Supplementary Materials for Timothy F. Bresnahan and Shane Greenstein, "Technological Competition and the Structure of the Computer Industry," *The Journal of Industrial Economics* 47(1), March 1999, pp. 1-40

The entries ("Topics") in this appendix are all linked to footnotes in the published document. Numbered paragraphs here refer to the corresponding footnote numbers in the text.

2. IBM invested heavily in many different System/360 component technologies and in its service and support capabilities. It also created a management structure that could coordinate technical decisions across these many technologies and product lines. (See Pugh et al. [1991], Watson and Petre [1991] and Sobel [1981, 1986] for the management conflicts surrounding System/360 and their resolution). IBM's customers' investments were also quite large (e.g., see Inmon [1985]).

3. Burroughs, Univac, NCR, and Honeywell attempted to develop broadly useful platforms in competition with, and incompatible with, the System/360. Burroughs found willing users for their architecture with innovative memory stacking. NCR's small systems were quite successful in some banking applications and especially in retailing. Honeywell and Univac found willing buyers in the federal government, particularly in the military. Honeywell successfully marketed its systems for use in communications and in large process-control problems, such as managing air conditioning within a large building. CDC found a niche producing computers for computation-intensive scientific and engineering applications. See e.g., Fisher, McKie and Mancke [1983], Katz and Phillips [1982] and Flamm [1987].

4. Much of this emphasis arises out of the *US vs IBM* antitrust case. Different authors took contrasting sides, seeing IBM as either a brilliant creator or a defender of monopoly. They see IBM's invention of the platform either as valuable use of scale and scope economies or as barriers to entry, and see IBM's customers either as well-supported or as locked-in. For contrasting analysis and characterizations see, e.g., Brock [1975b], Fisher et. al. [1983], and DeLamarter [1986].

10. IBM's management of the migration from the System/360 to the 370 can be interpreted either as (i) maintenance of IBM-created barriers to entry or (ii) efficient preservation of users' investments in IBM's platform (Fisher et al., [1983], Brock, [1975a, 1975b]). The debate over the social efficiency of technological lock-in to unsponsored standards, such as the QWERTY keyboard, exhibits a similar dichotomy. QWERTY can be interpreted either as (i) a socially inefficient lock-in or (ii) a rational preservation of durable investments with little foregone opportunity costs (David [1985], Liebowitz and Margolis, [1995]). These normative issues also arise in the discussion of Microsoft's behavior. Microsoft either (i) integrates technology for the good of all customers or (ii) it sabotages innovation by competitive software firms through its control of an essential facility (Reback et al. [1994] or FTC [1996]). Resolution of any or all of these normative debates is a distant but worthy research goal.

14. The lack of a sponsor created some coordination failures. CP/M supported a universally recognized 8-inch floppy disk format (the convention governing how data are to be written to, and read from, the physical disk medium). The move to 5.25-inch floppy disks saw a wide variety of distinct disk formats, frequently unique to each hardware seller. Customers could buy any CP/M software for their computer, but then had to specify the exact make of computer it would run on so

that the software could be read by the disk drive.

21. This gap was widely recognized and might have been filled in other ways. Extending an existing mainframe line would have permitted compatibility and growth. Alternatively, a whole new platform, unconstrained by design history, could be optimally designed for a new customer body. The latter strategy was attempted, with limited success, by IBM, Wang, and others in the early 1970s. Their "small business system," which included service, training and maintenance, were much more expensive than a standard (dedicated application) minicomputer.

22. The hardware for a supermini such as the VAX-11/780 was not really much different from its technical ancestors (i.e., the PDP-11). The advances were well within normal platform growth: enlarged capacity (for multiple users), superior peripherals and air-cooled technology (Bell and Mudge [1978]). Although DEC also sold computers under the VAX name for technical uses, we focus on the commercial segment.

24. After an initial period of marketing VAX systems to the traditional, technically sophisticated, segment, DEC added software tools and applications, simple servicing and maintenance contracts, and peripherals, which appealed to a broader market. DEC widened the range of available processor sizes and retained compatibility across the whole product line for much of the 1980s (Pearson [1992]). Wider general-purpose, especially business, use of the VAX was stimulated by the emergence of third-party application software (Friedman and Cornford [1989]). Multi-user minicomputers were especially suited to text-editing and printing, cash register monitoring, and accounts management (Inmon [1985], Cortada [1996]). Software publishers such as Oracle, which created database management systems, emerged to serve this segment. User groups in turn grew around these business applications, turning the VAX platform toward commercial applications.

25. A number of explanations are consistent with events, such as: (i) IBM's managers did not foresee the new segment and responded only after observing rivals' success; (ii) IBM was better off being a "strong second;" (iii) incentive problems within IBM (e.g., cannibalization, especially of the System/3) hindered the development of new platforms. Articulating an accurate organizational or strategic history of this decision does not influence our main point about the tension between technical progress for a new users and the limitations of satisfying old users.

26. The PC replaced time-sharing on large computers and dedicated word processing on minis. Neither was an important use of those kinds of computers. Small businesses simply did not use the microcomputer the way a larger business might use a superminicomputer or an even larger one a mainframe.

27. Entrant firms could quickly get into the microcomputer business. For example, Apple co-founder Steven Wozniak designed the Apple I in a matter of weeks and (with a little more help and more direction) the basic design for the Apple II in a matter of months. Dan Bricklin designed the first spreadsheet, Visicalc, for the Apple II in a few months. In other words, once the design goals of a platform component were defined, a small team of talented engineers could quickly execute them. See Freiberger and Swaine [1984], ch 7.

29. Some technologists object to our characterization of the 1980s as a period of stability without important platform inventions, pointing to such great technical achievements as portable PCs. However, portable computers from Osborne, Compaq, etc.,used existing platforms and were compatible with desktop machines. Another great technical achievement, high-end parallel processing, has not yet diffused to mainstream business use, remaining within a small niche of highly technical users. The closest thing to a new segment foundation was the diskless workstation, but that involved more a cheapening of already available capabilities (on a minicomputer) than introduction of a new platform.

30. Some analysts date the competitive crash to the mid-1980s, when several business minicomputer firms, Wang, Prime and Data General, began experiencing financial troubles (due primarily to competition from workstations and personal computers). We think this evidence is a red herring for an analysis of the dominant firms and platforms.

37. IBM had offered so-called "midrange" machines for some time. The System/3 family and the 9370, as well as the 4300 family, each generated a great deal of revenue, but none dominated a business segment or defined an enduring multi-generation platform. Measured against the standard of System/360-370, they were not successful.

40. See Ferguson and Morris [1993] for a detailed recounting of these events. IBM coordinated improvements in color monitors with the VGA standard after a challenge from a non-IBM sponsored alternative. IBM owned 13% of Intel for a period and helped coordinate the introduction of the Intel 80286 processor, the successor to the 8086 processor in the original IBM-PC. IBM coordinated improvements in the DOS operating systems even though these were supplied by contractual collaborator Microsoft.

45. Many industry analysts discern an array of "sub-platforms" within the dominant platform, which sometimes represent challenges for control over the whole platform. We leave open the issue as to whether variety presages more than one dominant client/server platform in a future equilibrium, in which platforms differ by intended application or primary customer base. Diversity within a platform may also represent a hierarchy in equilibrium market structure, in which control over a dominant platform is divided along the lines of standards set by software applications, or other configurations that build on top of the platform.

REFERENCES

Bell, C. Gordon, and J. Craig Mudge, 1978, "The Evolution of the PDP-11," *Computer Engineering: A DEC View of Hardware Systems Design* (Digital Equipment Corporation, Maynard MA)

Brock, G. W., 1975a, "Competition, Standards, and Self-Regulation in the Computer Industry," in Caves, R., and M. Roberts (Eds.) *Regulating the Product: Quality and Variety* (Ballinger Publishing, Cambridge MA)

Brock, G. W., 1975b, *U.S. Computer Industry: A Study in Market Power* (Ballinger Publishing, Cambridge, MA)

Cortada, J. W., 1996, *Information Technology as Business History: Issues in the History and Management of Computers* (Greenwood Press, Westport CT)

David, P. A., 1985, "Clio and the Economics of QWERTY," *American Economic Review, Papers and Proceedings*, 75, pp. 332-337

DeLamarter, R. T., 1986, *Big Blue: IBM's Use and Abuse of Power* (Dodd, Mead, New York)

Federal Trade Commission, 1996, "Anticipating the 21st Century: Competition Policy in the New High-Tech, Global Marketplace," `http://www.ftc.gov/opp/global.htm`

Ferguson, C. H. and C. R. Morris, 1993, *Computer Wars: How the West Can Win in a Post-IBM War* (Times Books-Random House, New York)

Fisher, F. M., J. J. McGowan and J. E. Greenwood, 1983, *Folded, Spindled, and Mutilated: Economic Analysis and U.S. vs. IBM* (The MIT Press, Cambridge MA)

Fisher, F. M., J. W. McKie and R. B. Mancke, 1993, *IBM and the U.S. Data Processing Industry: An Economic History* (Praeger Publishers, New York)

Flamm, K., 1987, *Targeting the Computer: Government Support and International Competition* (The Brookings Institution, Washington DC)

Freiberger, P. and M. Swaine, 1984, *Fire in the Valley: The Making of the Personal Computer* (Osborne\McGraw Hill, Berkeley CA)

Friedman, A. and D. S. Cornford, 1989, *Computer Systems Development: History, Organization and Implementation* (John Wiley and Sons, New York)

Inmon, W. H., 1985, *Technomics: The Economics of Technology & the Computer Industry* (Dow Jones-Irwin, New York)

Katz, B. and A. Phillips, 1982, "The Computer Industry," in Nelson R. R. (Ed.), *Government and Technical Progress: A Cross-Industry Analysis* (Pergamon Press, New York), pp. 162-232.

Liebowitz, S.J. and S. E. Margolis, 1995, "Path Dependence, Lock-In and History," *Journal of Law, Economics and Organizations,* pp.

Pearson, J. P., 1992, *Digital at Work: Snapshots from the First Thirty Five Years* (Digital Press, Burlington MA)

Pugh, E. W., L. R. Johnson and J. H. Palmer, 1991, *IBM's 360 and Early 370 Systems* (The MIT Press, Cambridge MA)

Reback, G., S. Creighton, D. Killam, and N. Nathanson, 1994, *Microsoft White Paper* (Wilson,

Sonsini, Goodrich & Rosati, Palo Alto, CA), November 14

Sobel, R., 1986, *IBM vs Japan: The Struggle for the Future* (Stein and Day, New York)

Sobel, R., 1981, *IBM: Colossus in Transition* (Bantam, New York)

Watson, T. J. Jr., and P. Petre, 1990, *Father Son and Co: My Life at IBM and Beyond* (Bantam, New York)