switching costs due to incompatibilities could be relevant to decision-making, they also suggest that many more economic factors modify the role of switching costs and hence, determine observed outcomes. These need to be further understood. Further work should explore the role of incompatibilities in a market of heterogenous products. It should also explore the character of principal-agent models in private industry where acquisitions are subject to switching costs. Further work should explore statistically estimating coefficients associated with choice amongst incompatible system families, in addition to choice of suppliers. It may also be possible to extend the existing frameworks to multi-vendor sites and possibly link the results in these essays to the prices paid by sites for systems, if the price data in the inventories can be recovered.

Essay 1 appendix: Proofs of Propositions.

Proof of (4):

A1. $\delta\pi^*/\delta t = -e^{-rt}R_1(t,P^2)\cdot[\ P^2 - c2\ ] < 0$, by assumption.

Proof that I is bounded:

As defined by (6), I can be rewritten as :

A2. $$I = \sum_{i=0}^{\infty} e^{-irt*}\cdot[\int_0^{t^*} e^{-rt}\pi(t)dt - e^{-rt*}F],$$ or as

A3. $$= \int_0^{t^*} e^{-rt}\pi(t)dt - e^{-rt*}F + e^{-rt*}I,$$ which implies

A4. $$I = [\int_0^{t^*} e^{-rt}\pi(t)dt - e^{-rt*}F\ ]/(1 - e^{-rt*}).$$

(A4) is bounded because $\delta\pi/\delta t < 0$ by (5a).

Proof of proposition (1a):

From (A3) and (7),

A5. $$I(t^*) = \int_{t_n}^{t^*} e^{-r(t-tn)}\pi(t)dt + e^{-r(t*-tn)}\cdot[I(t^*) - F],$$

A6. $$\delta I/\delta t^* = e^{-r(t*-tn)}\pi(t^*) - r\cdot e^{-r(t*-tn)}\cdot[I - F] + e^{-r(t*-tn)}\cdot\delta I/\delta t^* = 0\ ,$$

which leads to equation (8) in the text. To establish it is a maximum:

A7. $$\delta^2 I/\delta t^{*2} = e^{-r(t*-tn)}\cdot[\pi'(t^*) - r\pi(t^*)] + r^2e^{-r(t*-tn)}\cdot[I-F]$$

A8. $$= e^{-r(t*-tn)}\cdot\pi'(t^*) < 0$$ by (8) and (5a).

For the remainder of the proof, assume t^* exists. By the monotonicity and continuity of $\pi(t)$ and definition of t', $t^* \leq t'$. If it were not true, then for a $t'' = t^* > t'$ we get $r[I - F] = \pi(t'')$ by (8), implying a switch occurred at t''. But by the definition of t', $\pi(t') = \pi(t'')$, implying a switch took place at t', before t''. Contradiction. Therefore, if t^* exists, then $t^* \leq t'$. A similar argument establishes the uniqueness of t^* for all parts of $\pi(t)$ which are not strictly monotinic.

If $t^* = 0$, substituting into (A3) yields $I = I - F$, which implies that $F = 0$. Thus, if $F \neq 0$, then $t^* \neq 0$.

<u>Proof of proposition (1b):</u>

From (8) and (6) and (1a), and the continuity of π, if $\pi(0) > \pi(t^*) > \pi(t')$, then t^* exists. The first bound is always met if $F > 0$ because

A9. $$I - \int_0^\infty e^{-rt}\pi(0)dt < 0 < F$$ by construction, implying

A10. $$I - \pi(0)/r < F,$$ which gives

A11. $$\pi(t^*) = r[\ I - F\ ] < \pi(0).$$

Thus, if $r[\ I - F\ ] > \pi(t')$, t^* exists. But if that is true, using (A2) one gets

A12. $$\sum_{i=0}^{\infty} e^{-irt^*}\cdot\{\int_0^{t^*} e^{-rt}\pi(t)dt - F\} > \pi(t')/r,$$ or

A13. $$\sum_{i=0}^{\infty} e^{-irt^*}\cdot\{\int_0^{t^*} e^{-rt}[\pi(t)dt - \pi(t')]dt + \int_0^{t^*} e^{-rt}\pi(t')dt - F\}$$

$$> \pi(t')/r,$$

or

A14. $$\sum_{i=0}^{\infty} e^{-irt^*}\cdot\{\int_0^{t^*} e^{-rt}[\pi(t)dt - \pi(t')]dt - F\} > 0,$$ yielding

A15. $$\int_0^{t^*} e^{-rt}[\pi(t)dt - \pi(t')]dt > F,$$ which implies

A16. $$\int_0^{t'} e^{-rt}[\pi(t)dt - \pi(t')]dt > F, \text{ for } \pi(t) \geq \pi(t'),\ t > t',$$

which holds by (5a).

If $t^* = t'$, then $r[I - F] = \pi(t^*) = \pi(t')$ and a similar argument as above results in an equality in (A16).

For sufficiency: If

A17. $$\int_0^{t'} e^{-rt}[\pi(t)dt - \pi(t')]dt > F, \text{ for } \pi(t) \geq \pi(t'), \text{ then}$$

A18. $$\sum_{i=0}^{\infty} e^{-irt'}\cdot\{\int_0^{t'} e^{-rt}[\pi(t)dt - \pi(t')]dt - F\} > 0, \text{ implying}$$

A19. $$\max_{t^*} \sum_{i=0}^{\infty} e^{-irt^*}\cdot\{\int_0^{t^*} e^{-rt}[\pi(t)dt - \pi(t')]dt - F\} > 0, \text{ because}$$

t^* is a max in the range $[0,t']$.

A20. $$\max_{t^*} \sum_{i=0}^{\infty} e^{-irt^*}\cdot\{\int_0^{t^*} e^{-rt}[\pi(t)dt - \pi(t')]dt + \int_0^{t^*} e^{-rt}\pi(t')dt - F\}$$

$$> \pi(t')/r.$$

Using (A2), (A20) is equivalent to $r[I - F] > \pi(t')$, which implies t^* exists and it is a maximum.

<u>Proof of Proposition 2a:</u>

If $\alpha_1 = 0$, and $t \geq t'$, then from straightfoward substitution,

(A21) $\pi^*(t) = X1\cdot[P^1 - c1] + XB\cdot[P^B - c1 - c2]$.

Clearly, $\delta\pi^*/\delta t = 0$ in this range. Furthermore, since $\pi(t')$ defined by (A21) is the minimum of (9), and $\pi(t)$ is differentiable in the range

$0 < t \leq t'$, then there must exist some point after which $\pi(t)$ is declining until it reaches t'.

<u>Proof of proposition 2b:</u>

If $\alpha_2 = 0$, then for $t \geq t'$,

(A22) $\delta\pi^*/\delta t = \delta\alpha_1/\delta t \cdot [P^1 - c1] \geq 0$, by assumption.

$\delta\pi^*/\delta t = 0$ when $t > \tilde{t}$. Since $\pi(t')$ is not necessarily the minimum of (9), $\pi(t')$ is less than or greater than $\pi(0)$. Thus, $\delta\pi^*/\delta t$ can be positive or negative.

<u>Proof of proposition 3a:</u>

If $\alpha_1 = 0$, then the proof of 3a follows the same argument as the proof of proposition 1b for some t^* where $\delta\pi^*(t^*)/\delta t \leq 0$.

<u>Proof of proposition of 3b:</u>

Proof of (i) follows from (A22). This implies that for $t^* \geq t'$, if $\delta\pi(t)/\delta t > 0$, it must be the case that $[I - F]\cdot r < \pi(t)$ for all $t > t^*$. It then follows from (8) that t^* cannot exist at another $t > t^*$. But it also follows from (10) that t^* cannot exist if $\pi(t) > \pi(t^*)$ for $t > t^*$. This argument holds for all $t^* > t'$. Thus, if it exists, t^* is less than t'. If $\delta\pi(t)/\delta t = 0$ at t', then the proof is the same as that for proposition 1a.

Proof of (ii) follows exactly the same argument as proposition 1b except that the minimum guarenteed profit level is no longer $\pi(t')$. Substituting MIN $[\pi^*(t)]$ for $\pi(t')$ in (A9) - (A20) will complete the proof.

Proof of (iii) is also similar to the to (A9) - (A16) in proposition 1b where MIN $[\pi^*(t)]$ is substituted for $\pi(t')$. The sufficiency argument cannot hold if $\pi(\tilde{t}) > \pi(t^*)$ as t^* is define above. Figure 2 illustrates a possible example. Clearly, a sufficient condition is that future profits from the present interface be greater from switching interfaces. This is the condition stated in the proposition.

Essay 2 Appendix: Summary of Case Studies of Switching Costs

Agency. (i) Contract date to completion date (ii) Old system model new system model. (iii) General application and new machine justification.	Software conversion costs. (i) lines of code, number of application programs, and other measures of software size. (ii) Estimated software conversion expense. (iii) Actual software conversion expense.	Miscellaneous. (i) Additional conversion expense by type, total conversion expense, or savings with upward compatible machine. (ii) Recommendation for supplier using hindsight. (iii) Other misc.
1. Dept of Energy (i) 8/74-10/77 (ii) Cyber74 Uni1100/44 (iii) Service center for conteractors is saturated	(i) 1000 applied programs Est. at $5.88 per line (ii) Est. $366,424 in 2/77 (iii) Act. $3,412,300 in 2/79	(i) $2.6 mil less to stay with incumbent. (ii) Incumbent would have been chosen.
2. EPA (i) 8/70-3/74 (ii) IBM360/50 Uni1000 (iii) Service Bureau for EPA offices. User developed applications.	(i) 898 applied programs 408,100 lines (ii) Est. $200,000 in 6/73 (iii) Act. $1.5 mil	(i) $516,000 in dual operation costs $235,000 retraining $90,000 offsite processing Est. disruption cost at $387,300 to $774,650. (ii) Should have chosen incumbent. (iii) Severe disruption of operations. Delays of new work, 3 programmers quit.
3. Navy (i) 3/73-3/78 (ii) RCA, IBM Uni1100 (iii) Outmoded and saturated system. Replacements at several locations to result in unified system.	(i) 7 centers with 23 "systems or applications". 3 conversion contracts out to bid in 6/76, 4/78, and 7/78.	Only two upward compatible options available (IBM). RCA had exited industry. IBM did not submit proposals. See below for more detail from individual cases.

Agency. (i) Contract date to completion date (ii) Old system model new system model. (iii) General application and new machine justification.	Software conversion costs. (i) lines of code, number of application programs, and other measures of software size. (ii) Estimated software conversion expense. (iii) Actual software conversion expense.	Miscellaneous. (i) Additional conversion expense by type, total conversion expense, or savings with upward compatible machine. (ii) Recommendation for supplier using hindsight. (iii) Other misc.
3a. Navy Norfolk (ii) 2 RCA3301 & 1 RCA Spectra70/45 Uni1100/42 (iii) Batch oriented	(i) 620 applications 531 lines of code (iii) $950,000 in 3/77-7/78 with some modifications for new system needed.	
3b. Navy Jacksonville Not stated	(i) 207 applications 125,000 lines of code (iii) $559,000 in 8/77-4/79	(i) Space accomoda-tions at $315,000. Old equipment poorly maintained, in bad shape, $110,000 plus intangibles. (ii) No upward compatible system available. (iii) Required extra 200 staff hrs. and 352 overtime hrs. on top of contractor work.
3c. Navy Pensacola (ii) 2RCA3301, IBM360/65, IBM360/50 Uni1100/42 (iii) Online support, online DB, training and Est. $2.2 mil in 2/78 education. Continuous opera-tion required and substantial inconvenience	First contract for (i) 322 applications (iii) $486,000 in 3/78-7/79 No problems. Second contract for (i) software that interacts with DBMS. 1131 application. 650,000 lines of code 483 data files to convert (139 DMBS, 322 sequential, 12 indexed.) "37 system uses" (ii) Est. $2.2 mil in 2/78 (iii) $2.5 mil by 8/79, total $4.5 mil in 6/80.	(i) Second contract: $705,000 modified warehouse. $495,000 training $3. mil dual operations while conversion occurs (ii) No compatible system workable. (iii) Much delay as assumptions about new machines revised. Lack of compatible terminals delay system set up.

Summary of case studies of switching costs continued

Agency. (i) Contract date to completion date (ii) Old system model new system model. (iii) General application and new machine justification.	Software conversion costs. (i) lines of code, number of application programs, and other measures of software size. (ii) Estimated software conversion expense. (iii) Actual software conversion expense.	Miscellaneous. (i) Additional conversion expense by type, total conversion expense, or savings with upward compatible machine. (ii) Recommendation for supplier using hindsight. (iii) Other misc.
4. USDA, New Orleans, (i) 4/76-7/78 (ii) IBM360/65, 2 IBM7080s, 2 IBM1401s Honeywell66/80 (iii) Batch and online use. 1401 and 7080 systems were redesigned.	(i) 951 Cobol programs, Some assembly language, interaction with commercial DBMS, (iii) Act. 296 programs at $338,000 (all the easy work) done by contractor. 127 also partially done. Internal staff completed conversion	(i) $1.7 mil in dual operation cost, Total estimated at $1.1 mil, $7.5 mil actual (ii) IBM's bid was not "responsive to technical requirements." Compatible system would saved much.
5. VA, (i) 9/72 - 6/78 (ii) IBM370/168 Honeywell??, (iii) Online transaction database, connections with many regional offices, also payroll, inventory. Upgrade pilot program on IBM machine to Honeywell	(ii) Est. $1,244,280 in 6/78 Est. 12 months (iii) Act. $4,582,243 in 79? 15 VA programmers (i) 260 batch programs (Significant rewriting needed to take advantage of architectural features.)	(i) Substantial cost would be incurred even if IBM was chosen. Here: total $13.8 mil site modification at $3,783,963, Dual equipment at $3,892,997, Training at $1,512,806. (ii) Est. that $2.6 is saved if IBM was chosen. (iii) Note: IBM did not submit a proposal — one stated reason, conversion costs not a factor.

Summary of case studies of switching costs continued

Agency. (i) Contract date to completion date (ii) Old system model new system model. (iii) General application and new machine justification.	Software conversion costs. (i) lines of code, number of application programs, and other measures of software size. (ii) Estimated software conversion expense. (iii) Actual software conversion expense.	Miscellaneous. (i) Additional conversion expense by type, total conversion expense, or savings with upward compatible machine. (ii) Recommendation for supplier using hindsight. (iii) Other misc.
6. Corp of Engin. Portland, Or. (i) Unstated (ii) IBM360/50 IBM370/155. (iii) Batch processing, replacement needed due to processor and memory limits.	(i) 400 "models" in use. (iii) Act. $13,930 for compatible upgrade. Some reprogramming of job control language.	(i) Total at $32,935 site $4,839, Dual at $4,936 Training at $9230 (iii) Estimate replacement at $2.5 mil in conversion costs if non-compatible, unlike upgrade here.
7. Atlantic Electric (i) 1/79 - 3/82 (ii) RCA70 IBM370/158 (iii) "38 syste use for the machine"	(i) 760 programs 626,000 lines of code (ii) est. $995,000 (iii) act. $919,000 Note: Carefully planned and tightly controlled. cobol programs transferred fairly easily.	(i) ??? (ii) No evaluation reported.
8. Bureau of Indian Affairs (i) 6/79 - 3/81 (ii) 2 CDC3100s, CDC3150, CDC3170 IBM (iii) In house batch processing converted to service.	(i) 418 programs 320,000 lines of code (ii) planning costs: $185,000, Conversion costs est. at < $875,000. (iii) Major source of trouble is converting out of CDC proprietary language. contracting	(i) 15 contractor employees work on the conversion. 5 in-house employees. (ii) No evaluation reported

Summary of case studies of switching costs continued

Agency. (i) Contract date to completion date (ii) Old system model new system model. (iii) General application and new machine justification.	Software conversion costs. (i) lines of code, number of application programs, and other measures of software size. (ii) Estimated software conversion expense. (iii) Actual software conversion expense.	Miscellaneous. (i) Additional conversion expense by type, total conversion expense, or savings with upward compatible machine. (ii) Recommendation for supplier using hindsight. (iii) Other misc.
9. USDA, (i) 1/80 - 7/80 (ii) Uni1108 IBM370. (iii) Center for reporting agricultural data. Large on-line data base in service bureau framework.	(i) 1000 programs 500,000 lines of code (ii) est. $1,000,000 (iii) act. $1,500,000 (system software difficult to transfer) data files using commercial program available on both systems eases the transfer.	(i) Est. internal labor expenses at $1.5 mil (ii) No evaluation reported

Sources: GAO 1980, Appendix II, and OSD 1983b, chapters 2-6.

Essay 4, Appendix A: Profit functions and outcomes

What is the equilibrium to this model under the first three assumptions? If the incumbent cannot profitably bid at all (i.e. $\pi^I2 < \pi^I1 < 0$) then if the second most profitable challenger expects positive profits (i.e. $\pi^C5 > 0$) than we observe competition. If not, then we observe a single supplier with a non-incumbent (i.e. $\pi^C4 > 0$ by assumption). If the incumbent can profitably bid against a challenger (i.e. $\pi^I2 > 0$) then we observe a single supplier when the most profitable entrant cannot profitably enter (i.e. $\pi^C2 < 0$). If an incumbent seller (i.e. $\pi^I2 > 0$) can profitably bid, and if a challenger to the incumbent (i.e. $\pi^C2 > 0$) can profitably bid, then several outcomes are possible, most of which are competitive. Either the second challenger does not enter (i.e. $\pi^C3 < 0$), in which case the challenger and the incumbent compete, or the second challenger does enter (i.e. $\pi^C3 > 0$) then (a) either the incumbent competes (i.e. $\pi^I3 > 0$) and competition is observed, or (b) the incumbent does not bid (i.e. $\pi^I3 < 0$) in which case two challengers are certain to enter (because $0 < \pi^C3 < \pi^C5$ by assumption) and competition is observed. If the incumbent cannot profitably compete against the single challenger (i.e. $\pi^I2 < 0$), then the incumbent, either (a) a single supplier is observed (i.e. $\pi^C5 < 0$, and $0 < \pi^C2 < \pi^C4$) or (b) competition is observed (i.e. $\pi^C5 > 0$), depending on the profitability of bidding for a challenger against a challenger.

When there is no incumbent, outcomes are easily predicted. We observe competition or a single supplier, depending only on the profitability of the second challenger to a challenger, conditional on there being no incumbent (i.e. some function similar to π^C5).

If $\pi^I2 < 0$, $\pi^I1 > 0$, and $\pi^C2 > 0$ cannot all hold at once then we have effectively eliminated the possibility that the incumbent could profitably be a monopolist ($\pi^I1 > 0$), but not a competitor ($\pi^I2 < 0$) against another unprofitable competitor ($\pi^C2 < 0$), which results in sole sourcing with the incumbent. The only combination of profit functions that leads to sole-sourcing with an incumbent then becomes $\pi^I1 > 0$, $\pi^I2 > 0$, $\pi^C2 < 0$. Sole-sourcing with a challenger then results from $\pi^I2 < 0$, $\pi^C2 < 0$, $\pi^C5 < 0$, which implies $\pi^I1 < 0$, $\pi^C4 > 0$.

The fourth assumption means that $\pi^I2 < 0$, and $\pi^C5 > 0$ is sufficient to produce only an equilibrium in situation 5; $\pi^I2 < 0$, and $\pi^C5 < 0$ leads only to situation 4; $\pi^I2 > 0$, and $\pi^C2 < 0$ leads only to situation 1; and $\pi^I2 > 0$, and $\pi^C2 > 0$ leads either to situation 2 (when $\pi^C5 > 0$) or any of situations 2, 3 or 5 (when $\pi^C5 < 0$), depending on the values of π^I3 and π^C3. Hence, I say that $\pi^I2 > 0$, and $\pi^C2 > 0$ leads generically to competition. These are the conditions found in the specification of the probabilities of each situation and each observed outcome. These are summarized in Table below.

Note that it is also possible to reduce the formal model to three functions, π^I1, π^C2 and π^C5, if we assume that $\pi^I1 > 0$, and $\pi^C2 > 0$ leads either to $\pi^C5 > 0$, or $\pi^I2 > 0$. The form of the probabilities will very closely resemble those already in use except that π^I2 is replaced by π^I1. This is also summarized below.

If $\pi^{I_2} < 0$, $\pi^{I_1} > 0$, and $\pi^{C_2} > 0$ cannot all hold at once, then the following combinations of profit function values lead to the equilibrium in the table (See figure 1):

$\pi^{I_2} > 0$

	$\pi^{C_5} > 0$	$\pi^{C_5} < 0$
$\pi^{C_2} > 0$	2, 3 or 5	2
$\pi^{C_2} < 0$	1	1

$\pi^{I_2} < 0$

	$\pi^{C_5} > 0$	$\pi^{C_5} < 0$
$\pi^{C_2} > 0$	5	4
$\pi^{C_2} < 0$	5	4

If we assume that $\pi^{I_1} > 0$, and $\pi^{C_2} > 0$ leads either to $\pi^{C_5} > 0$, or $\pi^{I_2} > 0$, then the following combinations of profit function values lead to the equilibrium in the table below.

$\pi^{I_1} > 0$

	$\pi^{C_5} > 0$	$\pi^{C_5} < 0$
$\pi^{C_2} > 0$	2, 3 or 5	2
$\pi^{C_2} < 0$	1	1

$\pi^{I_1} < 0$

	$\pi^{C_5} > 0$	$\pi^{C_5} < 0$
$\pi^{C_2} > 0$	5	4
$\pi^{C_2} < 0$	5	4

Note: Numbers of outcomes correspond to those in figure 1. These are:

1: Incumbent bids and challenger does not.
2: Incumbent bids and one challenger bids.
3: Incumbent bids and two challengers bid.
4: Incumbent does not bid and one challenger bids.
5: Incumbent does not bid and two challengers bid.

Essay 4, Appendix B: Estimates using alternative samples.

No matter what specification was used, it did not prove worthwhile to use different proportionality constraints, as represented in equations (10') and (16'). The improvement in the loglikelihood was so small that likelihood ratio tests never came close to rejecting the hypothesis that (16) held instead of (16').

The tables below include estimates for LL(5) using the two alternative schemes for INCSYS and COMPSYS when GE and RCA are incumbents. The estimates labeled as (1) treat GE and RCA as separate firms from their acquiring firm. The estimates in (2) eliminate the 11 acquisitions where defining a firm was an issue. There is a similar table for LL(6). These estimates hardly differ from those in Table 5.

The estimates do not differ much in magnitude and never in the sign of an important coefficient. Moreover, the average predicted probability of the various outcomes hardly differs between the two estimates, especially for P(SI) and P(SC). Comparing columns 1 and 2 of Table 5, the estimated probability of an incumbent winning a competitive procurement (i.e. P(CI)) for all sample points is .058 higher on average in LL(5) than LL(6), and the estimated probability of a challenger winning a competitive procurement (i.e. P(CC)) is .052 lower on average. The average absolute difference between the estimated probabilities in the two equations is just above .10 (s.d. = .12). For observations in which CI = 1 or CC = 1, which enter the estimated loglikelihood, the differences in the estimated probabilities were much smaller.

Estimates from LL(7) were virtually the same as those using LL(6) and DD' was typically estimated at zero because it was constrained to be positive. I rejected the hypothesis that H:DD' = PP' in favor of accepting H:DD' = 0. Given this result, and given that the estimates do not differ greatly between LL(5) and LL(6), and since the loglikelihood of LL(6) exceeds that of LL(5), I conclude that LL(6) is superior to LL(5).

Concerns about the correlation of errors across offices within the same "office command bureau" were allayed by estimating LL(6) with a sample of systems that randomly took no more that one acquisition from the same office command bureau in a given year. This eliminated 30% of the sample but did not change the qualitative results at all. Hence, the estimates appear insensitive to this potential problem.

Appendix 4B continued

Loglikelihood (5)
(Standard errors in parenthesis)

	Sample 1	Sample 2
LOGLIKELIHOOD	-207.411	-190.781
NUMBER OF OBSERVATIONS	221	210
SINGLE BIDDER, INCUMBENT	26	26
SINGLE BIDDER, CHALLENGER	10	10
COMPETITION, INCUMBENT WINS	102	97
COMPETITION, CHALLENGER WINS	57	51
SINGLE BIDDER, NO INCUMBENT	5	5
COMPETITION, NO INCUMBENT	21	21
CONSTANT Θ5	0.06 (0.56)	0.22 (0.58)
NUM COMPETITORS' SYSTEMS	0.0063 (0.074)	0.008 (0.008)
PROCURE SIZE	0.05 (0.06)	0.057 (0.062)
NUM ACQUISITIONS IN NETWORK	0.02 (0.02)	0.029 (0.031)
DEDICATED APPLICATION	-0.06 (0.09)	-0.10 (0.12)
CONSTANT Θ2	-3.38 ** (1.27)	-2.93 ** (1.24)
IBM INCUMBENT	1.05 ** (0.29)	0.84 ** (0.26)
DOLLAR INVESTMENT	-0.012** (0.004)	-0.010** (0.007)
SUM EXPERIENCE	-0.16 (0.15)	-0.19 (0.14)
SUM EXPERIENCE2	0.025 (0.017)	0.024 (0.015)
COMPUTER CAPACITY	0.006 (0.007)	0.010 (0.007)
CONSTANT Θ1	-3.42 ** (1.47)	-3.79 ** (1.65)
NUM INCUMBENT'S SYSTEMS	0.41 ** (0.16)	0.32 ** (0.15)
NO INCUMBENT VENDOR	0.29 (0.45)	0.20 (0.49)
DDD, P. OF INC WINNING	0.36 ** (0.10)	0.38 ** (0.10)
DELTA = δ = $(\Gamma * \sigma 5/\sigma 2)$	8.03 (9.38)	6.08 (6.61)
ALPHA = α = $(\tau * \sigma 2/\sigma 1)$	1.07 ** (0.48)	1.60 ** (0.75)

Appendix 4B continued.

Log likelihood (6)
(Standard errors in parenthesis)

	Sample 1	Sample 2
LOGLIKELIHOOD	-204.942	-187.731
NUMBER OF OBSERVATIONS	221	210
SINGLE BIDDER, INCUMBENT	26	26
SINGLE BIDDER, CHALLENGER	10	10
COMPETITION, INCUMBENT WINS	102	97
COMPETITION, CHALLENGER WINS	57	51
SINGLE BIDDER, NO INCUMBENT	5	5
COMPETITION, NO INCUMBENT	21	21
CONSTANT f5	-0.12	-0.31
	(0.52)	(0.53)
NUM COMPETITORS' SYSTEMS	0.0043	0.009
	(0.054)	(0.007)
PROCURE SIZE	0.032	0.072
	(0.04)	(0.051)
NUM ACQUISITIONS IN NETWORK	0.014	0.031
	(0.02)	(0.023)
DEDICATED APPLICATION	-0.008	-0.07
	(0.03)	(0.08)
CONSTANT f2	-2.65 **	-2.84 **
	(1.03)	(1.06)
IBM INCUMBENT	0.98 **	0.92 **
	(0.27)	(0.27)
DOLLAR INVESTMENT	-0.011**	-0.012**
	(0.004)	(0.004)
SUM EXPERIENCE	-0.13	-0.18
	(0.13)	(0.14)
SUM EXPERIENCE2	0.021	0.027*
	(0.015)	(0.016)
COMPUTER CAPACITY	0.001	0.007
	(0.005)	(0.007)
CONSTANT f1	-2.87 **	-3.00 **
	(1.19)	(1.37)
NUM INCUMBENT'S SYSTEMS	0.41 **	0.36 **
	(0.14)	(0.13)
NO INCUMBENT VENDOR	0.63	0.39
	(0.45)	(0.47)
PPP, P OF INCUMBENT WINNING	0.52 **	0.56 **
	(0.12)	(0.14)
DELTA = δ = $(\Gamma*\sigma5/\sigma2)$	9.83	4.77
	(14.0)	(3.53)
ALPHA = α = $(\tau*\sigma2/\sigma1)$	1.18 **	1.19 **
	(0.52)	(0.53)

Data Appendix: Documentation of Government Inventory

The data set is taken off tapes donated by IBM corporation to the Center of Economic Policy Research at Stanford University. These tapes are copies of the Federal Government's computer inventories for the years 1967 through 1979, and 1983. Summaries of this data and part of the machine, system and unit records for all CPUs are published in the Federal ADP inventories (1960,1,4-83 in Stanford Government Documents).

This appendix describes the procedures used to identify all the acquisitions of systems by offices within the Federal government between 1972 and 1983. Each of these acquisitions was then associated with summary statistics of the stock of systems at the office in the previous year. Acquisitions first noted in 1983 are associated with characteristics of the office in 1979. This comprises the data used in essays 2, 3 and 4.

GSA altered their inventory collection procedures after 1983. Hence, my sample period ends in 1983. The data set begins in 1972 rather than 1971. The 1971 information is not used, because Martha Gray tells me that she found that that year's data was suspect when she did her statistical compilations (1977, 1979, 1981, 1982). This is plausible since it was the first year of a new format was adopted by the General Services Administration (GSA).

The inventory was originally designed to show at any point in time the character of the computer holdings of the federal government. It is not designed to track systems or machines over time and needs considerable alteration and "cleaning" to do so.

Government officials familiar with the inventory feel that it is most accurate when recording large machines and increasingly less so with smaller machines. All have suggested that certain other types of systematic reporting errors are prevalent, most of which were controlled for when the sample of systems used in this research was constructed. How these were anticipated and how other problems were handled is detailed below.

Characteristics of the Raw Data

Labels for system designs were eventually standardized by GSA (See Gray "Adp/MIS Master Table File, EDPE Manufacturer System Table", 2-2-81). Martha Gray has warned that agencies occasionally fit their systems to the "closest" label if the system did not quite fit in. Inspection indicates that this does not appear to be a big problem for the general purpose class of systems, however. It is more true for SGD systems (special government designs) and some military systems, which are not used in the work of this dissertation.

Processors were identified by their serial numbers. Serial numbers are unique for every agency - unit - system - manu - machine type - model in any given year. However, they can be identical across the same machine types in different systems, or in the same system across machine types, and most certainly across adpu units for different or the same machine types. They are not constant over time for a set of over two hundred machines though the relationship of parent to child is usually obvious. A number of steps, detailed below, describe the necessary corrections.

Acquisition dates in the inventory records are hard to interpret, though they do not tend to change with time, for the most part. Acquisition date is the one used in all the 'average age' calculations done by GSA (1986, 1987). Conversations with Martha Gray indicate that the "purchase date" is supposed to be the date when the contract is signed and money possibly changed hands and "unit acquisition" the date (sometimes much later) when the unit actually took delivery of the machine. "Acquisition date" is supposed to be the date of the machines physical arrival to the GSA warehouses and is often the date the money actually changes hands. Given the wide variety of time intervals between the dates (and often there is none) it is hard to say what those categories really meant when they were filled out. Hence, I relied on the year that an acquisition first appeared in the inventory as the indication of the year of acquisition.

Each machine was given an identifier code composed of the concatenation of its department code, adpunit number and serial number. The earliest known data, as far back as 1972, for a given record is then assigned to most of the categories. If the earliest information in a field is blank then the following year's data is assigned in that field.

General Purpose

The only data assembled is restricted to CPUs in systems that are large mainframes and "General Purpose" in my estimate. The determination of what systems were and were not "general purpose" was done through a laborious reading of IDC industry surveys (1974-1983, Stanford Jackson Library, EDP Industry Report), Auerbach Reports (1968 - 1975, GSB Library again), and Phister, 1979.

A system acquisition was included in the data set if its system number was exactly named in the IDC reports on "General Purpose" [1] systems (1974 -1983 [2], with a definition change after 1977 that excluded smaller business systems, which were not included). This accounts for over 80% of the system names eventually included and most of the systems in the data set. Hence, obvious general purpose systems making up the vast majority. If the system name was exactly mentioned on the IDC reports for "minicomputers" (1977 - 83), "dedicated application systems" (1974 - 1977), "desk top computers" (1981 - 1983), or "small business systems" (1978 - 1983) then it was excluded, with the notable exception of the Digital VAX family (in chapter 2)[3].

Please note, that IDC does not distinguish between "general purpose" use and "scientific" use in these market definitions, a distinction that could have been made when describing second and some third generation machines, but increasingly less so as the decade proceeded.

I relied on IDC's market definition, because they have more analysts and resources than I do and they are well known market research firm with many clients who pay good money to have the industry trends categorized for them. Thus, I am willing to follow their definitions pretty strictly, since many in the industry also do so. It is possible to quibble with some exclusions on the margin, but I chose not to do so because of the absense of a consistent set of principles to apply.

This still leaves a number of systems in an ambiguous area. When in doubt, exclusion from, or inclusion in the data set was determined by the following principles: 1. All Special Government Designed system were eliminated; 2. Any military system with an especially unrecognizable name (which might have something to do with the system's function), such as "ANGY5087" was also excluded; 3. Any system whose first numbers "matched" others that were mentioned in IDC or Auerbach reports, but whose whole number was not mentioned, were assumed to be from the same family. For example, the Univac 1717 was assumed to be part of the 1700 series, all of which were included, and the CDC Cyber 70 was included, even though CDC formally only produces the Cyber 72, 74 and 76; 4. If the above was not enough, then I looked at the processor to see if it was familiar, or possibly that system's name in other years; 5. If after this procedure, a system was still in doubt, i.e. if nothing resembling it was mentioned anywhere in IDC, Auerbach or Phister, then it was excluded. This presumes that "General Purpose" and "popular" or "well-known" are similar, which makes me uneasy. However, most of these ambiguously named systems appeared in only the military, typically in only one branch, and often at only one site, and look like nothing else in the whole inventory, and they just do not amount to very many systems. The presumption of dedicated application or special design is probably a fair one to make for these systems. At the very least, the resemblance of these systems to general purpose systems outside the government is doubtful.

On the whole this leaves a data set confined to large general purpose mainframe systems that resemble the general purpose mainframes used in the private sector.

Complications with assembling the inventories over time.

When making a catalogue of the acquisition of a new systems by agency offices, it was obvious that the time-series data set initially constructed had internal inconsistencies, the first being a small but significant number of repetitious data records. This was caused by three features of the raw data from the inventories: 1. The same serial number could be assigned to two machines in different systems at the same unit; 2. The same serial number could be assigned to two different types of machines in the same system. 3. Records could be repetitious because someone had failed to delete an old record when a new feature for the new record was entered.

Several solutions to the above problems were tried. First, the obviously inconsistent records, identified by looking at the raw data, were eliminated. Then, the records were again called up and recombined with an extra code designed to make each record unique. Once this assignment was made, it resulted in 8763 unique machine records.

The major troublesome decisions occurred when there was a repetition of serial numbers for machines which were not in different systems. Machine records would seemingly repeat themselves in a given year because the central inventory keeper had failed to delete a recently updated model. That is, if some feature of a machine changed in a given year (say its maintenance contract), sometimes that machine's record would appear twice in that year's inventory -- one with the old information and one with the new information, giving the appearance of two machines in existence. In the few cases where this seemed to occur and the record only appeared once in any year except 1979, I counted only one machine and deleted the other (note: this means that my cumulative statistics will disagree slightly with Martha Gray's and IDC's (found in NBS 1983)). On the other hand, if the machine record appeared in more than one year, no matter how unlikely it seemed to me that another machine existed instead of someone simply failing to eliminate that record, then I let the machine record stay as it was and distinguished it from the others with similar features.

These are tough decisions which will affect the less than two dozen records in the dataset. However, these two dozen data points did not seem to play a crucial role in later analysis. Hence, reconsideration of their data points was not made.

Changes that are changes in name only

The data set also accounted for changes in serial numbers over time and changes in ADPU numbers that do not indicate any change in the physical location of the machine. The principles for determining how to code that a changed serial numbers in the raw data was probably an error or a deliberate alteration went as followed: (1) If the records are nearly identical (including acqdt, sysid, and adpu) in all records except transdt; AND (2) (a) The serial numbers are similar enough to suggest a new person filling out the form without consulting the previous form or a managerial decision to append serial numbers to indicate ownership, as in DOE -- the majority of the cases, or (b) The serial number change in the only difference between identical records; AND (3) The life histories of the machines fit together perfectly, usually eliminating a seeming inconsistency between the acquisition year and the appearance of the machine in the inventory...then these were counted as the same machine at the same location.

A number of other records apparently did not change physical location, even though a change was apparent due to change in ADPU number. The principals for determining inclusion when a move did and did not take place were: If (1) Identical records (including acqyr and serial and sysid) appear in all field except adpu and transdt (suggesting that a new form was filled out); AND (2) The two adpu offices are similar enough in at least one of the three identifying categories for an agency ADP unit -- i.e. office, activity (or contractor), and managing city -- to suggest a renaming of location and not an actual physical relocation of machines; AND (3) The life histories of the machines fit together so as to eliminate an apparent inconsistency between the acqdt on a machines record and when it first appears in the inventory; AND (4) No interagency transfer code (=1 or 2) appears or is altered in conjunction with the adpu change. That is, if 1 or 2 appeared then a machine was presumed moved unless the 1 or 2 was part of the record before the adpu change and it did not change when the adpu unit also changed; OR (5) Most of the above (3 of 4) holds and a wealth of similar changes across a number of machines suggests that all underwent the same location renaming.

There also were several agonizing decision here, particular in deciding whether an adpu number change was a change in location or not. Since an interagency code exists to indicate when such moves occur, and my investigation indicated that when it did so, it was accurate, I was inclined to think that most adpu unit number changes were in name only. In other words, the location records had to be pretty dissimilar to convince me that a system moved and that someone had neglected to fill in the correct code. This seemed to be the proper place to put the burden of proof.

In sum, all the acquisitions of systems by offices within the Federal government between 1972 and 1983 was associated with summary statistics of the stock of systems at the office in the previous year. Acquisitions first noted in 1983 are associated with characteristics of the office in 1979. This comprises the data used in essays 2, 3 and 4.

Endnotes

1. IDC's 1974 - 1980 lists contain the following header: "...The computers included...comprise the bulk of digital computers (by value) in operation. They are byte or character oriented -- with the exception of large scale scientific machines -- and are primarily programmed in higher-level languages. " After 1981 the list includes the following sentence: "General Purpose computers -- as characterized by IBM's system/3, system/38, 370, 4300, 303x, 3081 and competitors -- are designed for use in a wide variety of applications."

2. Because of increasing ambiguity between market segments, in 1982 IDC proposed a new organization, which it adopted for 1983 and thereafter.

3. Dedicated application systems include the remark: "...are those commonly referred to as minicomputers, plus certain larger systems designed primarily for a single application such as process control, data communications, and data entry. ...though general purpose by design -- are typically word oriented..., usually sold outright, and predominantly programmed in machine language... Exceptions in all cases do occur. Indeed, definition is becoming increasingly difficult, and subjective judgement is necessary..."

Minicomputers are defined as "...general purpose in design but sold as tools, not just solutions; are available from the makers as complete systems, not just boards; are available to OEMs and usually discounted in volume buys; and are part of a family that has at least one product in the $2000 - $25000 price range and comes with at least 4K RAM." Later additions further note that super-minis were increasingly competing with those in the general purpose category.

Small Business systems were defined as "... those small general purpose computers marketed by the major mainframers and their competitors to small business and first time users. they include offerings from the major mainframers (old size class 1 in the superceded Group A census); products...from the mini-makers aimed at commercial first time users; offerings from firms... that manufacturer only SBCs; and offerings from companies that assemble systems from other's minis..."

Desk top systems were definitely in a separate market.

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