Lock-in and the Costs of Switching Mainframe Computer Vendors in the US Federal Government in the 1970s

SHANE M. GREENSTEIN

No careful empirical research has tested the widely held belief that the cost of switching computer vendors tends to produce technological "lock-in," meaning that the cost of switching between incompatible vendors is prohibitively expensive. Using several studies by federal agencies into the costs of switching mainframe computer vendors, this article concludes that mainframe computers of the late 1970s possessed many of the features typically associated with lock-in. However, many other factors also attenuated tendencies to lock-in. While lock-in was important for the outcomes of several well-documented instances, it is not clear whether lock-in was important for the outcomes of a wide set of cases.

> 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, . . . 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, 1987[1]

Switching costs are expenses incurred as a consequence of a buyer switching between alternative suppliers of essentially the same product. Large switching costs can make buyers reluctant to switch to incompatible technologies. Often this means that these users are also reluctant to switch to incompatible vendors. This reluctance has two important consequences. First, it potentially provides incumbent suppliers with market power.[2-12]* Second, it may influence buyer and supplier choices among alternative technologies for a product. Markets may "lock-in" technical alternatives compatible with early technological leaders and "lock-out" incompatible alternatives.[13-19]**

Lock-in occurs in a surprisingly wide variety of forms and contexts. Notable empirical studies of technology lock-in include studies of nuclear power plant design,[20] videocassette recorders,[21] the typewriter keyboard,[17,18] and stereo systems.[22] These studies show that if a user invests in systems of compatible components, some past investments retain their value when the user purchases more compatible components but lose their value when the user purchases incompatible components. This produces an inter-temporal link in a buyer's decisions, which in turn influences producer pricing, output, and product-design decisions over time. All these links help produce technological lock-in.

The computer market is another example often cited as one that fits the mold. Because users of computer systems invest in systems of compatible components (hardware and software), it is widely believed that computer users tend to "lock-in" to their incumbent vendors.

No careful examination of the computer market has confronted this belief with empirical fact or with skepticism. This is unfortunate because the belief need not necessarily survive the close scrutiny of such a confrontation. By itself, the fact that buyers invest in a system of compatible components does not establish that buyers find the cost of switching vendors greater than the benefits of doing so. Nor, by itself, does it establish that buyer and vendor decisions are linked in a way that produces technological lock-in.

Why has this belief not been examined? The absence of empirical research on this issue is probably best explained by the difficulty of collecting information about the majority of computer users in the United States, who are employed by private firms. Summaries of many users' experiences with changing vendors, if there is any experience at all, are usually not publicly available. What is often made public are surveys of "customer loyalty," which provide ambiguous inferences regarding the relevance of switching costs to most buyers' decisions.[23,24]*

---

*See References 2-10 for theoretical work on buyer behavior when it is subject to switching costs. Also see References 11 and 12 for a stimulating discussion (and skepticism) about the role of lock-in for the mainframe market.

**See References 13-18 for recent theoretical analyses of the "lock-in" phenomenon. See Reference 19 for an overview of the extensive standardization literature, which overlaps with the literature on both lock-in and switching costs.

*See International Data Corp., *EDP Newsletter*, 12/18/74, 2/12/75, 12/8/75, 1/21/77, 12/5/78, and 12/29/80.[23] See Reference 24 for a discussion of these surveys and the difficulties of interpreting them.

1058-6180/95/$4.00 © 1995 IEEE

Because of the dearth of information about private firms' experiences, it would be remarkable if enough examples existed for an empirical study of technological lock-in. One of the contributions of this article is that it brings one such set of examples to light.

The set of examples used in this article were recorded in the late 1970s. At that time many federal agencies began to experience large expenses related to the conversion of their software from one mainframe architecture to another. These "conversion costs" raised a number of unexpected problems when agencies ordered replacement acquisitions. Because of these problems, the topic of conversion was closely studied by several federal oversight agencies: the General Accounting Office (GAO), the National Bureau of Standards (NBS), and the General Services Administration (GSA), all of which employed specialists in the computer field.[25-34]* These studies left a detailed and public record of the conditions surrounding more than a dozen actual acquisitions and the solutions attempted to conversion problems.

This article aims to synthesize these studies for an audience interested in the economics of lock-in. It will identify the structural conditions contributing to switching costs and lock-in, when it occurred in practice. The article verifies what was long suspected: Mainframe computer systems possess many of the technical features that may lead to large switching costs. That is, computer systems exhibit "technological interdependence," and incumbent vendors have advantages in a competitive procurement. The analysis also points out, however, that many other factors attenuated the full impact of switching costs on buyer behavior. Since empirical evidence on the magnitude and importance of switching costs for vendor choice is inconclusive, this article motivates a closer examination of the incentives of those making decisions subject to switching costs.

The main danger in studying US federal agencies is that their experiences may not represent those of other mainframe users in the country. Though total expenditure on computers by public and quasi-public organizations represents roughly a quarter of the United States' computer market, federal agencies constitute less than 5 percent of the mainframe market.[23] To guard against the danger of inference from an odd example, the discussion focuses on agency use of commercial general-purpose computers commonly used in the United States in the late 1970s and early 1980s.[35]** Moreover, the discussion highlights where the federal procurement process resembles or differs significantly from that of other mainframe users, universities, and private industry.

*An extensive record exists. The most relevant studies for this article include investigations on the problem from the General Accounting Office,[25,26] the General Services Administration's Office of Software Development and Information Technology,[27-32] and the National Bureau of Standards,[33,34] as well as studies cited in the last two reports. A partial bibliography is produced in the references.

**Gray provides a discussion of general-purpose applications in the federal government.[35]

Switching costs for mainframe computers in federal agencies

Technical interrelatedness and incompatibility. In most models of buyer choice subject to switching costs, a buyer makes investments with a supplier that continue to have positive value if the same supplier of compatible technology is selected again, but the investments have no value if any other incompatible supplier is chosen. The standard reference case is one where an old and depreciated system is replaced with a new, similar system. Some old investment, such as software, works with new system hardware from the incumbent supplier, but not with hardware from any other supplier. It's as if the nonincumbent supplier charges $P_{ni} + S$ for his system and the buyer pays that price, while the incumbent charges P_i for essentially the same system, where S is the value of the old equipment the buyer will continue to use with the new system. Of course, this simplifies matters because expenses are not entirely for replacement. Even if users also upgrade and modify their system, they will tend to buy from the manufacturer of compatible equipment.

Mainframe computer systems possess many of the technical features that may lead to large switching costs.

Previous research has identified several technical features of products that result in switching costs, and not surprisingly, these features can be found in mainframe systems. Commercial computer systems display what Paul David[16-18,36] has called "technical interrelatedness": (1) generating output requires a multicomponent system, and (2) the collection of components must be technically compatible to work together and achieve efficiency in system performance.

It is easy to illustrate the two aspects of technical interrelatedness with mainframe computer systems. First, they are obviously multicomponent. 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, system software, and application software. These components are often supplied by the same firm, but need not be if there is more than one supplier of incompatible technology. Note, however, that though hardware equipment complementarities are important, the most important complementarity for economic purposes is the relationship between hardware and software and/or software and human training, which is hard to observe or quantify directly.

Second, compatibility plays an obvious role in agency decisions. Incompatibilities can occur on many levels:

- Plug and socket do not necessarily fit together physically, or if they do fit together, they may not translate electronic signals in a similar manner;
- system software is usually unable to work with hardware architectures other than the one on which it is written unless the software is altered;
- higher level software can be incompatible with particular system software implementations available on the new machines;
- higher level software that is optimized for implementation on one machine architecture can lose significant performance if implemented on another system.

Incompatible software is not a dichotomous variable; rather, it describes a condition that varies by degrees.* For example, higher-level-language software will transfer across some incompatible operating systems, while data files written in a particular form may be unsuitable for specific hardware models.[33,34] As another example, different manufacturers' systems use different system software, requiring retraining of the personnel who use the system; yet many of the skills developed on one operating system carry over to another. The more similar the operating systems, whether developed by the same or a different manufacturer, the more skills that are carried over.

Because of all these levels of technical interrelatedness, most switching costs resulted from changing from one incompatible operating system to another, not from changing suppliers per se. Yet, there tended to be a one-to-one association of suppliers with computer mainframe technical families in the 1970s and early 1980s,[37]** with a few notable exceptions. First, not all IBM systems use the same system software, so moving between families of systems was potentially costly. Other exceptions came in two forms: Several manufacturers made plug-compatible IBM System 360/370 peripherals and two firms made plug-compatible IBM System 360/370 CPUs and their descendants.† In principle, users could "mix and match" components in the 360/370 operating system from different manufacturers by the end of the 1970s.

What was done in practice? Tables 1 and 2 (pages 63 and 64) show little evidence of the use of plug-compatible CPUs. For example, Amdahl had only a tiny number of sales by 1983. It was also well known that most CPUs within a system made by another firm are used as front-end servers for the main CPU within the system. This evidence suggests that switching to products made by (non-IBM) compatible peripheral firms was easy, but switching to products made by compatible CPU firms may not have been as easy.

In addition to the direct costs of converting software, switching costs also arise because of

1. site preparation, such as raising floors, installing new cooling units and new electrical and communication connections;
2. training personnel to use a new vendor's unique system features;
3. dual operation of systems while one is installed, tested, and brought up to an acceptable operational level;
4. disruption of operations while new hardware is installed; and
5. reoptimizing new systems to unanticipated problems.

Most of these expenses are minimal if one stays with the same supplier when upgrading mainframe purchases, but the costs of (2), (3), and (5), and especially switching software, can be substantial if a change between suppliers of incompatible technologies occurs (see GAO, Appendix II).[26] The costs of converting software depends on many factors, for example, how much application and third-party software is customized to an operating system. More will be said about these costs below.

Other evidence of lock-in: Incumbent's competitive advantages. With vendors offering incompatible systems, was there evidence that many factors worked to an incumbent's advantage in a competitive procurement to replace hardware?[25,38]*

Long-lived assets obviously give the incumbent an advantage. Different components depreciate at different rates, leaving, at any time, some components that could continue to be used in future systems and some that require immediate scrapping. For example, the median age of processors of commercially available general-purpose systems in 1979 was six years (mean = 6.3, s.d. = 3.6).[26]** In addition, software and programming obviously

---

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

**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*,[37] for example).

†A limited amount of CPU compatibility across firms also existed. (For example, the RCA 7000 series, IBM 360/370 series, Amdahl, and National Advanced Systems all roughly fall into the same product family.) However, these constituted a small fraction of total federal sales through the early 1980s.

*Competitive procurement means that agencies hold an auction for the right to provide some component of their system. In practice, agencies may anticipate that one vendor is likely to possess a large advantage over all competitors. In this case, the agency may choose to bypass competitive procedures and sole-source (see References 25 and 38).

**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 six to eight years. (See Reference 26 for an example.) Focusing only on length of life of assets paints a somewhat deceptive picture, however. Also important is whether that old hardware, software, or training continues to have value in use. Generalizations are difficult because the details vary from one situation to another. In some instances, the interrelationship between the idiosyncrasies of an application and the idiosyncrasies of software constrained changes in the applications, which left the incumbent as the natural supplier of complementary components. In other cases, where the applications were in need of radical alteration, rewriting most of the system software was a viable economic alternative and the incumbent's advantage was partially attenuated.

do not physically fall apart, nor is previous training immediately forgotten.[17]* Once operational, software and training are useful as long as the proper complementary components are in place. Hence, to provide an equivalent, fully operating system, the nonincumbent must supply features already supplied by the incumbent.

Software that was difficult to transport also contributed to an incumbent's advantage. Software lost some (if not all) of its functionality when implemented on alternative systems, even on hardware that was technically more advanced, because software typically embodied features needed for a unique application in the agency, was technically complementary to the system on which it was developed, and was written for a fixed set of users trained to use it. Examples of functional loss due to transportation of software are numerous. The GAO[26] reports a case of converting line for line a program that previously took 3 minutes but then took 45 minutes to operate on a new system. It also reports a case where a program that previously took 5 hours then 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 to run when completely rewritten).

Another factor contributing to an incumbent's advantage in a competitive procurement involves the time it took to correct conversion problems. It is well known 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. This process is often known as "tuning" a system. Moreover, this trial and error must occur in sequence — only after one part of the program is polished can another be developed. In addition, programmers cannot usually anticipate all the practical difficulties to achieving a desired "look and feel" in system performance. Agencies' experiences confirm this general property of software design: 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.[39]**

The consequence of these technical constraints should not be underemphasized. Buyers typically do not know with much certainty the likely future monetary level of switching costs, the overall feasibility of conversions, or the likely length of time to complete a conversion. Users faced a choice between (1) a relatively "quick" conversion to a compatible system, or (2) a longer wait (as much as a year or more) at unknown cost to install a new working system from a nonincumbent, which usually implied a lengthy dual-system operation. The net result was that the overall "cost" of the move between incompatible systems was uncertain. Agencies could anticipate that there would be problems during conversion, even if they could not anticipate what those problems would be.

Large conversion expenses were inherently difficult to estimate, even for experienced conversion experts.

Another factor contributing to an incumbent's advantage in a competitive procurement involves the time it takes to correct conversion problems.

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 poor documentation of earlier programs, 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 "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 many creators had departed from the agency. The GAO (pp. 20-21)[25] blamed most poor documentation quality on programmers who sacrificed documentation to other urgent needs of the past and on programmers who developed patchwork and unsystematic code due to insufficient care.

In the 1970s, agencies could either invest in preserving old software on new machines or invest in reinventing their software on the new hardware. Either option was time-consuming and costly. In-house conversions usually took too long because the required number of programmers exceeded an agency's available staff, especially with large jobs. Moreover, experienced staff usually had little experience with conversion and misunderstood what was required. Programmer knowledge about software implementation and programming procedures was useful on an old system but not necessarily useful on a new system.[26]* It was no better out-of-house: Contracting out for conversion services could be quite difficult and expensive 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.

*There was an analogous phenomena in the typewriter keyboard case. David notes that the durable asset in that case was the memorization of keyboards by a touch typist.[17] Like software for the human mind, it was costly for some users to reprogram themselves.

**See Brooks[39] for a similar emphasis on the technological necessity of solving complex software design problems in sequence rather than in parallel. Each subproblem needs its approach to be based on solutions to previous problems in the sequence.

*This last switching cost is typically incurred during "retraining" and does not include nonpecuniary costs such as morale or staff turnover. (See GAO, p. 44.[26])

Many private firms were undependable, and agencies frequently had to use their own staff to refine the conversion programs for which they contracted (GAO, pp. 49, 51, 52, 57, 61).[26]

Many of these problems were difficult to anticipate until software conversion was underway or largely accomplished. Not surprisingly, conversion costs could be greatly underestimated or overestimated if the agency's office was not very experienced with conversion. With a few exceptions, most staff were not experienced, since conversions occur infrequently at the same location. Conversion costs could also be greatly underestimated or overestimated if the conversion work contained several unpredictable and largely intractable problems.

The uncertainty due to switching costs, as well as their magnitude, plays an important role in vendor procurement in the federal government. The estimation of uncertain costs largely determined future decisions. A large underestimate of the costs of switching vendors could lead (ex post facto) to an "unnecessary" and costly switch to a new vendor. A large *over*estimate effectively grants an incumbent vendor monopoly power over the next upgrade, which can lead to a more costly acquisition price.[40]*

Switching costs and uncertainty contributed to the advantages of incumbency, but technical change was an important countervailing factor. During the 1970s, many of the large system manufacturers were competing to develop new applications for their systems and to reduce their costs in order to attract new users and prevent the exit of marginal users. New government users could especially benefit from the well-known and well-documented[41,42] decreases in price/performance for newer systems. A large lead in price/performance by one firm or system over an incumbent's system could be sufficient to motivate a buyer to incur the costs of switching for the additional benefits. Technically motivated moves were especially likely when old system applications were in need of radical redesign — that is, the amount of software being preserved was small and the database was not large. A certain amount of "technology lust" also motivated some moves, but there is little to indicate how important or decisive this particular motive was.

The costs of conversion. Establishing the existence of switching costs, by itself, does not demonstrate their relevance over a wide range of situations. Switching costs matter most when 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 earlier, are not relevant to vendor selection where old technologies have been orphaned — for example, no new upgrade is available, which was not uncommon in the 1970s. Incumbents no longer possess advantages because the old equipment is not upward compatible with any new generation. All potential vendors and the incumbent are on equal footing. However, an orphaned system's switching costs may influence other aspects of new system choice, such as the timing of an acquisition.[29,31]*

What is the quantitative evidence that the switching costs were a large problem in many cases? Despite much information about computer procurement, an answer is difficult to formulate because the relative influence of switching costs on buyer decisions is not easy to measure, and disclosure laws prevent outsiders from examining the costs that influenced decision making in an actual acquisition.

However, several publicly available studies were done of federal agency conversions. These are summarized in the appendix to "Computers, Compatibility and Economic Choice."[24] These studies found that the total switching costs between incompatible systems could vary over a large range. They could be anywhere from 22 to 250 percent of the price of the acquisition of the new system, depending on management practices, software quality, and other uncertain factors. The estimated and actual costs (mid-'70s dollars) of software conversion alone were large: $1.5 million for software conversion at the EPA; 531,000 lines of code converted for an estimated $950,000 at the naval base in Norfolk; 125,000 lines of applications for an estimated $559,000 at the naval base in Jacksonville; 332 application programs for an estimated $486,000 at the naval base in Pensacola, but 291 programs eventually were converted for $4.5 million; 14 of 571 programs 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 Veterans' Administration. In contrast, the one compatible upgrade had total software conversion expenses of $13,900. These cases slightly overestimated net conversion costs, because even an upgrade with the same supplier will contain some switching costs; but they underestimated switching costs by neglecting some nonpecuniary costs.[24]**

By another measure, these conversion costs were many times the average monthly rental for the newly acquired system, though admittedly, these are ball park estimates. These estimates were computed by taking the estimates of total conversion costs in the case studies and comparing them with the average system price, as listed in the

*In a competitive procurement in the 1970s vendors could and did bid against one another, even if one had a system compatible with the user's while another did not. If S represents the estimate of the costs converting to a new system, then the level of S largely determines the bidding behavior of the two vendors. These bid prices then determine the likelihood that a user will switch vendors. (See Cabral and Greenstein.[40])

*There is some evidence to suggest that federal users of Control Data systems persisted in holding on to their "orphaned systems," delaying new purchases for a long time.[29,31]

**See the appendix in Reference 24 for a conversion costs component breakdown.

Table 1. System supplier for stock of general-purpose mainframe systems.

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	1,205	1,186	1,166	1,087	1,044	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
MANU	71	72	73	74	75	76	77	78	79	83
Total	3,229	3,053	3,037	3,860	2,646	2,544	2,508	2,565	2,509	2,395

Notes: The table includes only commercially available general-purpose mainframe systems, as defined by IDC EDP Industry Reports (various years), and Digital Equipment Corp. VAX systems. The table includes only acquisition of federally owned or leased systems from external supplier.
Source: Federal ADP Equipment Inventory, 1971-1979, 1983, original data. See GSA ADP Activities Summary, various years; References 1-4 below; and Reference 5 for summaries and detail.

References

1. M.M. Gray, *Computers in the Federal Government: A Compilation of Statistics*, June 1977, C13.10:500-7.
2. M.M. Gray, *Computers in the Federal Government: A compilation of Statistics — 1978*, Apr. 1979, C13.10:500-46.
3. M.M. Gray, *Federal ADP Equipment: A Compilation of Statistics — 1981*, Nov. 1982, C13.10:500-97.
4. M.M. Gray, *An Assessment and Forecast of ADP in the Federal Government*, Aug. 1981, C13.10:500-79.
5. S. Greenstein, "Computers, Compatibility and Economic Choice," unpublished doctoral dissertation, Stanford Univ., June 1989.

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 22, 23, 27, 50, 68, 79, 150, 210, and 250 percent of the purchase price of a typical system. The other estimates 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.

All these studies leave the impression that switching costs are distributed asymmetrically — bounded from below and skewed upward by a few especially costly unpredictable circumstances. However, some allowance in these numbers must be made for the limited technical expertise concerning switching costs in the late 1970s within the US federal government. Once switching costs were better understood, they should have been lower. Nevertheless, these studies leave the impression that the costs could only partially be attributed to the limited technical expertise. Even where there was some expertise, as in the military, the costs could still be substantial.[26]

The lowest conversion expenses involved 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. These conversion expenses totaled 1 percent of the price of acquisition, or one half the cost of one month's average rental.

There are several reasons to think that conversion expenses in federal agencies could add up to a lot of money. The installed stock of commercial general-purpose mainframes, as shown in Table 1, is quite large, often exceeding 2,000 systems in any year.[24]* Table 2 on the next page shows 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.

References 25-34 are publications by federal oversight agencies that dealt with problems related to switching vendors. There is also considerable documentation by oversight and advisory agencies providing aid in the form of expert advice, bibliographic material on conversion tools, and other managerial guidance material. For example, in the early 1980s the GSA created the Office of Software Development, which has experts in conversion problems, professionals who are experienced in the special tools required for these problems. It is hard to imagine that this effort would be expended if switching costs

*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 in Reference 24 for a definition of commercial systems.)

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	2,282

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 1980-1982, all acquisitions in these years were estimated from inventories for 1983.

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

were not a problem for a substantial number of federal agencies. Ironically, the effort to extinguish the blaze, as represented by the federal oversight agencies' publications cited in the references,[25-34] is the best evidence that the blaze was large in the late 1970s. It is also evidence that it may be under more control by now.

Statistical evidence of buyer behavior. Despite the previously described suggestive evidence, systematic statistical evidence of buyer behavior must lead to ambiguous conclusions if not examined carefully. 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 a customer's anticipated switching costs or buyer preferences; thus, data does not permit an observer to distinguish between the effects of switching costs and other preferences in describing a user's temporal patterns of purchases. Econometricians have not found methods for solving this problem other than by imposing arbitrary functional forms. (See Heckman and Singer[43] and Greenstein.[44])

Despite these difficulties, I found some evidence[44] that incompatibility influenced vendor choice from 1972 through 1983. This research investigated the patterns of vendor choices by offices of federal agencies that had experience with only one vendor prior to their next acquisition. It found that after many economic factors were accounted for, a large part of the tendency for former IBM users to switch to other vendors arose primarily from the fact that limited compatible upgrades were available for users of very old IBM equipment (for example, the IBM 1400 series). Federal buyers who previously used IBM equipment and could upgrade to a new compatible system (say, IBM 360/370) tended to choose IBM as often as users of other vendors selected those vendors again. This result is the first econometric analysis of the relevance of compatibility for vendor choice.[44]*

Other quantitative work yields more cautious conclusions. I have investigated whether the extent of a user's investment, which should correlate with switching costs, helps predict whether agencies sole-sourced rather than competitively procured from an incumbent.[38] This research formally tested the hypothesis that high switching costs could give incumbents such an advantage that only the incumbent would bid and agencies would have little reason to solicit multiple bidders under competitive procurement procedures. A sample of single-incumbent users revealed that the extent of investment with an incumbent does positively predict sole-sourcing from the incumbent, but (contrary to expectations) it does not dominate other economic factors such as the costs of changing bids and the supply conditions in the market. Many other economic factors influenced the choice of procurement procedures, and these can often overwhelm any apparent (and measured) advantage an incumbent seems to have.

Mainframe computer systems display the technical features typically associated with switching costs. However, several countervailing factors, such as technical

*In addition, I have argued[44] that evidence is consistent with the view that most switching costs originate with the installation of the first system. In other words, the user pays a one-time expense in order to learn how to use a vendor's machines. All subsequent hardware acquisitions after the first do not contribute much to the costs of switching vendors later.

change and the entry of plug-compatible manufacturers, began to attenuate the full force of these factors on buyer behavior by the late 1970s.

The evidence in government documents is suggestive but inconclusive about the importance of switching costs for a wide set of cases. A deeper understanding of switching costs and lock-in warrants careful analysis of actual acquisitions. It is important to understand the incentives of managers and users to bias their estimates of switching too high or too low in order to enhance the advantage to an incumbent vendor. Previous user management decisions also influenced the costs of switching vendors when a switch was made, because users who did not anticipate conversions made investments that resulted in higher switching costs than experienced by those who did. If conversions are a likely option, it is important to understand the incentives of managers to account for the value of making efforts to reduce their future costs. At the very least, we should expect to find in public and private firms a variety of responses to these difficulties. Those responses ultimately determined the observed tendency of buyers to lock in to incumbent vendors in practice. ■

Acknowledgments

Tim Bresnahan, Paul David, Roger Noll, Pablo Spiller, J.A.N. Lee, and an anonymous reviewer provided useful advice. The Center for Economic Policy Research at Stanford University, the Charles Babbage Institute, and the National Science Foundation provided funding. All remaining errors are mine.

References

1. Office of Technology Assessment, *Federal Government Information Technology: Management, Security and Congressional Oversight*, Feb. 1987, Y3.T22/2:2F31/2, p. 20.

2. J. Farrell and G. Saloner, "Standardization, Compatibility, and Innovation," *Rand J. Economics*, Spring 1985.

3. J. Farrell and C. Shapiro, "Dynamic Competition with Switching Costs," *Rand J. Economics*, Spring 1988.

4. J. Farrell and C. Shapiro, "Optimal Contracts with Lock-in," *American Economics Rev.*, Mar. 1989.

5. P. Klemperer, "Markets with Consumer Switching Costs," *Quarterly J. Economics*, Vol. 102, 1987.

6. P. Klemperer, "The Competitiveness of Markets with Switching Costs," *Rand J. Economics*, Spring 1987.

7. D. Scheffman and P. Spiller, "Buyers and Entry Barriers," mimeo., Univ. of Illinois, 1989.

8. C.C. von Weizsacker, "The Costs of Substitution," *Econometrica*, Vol. 52, No. 4, Sept. 1984.

9. O.E. Williamson, *Markets and Hierarchies: Analysis and Antitrust Implications*, Free Press, New York, 1975.

10. O. Williamson, "Transaction-cost Economics: The Governance of Contractual Relations," *J. Law and Economics*, 1979, pp. 233-261.

11. F. Fisher, P. McGowen, and J. Greenwood, *Folded, Spindled and Mutilated: Economic Analysis and US vs. IBM*, MIT Press, 1983.

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

13. B. Arthur, "Competing Technologies: An Overview," in *Technical Change and Economic Theory*, Dosi et al., eds., Pinter Publishers, London, 1988.

14. B. Arthur, "Competing Technologies, Increasing Returns, and Lock-In by Historical Events," *Economic J.*, 1989.

15. R. Cowan, *Backing the Wrong Horse: Sequential Technology Choice Under Increasing Returns*, thesis, Stanford Univ., July 1987.

16. P. David, "The Landscape and the Machine: Technical Interrelatedness, Land Tenure and the Mechanization of the Corn Harvest in Victorian Britain," in P. David, *Technical Choice, Innovation and Economic Growth*, Cambridge Univ. Press, 1975.

17. P. David, "Clio and the Economics of Qwerty," *American Economic Rev.*, May 1985.

18. P. David, "Some New Standards for the Economics of Standardization in the Information Age," in *The Theory of Technology Policy*, P. Dasgupta and P.L. Stoneman, eds., Cambridge Univ. Press, 1987.

19. P.A. David and S.M. Greenstein, "The Economics of Compatibility Standards: An Introduction to Recent Research," *Economics of Innovation and New Technology*, Vol. 1, 1990, pp. 1-29.

20. R. Cowan, "Nuclear Power Reactors: A Study in Technological Lock-in," working paper, C.V. Starr Center for Applied Economics, NYU, Oct. 1988.

21. M.A. Cusamono, Y. Mylondadis, and R. Rosenbloom, "Strategic Maneuvering and Mass Market Dynamics: The Triumph of VHS over BETA," Working Paper 91-048, Harvard Business School.

22. S. Postrel, "Competing Networks and Proprietary Standards: The Case of Quadrophonic Sound," *J. Industrial Economics*, Vol. 39, No. 2, Dec. 1990.

23. International Data Corp., *EDP Industry Report*, Framingham, Mass., various years.

24. S. Greenstein, "Computers, Compatibility and Economic Choice," unpublished doctoral dissertation, Stanford Univ., June 1989.

25. "Millions in Savings Possible in Converting Programs from One Computer to Another," General Accounting Office, Sept. 15, 1977, FGMSD-77-34.

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

27. *Conversion Contracting Techniques Associated with Procurement of Replacement ADP Hardware System*, General Services Administration (Office of Software Development and Information Technology), GSA/FCSC-1/003, PB82-145079, NTIS, Sept. 1981.

28. *Conversion Work Packages*, General Services Administration (Office of Software Development and

Information Technology), Report No. OSD/FCSC-82/002, July 1982.

29. *Conversion Plan Outline*, General Services Administration (Office of Software Development and Information Technology), Report No. FCSC-83-002, Jan. 1983.

30. *Software Conversion Lessons Learned, Volume I*, General Services Administration (Office of Software Development and Information Technology), FCSC-83/003, 1983.

31. *Preparing Software Conversion Studies*, General Services Administration (Office of Software Development and Information Technology), OIT-FCSC-84/001, 1984.

32. *Conversion Cost Model (Version 4), Cost Model Handbook*, General Services Administration (Office of Software Development and Information Technology), May 30, 1986, OSDIT/FSMC-86/005.

33. *Conversion of Federal ADP Systems: A Tutorial*, National Bureau of Standards, Aug. 1980, C13.10:500-62.

34. *Data Base Directions — The Conversion Problem*, National Bureau of Standards, Sept. 1980, C13.10:500-64.

35. M.M. Gray, *An Assessment and Forecast of ADP in the Federal Government*, Aug. 1981, C13.10:500-79.

36. P.A. David, "Narrow Windows, Blind Giants and Angry Orphans: The Dynamics of Systems Rivalries and Dilemmas of Technology Policy," in *Innovation Diffusion*, Vol. 3, F. Arcangeli et al., eds., Oxford Univ. Press, New York, 1990.

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

38. S. Greenstein, "Sole-Sourcing versus Competitive Bidding: U.S. Government Agencies' Procedural Choices for Mainframe Computer Procurement," *J. Industrial Economics*, Vol. 43, No. 2, June 1995, pp. 125-140.

39. F. Brooks Jr., *The Mythical Man Month: Essays in Software Engineering*, Addison-Wesley, Reading, Mass., 1972.

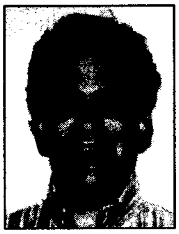
40. L. Cabral and S. Greenstein, "Switching Costs and Bidding Parity in Government Procurement of Computer Systems," *J. Law, Economics, and Organizations*, Vol. 6, Fall 1990, pp. 453-469.

41. E.R. Dulberger, "The Application of a Hedonic Model to Quality-Adjusted Price Index for Computer Processors," in *Technology and Capital Formation*, D.W. Jorgenson and R. Landau, eds., MIT Press, 1989.

42. R.J. Gordon, "The Postwar Evolution of Computer Prices," in *Technology and Capital Formation*, D.W. Jorgenson and R. Landau, eds., MIT Press, 1989.

43. J. Heckman and B. Singer, "The Identification Problem in Econometric Models of Duration Data," in W. Hildebrand, *Advances in Econometrics*, Cambridge Univ. Press, 1982, pp. 39-77.

44. S. Greenstein, "Did Installed Base Give an Incumbent Any (Measurable) Advantages in Federal Computer Procurement?" *Rand J. Economics*, Vol. 24, No. 1, 1993, pp. 19-39.



Shane Greenstein is assistant professor of economics at the University of Illinois in Urbana/Champaign, where he teaches courses on the economics of technology and the economics of regulation. He is also a faculty research fellow with the productivity group at the National Bureau of Economic Research. For the 1994-95 academic year he is a visiting scholar with the Computer Industry Project at Stanford University and a research associate with the Center for Research and Management at the University of California at Berkeley. He received his BA from UC Berkeley and his PhD from Stanford University, both in economics. His research interests cover the economics of high technology, particularly issues related to the computer and telecommunications industries. He has written about government procurement of computers, buyer benefits from computing equipment, standardization in electronics markets, the demand for mainframes, and investment in digital communication equipment.

The author's address is Center for Economic Policy Research, Stanford University, CEPR/Economics Building, Mail Code 6015, Stanford CA 94305, e-mail grnstn@leland.stanford.edu.