SUCCESSFUL INCUMBENTS: PUZZLES IN THE ADOPTION OF RISC (REDUCED INSTRUCTION SET COMPUTERS)

Allan N. Afuah

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SUCCESSFUL INCUMBENTS: PUZZLES IN THE ADOPTION OF RISC (REDUCED INSTRUCTION SET COMPUTERS)

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Abstract:
Both organizational and neoclassical economic theory suggest that incumbents should fail and new entrants prosper in the face of radical technical change. However, in many industries, incumbents have been more successful in adopting radical innovations than new entrants. This paper argues that this deviant behavior can be explained by two factors. On the one hand, an innovation that is radical to the innovating entity may not be radical to the members of its innovation value-added chain of suppliers, customers and complementary innovators. Therefore, to understand the success or failure of firms in adopting technologies, one must examine not only the effects of the technology on the adopter's competence, one must also examine its effects on the competence of the firm's innovation value-added chain. On the other hand, what may be seen as competence-destruction by organizational theorists may be regarded as obsolescence of network externalities by economists. Therefore success is better understood using the combined multidisciplinary approach of exploring both competence and network externalities effects along the value-added chain.

This paper uses detailed data on the adoption of RISC (Reduced Instruction Set Computers) by computer workstation makers to explore the importance of the above two factors in explaining the success of firms in the face of new technologies. Both qualitative and quantitative analysis of detailed field and archival data suggest that firms whose value-added chain of suppliers, customers and complementary innovators experience the least competence-destruction and obsolescence of network externalities are more successful, ceteris paribus. It distinguishes between the effects of competence and network externalities and suggests that customer competence plays a larger role in the success of firms in the face technical change than do network externalities.
1. INTRODUCTION

Why do incumbents sometimes succeed in the face of radical innovation? Organizational theory suggests that new entrants are more likely to be successful at adopting radical innovation than incumbents. Organizational scholars who have examined the effect of radical technology on the adopting organization's information processing ability, suggest that incumbents are handicapped by the information processing mechanisms which they developed to cope with the old technology, but which are useless with the new one (Arrow, 1974; Nelson and Winter, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990). The "mechanistic" nature of these firms and the inertia resulting from their success with the old technology make it more difficult for them to successfully adopt a new radical technology (Burns and Stalker, 1961; Hannan and Freeman, 1984). Neoclassical economic theory argues that new entrants have a greater incentive to invest in radical innovation than do incumbents who would rather invest in incremental innovations (Reinganum, 1983, 1984; Gilbert and Newberry, 1982, 1984; Henderson, 1993), suggesting that incumbents are more likely than new entrants to fail at radical innovation, all else equal.

In some industries, however, incumbents have been more successful than new entrants in adopting radical innovation. For example, IBM was better able to exploit integrated circuits in mainframe computers than most new entrants. Sun Microsystems, an incumbent in the workstation market, and HP, an incumbent in minicomputers, were better able to exploit the emerging technology of RISC (Reduced Instruction Set Computers) than new entrants such as MIPS Computer or fellow incumbent DEC. In other industries, some incumbents have failed in adopting incremental innovations. For example, the evolution of DRAMs\(^1\) from 16K to 256K saw many incumbents like Intel and Mostek replaced by new entrants like Fujitsu and NEC. While empirical evidence suggests that these economic and organizational theories have been very successful in explaining firm failure in the face of technical change (Henderson and Clark, 1990; Christensen, 1992), examples like these need a different explanation.

This paper suggests that an explanation for these deviant observations rests in two critical factors. On the one hand, an innovation that is radical to the adopting entity may not be radical to its suppliers, customers and complementary innovators. Therefore, to understand the success or failure of firms in adopting technologies, one must examine not only the effects of the technology on the adopter’s competence, one must also examine its effects on the competence of the firm’s innovation value-added chain of suppliers, complementary innovators and customers.

On the other hand, what is seen by organizational theorists as competence-destruction for a customer, may be obsolescence of network externalities from an economist’s point of view. For example, a customer who decides not to buy a new computer incorporating the latest technology may not do so because of one or a combination of three things: the new computer has an operating system that the customer is not familiar with, and the computer is therefore competence-destroying

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\(^1\)DRAM stands for Dynamic Random Access Memory, a type of memory chip that is used as the main memory of computers. The K stands for kilobit, i.e., 1024 bits of information. 1M stands for Megabit or million bits of information.
to her; the customer has many applications software packages that cannot run on the new computer, and buying it obsoletes this software; and the computer is not compatible with her co-workers' computers and she cannot share software with them. While organizational theorists might argue that the customer refused to buy the computer because it was competence-destroying, economists may argue that she refused to buy it because of the potential obsolescence of her network externalities. This suggests that an approach which examines both organizational (competence), and economic (network externalities) effects may provide more insights than each discipline alone, in exploring why incumbents perform better than new entrants in adopting radical innovation.

This paper examines the role of competence-destruction along the innovation value-added chain, on the one hand, and that of network externalities, on the other, to explore why some incumbents succeed and new entrants fail in adopting radical innovations. Using detailed data on the adoption of RISC (Reduced Instruction Set Computers) by computer workstation makers, I show that incumbents who succeeded are those whose value-added chains experienced the least competence-destruction and obsolescence of network externalities. In particular, I show, using five cases and econometric analysis, that customer competence plays a larger role in determining success than do network externalities.

The paper is organized as follows: In Section II, I briefly review some literature and develop the relevant hypotheses for the paper. In Section III, I present some facts about RISC and its adoption by incumbents and new entrants in the workstation industry. I also discuss the data used in the analyses and their sources. Section IV is the qualitative analysis. There, I discuss the impact of RISC on competence and network externalities along the innovation value-added chain. Then I present five case studies, chosen so that, together, they highlight the impact of competence at each stage of the innovation value-added chain on the success of workstation makers. The cases of DEC and Sun—both incumbents with contrasting approaches to adopting RISC—illustrate the effect of competence-destruction and obsolescence of network externalities on customers and complementary innovators on success. The case of Sun "cloners" distinguishes between the effects of competence and network externalities. That of IBM illustrates the importance of competence destruction at suppliers, while that of MIPS, a new entrant, demonstrates how a new entrant can fail despite superior products, because of potential customer competence-destruction, and obsolescence of network externalities. Section V is the quantitative analysis. There, I use econometric tools to extend the analysis to the more than sixty other firms that have adopted RISC for their workstations; to examine the role of such control variables as time of adoption; and to further explore the distinction between the effects of competence and network externalities on success. In Section V, I summarize the findings and conclude that those workstation makers (incumbents and new entrants alike) whose innovation value-added chain experienced the least competence-destruction perform best, ceteris paribus. I also suggest that an exploration of the combined effects of competence and network externalities better explains the success of firms, and distinguishing between the impact of an innovation on competence and network externalities further underscores the importance of both effects in explaining the success of firms in the face of radical technical change.
2. FRAMEWORK AND HYPOTHESES

1) Impact of innovation on the competence of the innovating entity.

Both organizational and neoclassical economic theory suggest that incumbents have more problems dealing with radical innovation than new entrants. Organizational theory argues that, in exploiting a technology, firms develop information processing mechanisms that become embedded in their organizational routines and procedures (Arrow, 1974; Henderson and Clark, 1990, Allen, 1984). When a radical innovation comes along—one that requires fundamentally different skills, and knowledge—the information processing mechanisms developed by incumbents to cope with the old technology, may not only be useless but may also be a handicap to incumbents in exploiting the radical innovation (Henderson and Clark, 1990). Such an innovation is said to be competence-destroying since the knowledge, skills and firm-specific assets developed to exploit the old technology are useless with the new (Tushman and Anderson, 1986). Thus incumbents are more likely to fail in the face of such innovations than are new entrants.

On the other hand, if the innovation is competence-enhancing, incumbents are more likely to succeed since the information processing mechanisms put in place to exploit the old technology are an asset in exploiting the new one. By a competence-enhancing innovation, I mean one in which the knowledge, skills and firm-specific assets that the firm needs to stay competitive build on those that it developed in capitalizing on the previous technology (Tushman and Anderson, 1986).

Incumbent competence-destruction is not limited to technological knowledge. An incumbent’s market competence—knowledge of the market it serves—can also be destroyed with the arrival of a radical innovation (Abernathy and Clark, 1985; Christensen, 1992). The same information filters, communication channels, and routines and procedures that the firm uses to keep out new technological knowledge, are used to filter out new market knowledge. An incumbent’s knowledge of the market for its old technology, and the mechanisms it developed to exploit that market are also a handicap when the new technology comes along.

Neodclassical economics on the other hand, argues that an incumbent, for fear of cannibalizing its existing technology, is less likely to invest in radical innovation than a new entrant, and therefore less likely to succeed in adopting such innovations (Reinganum, 1983, 1984; Gilbert and Newberry, 1982, 1984). A radical innovation in the economic sense is one that renders the old technology obsolete, i.e., the old technology can no longer compete with the new (Arrow, 1962). An incumbent is, however, more likely to invest in incremental innovation, and therefore more likely to succeed in adopting incremental innovation than are new entrants.

ii) Impact of innovation along the value-added chain

The focus of the above theories has been largely on the effects of the technology on the competence of the individual innovating entity. But innovation also has implications for the rest of the innovating entity’s value-added chain of suppliers, complementary innovators and customers (Afuah and Bahram, 1992; Tushman and Anderson, 1986). Members of the innovation value-added chain in this context are those suppliers, complementary innovators and customers who interact
directly with the innovation as it moves from its origin to its end user. For example, if the innovating entity is a supercomputer maker using massively parallel computer technology, the members of its value-added chain are its suppliers of microchips, it's customers are organizations like the Lawrence Livermore Laboratory that buy the supercomputers, and its complementary innovators are those independent software vendors (ISVs) whose software Lawrence Livermore needs in order to better utilize the massively parallel supercomputer. An innovation that is incremental to a firm can be radical to the firm's customers and complementary innovators, and incremental to its suppliers. Therefore an exploration of the effects of the innovation on the competence of the innovating firm alone may not explain why the firm failed or succeeded. For example, the DSK (Dvorak Simplified Keyboard) keyboard arrangement that by many estimates performed 20-40% better than the QWERTY arrangement that most of today's keyboards have, was competence-enhancing to its innovator, Dvorak, and other typewriter manufacturers. But it was competence-destroying to customers who had already learnt how to type with the QWERTY keyboard (David 1985), since to use the new keyboard, they would have to relearn how to touch-type again. The various faces of this innovation at the different stages of the innovation value-added chain are shown in Figure 1a.

Another example (also illustrated in Figure 1a) is Cray Computer's decision in 1988 to develop and market a supercomputer that would use gallium arsenide (GaAs)\(^1\) chips—a technology that yields very fast chips and consumes very little power but is still relatively unproven—instead of proven silicon chip technology that its suppliers had built their competence in (Afuah and Utterback, 1991). While the supercomputer design was competence-enhancing to Cray, its decision to use gallium arsenide was competence-destroying to Cray's traditional silicon chip supplier base. In each of these cases, the innovation assumed a different meaning at different stages of the innovation value-added chain. This concept is illustrated in Figure 1b where two incumbents, A and B, face a radical innovation, but the innovation is incremental to firm A's customers and complementary innovators but radical to firm B's customers and complementary innovators. If firm B failed in adopting the innovation, an examination of the effect of the innovation on the competence of firms A and B would suggest that both firms should have failed. But an examination of the whole innovation value-added chain suggests that B's failure may have been due to the fact that the innovation was radical to its customers and complementary innovators.

This suggests that while an incumbent may be handicapped by its knowledge of the old technology when adopting a radical innovation, the competence which it built at customers, suppliers, and complementary innovators in exploiting the old technology, may be an asset to it if the innovation is not competence-destroying to those members of its value-added chain.

**Hypothesis 1:** In adopting a radical innovation, the less competence-destroying the innovation is to a firm's innovation value-added chain of suppliers, complementary innovators and customers, the more successful the firm will be.

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1 Gallium arsenide is a chip technology that can result in chips that are three and half times as fast, and consume half as much power as their silicon counterparts. The technology still has many problems.
iii) Network Externalities

The discussion so far has focused on the impact of the innovation on the organizational competence of the various members of the adopting firm's innovation value-added chain. But what is seen as competence-destruction by organizational theorists may be seen as obsolescence of network externalities and/or complementary innovations by economists. Take, for example, an employee who has used an IBM PC for many years and now understands the PC's DOS operating system, has invested in a library of software programs for the machine, and has often shared software and programming tips with co-workers who own compatible PC's. When it is time to buy a faster computer, he may choose to buy another IBM PC over a much faster but incompatible UNIX workstation because he either doesn't want to learn a new operating system, or wants to still use the applications software he has accumulated over the years, or wants to continue to share software with co-workers. The organizational theorists would argue that the employee doesn't want the workstation because it is competence-destroying to him while economists would argue that he doesn't want it because the new machine obsoletes his network externalities. Clearly, in exploring why incumbents succeed in adopting radical innovation, a multidisciplinary approach of examining both the effects of competence as well as of network externalities would provide more insights.

A technology is said to exhibit network externalities if the more people that use it, the more valuable it is to the users (Katz and Shapiro, 1985, 1986; David, 1985, 1986). Technologies that exhibit both network externalities and learning by doing (Arthur, 1985; Rosenberg, 1982), manifest demand-side economies of scale—i.e., the technology is more attractive the more consumers that are already using it (Katz and Shapiro, 1986). The performance of incumbents adopting these technologies depends, in part, on whether the adopter decides to keep its network private (incompatible with any other firm's)—maintaining tight appropriability—or public. In the former case, an incumbent—which already has an installed base of products from the old technology—stands to benefit from demand-side economies of scale if it decides to make its new technology compatible with the old; but at the risk of cannibalizing its old products. New entrants don't have any installed base and cannot reap the benefits of demand-side economies of scale, and are therefore less likely to be successful than incumbents.

Hypothesis 2: Incumbents with large private networks of compatible old and new technologies are more likely to succeed in adopting a radical innovation than new entrants or those incumbents with smaller or incompatible private networks.

On the other hand, the firm can make its new technology compatible with that of other firms establishing a more public, less appropriable network (Katz and Shapiro, 1985; Farrell and Saloner, 1985, 1986). In that case, the success of the firm in adopting the technology is a function of how compatible its new technology is to its old one and to other firms' technologies—old and new. Incumbents are therefore not likely to have a distinct advantage over new entrants, all else equal.
Hypothesis 3: A firm (incumbent or new entrant) is more likely to succeed in adopting a technology, the larger the installed base of products that are compatible with its products.

A customer's valuation of a product is also a function of the expected future network of compatible technologies. Customers care about what the size of the network they join now will be tomorrow (Katz and Shapiro 1986). This suggests that a firm's ability or reputation in building networks may be instrumental to customer's choice of the technology they adopt. For example, when IBM entered the personal computer (PC) market, many customers were quick to adopt its PC standard because they believed that IBM's reputation would attract many applications software developers and a large network in the future. A liberal licensing policy in which a firm licenses its technology at low cost to anyone who wants it, not only rapidly increases the installed base, it can also be a signal to customers and complementary innovators that the firm's future network will be large. Khazam and Mowery (1992) suggests that such a liberal licensing policy by Sun Microsystems (of its SPARC RISC chip technology) is the reason why Sun's technology is emerging as the dominant microprocessor RISC design.

Hypothesis 4: The larger a firm's expected network of a technology, the more likely it is for the firm to succeed in adopting the technology.

iv) Distinguishing between the effects of competence and network externalities

The primary factor in the network externalities point of view is network size; the larger the network size, the better. This suggests that a firm can switch from its old technology to a new incompatible one so long as the size of its new network is larger. This flies right in the face of the competence view. For example, a farmer who uses a Macintosh computer, and has accumulated applications programs that constitute an integral part of his competence in growing animals, will not switch to an IBM PC overnight just because the switch will provide him with the benefits of a larger network. To discard the accumulated library of software that has become an integral part of his expertise, and to have to learn a new operating system in DOS, is competence-destroying to this farmer, no matter the size of the new network. The benefits of staying with the smaller network may well outweigh those of switching to the larger one. The externalities point of view suggests that he would switch to the new computer since he can enjoy the benefits of a larger network. The benefits from competence are path-dependent while those from network externalities are not. The relationship between the old and the new technology is important for competence, whereas only the size of the network matters in externalities.

v) Alternate hypotheses

Rosenbloom and Christensen (1993) suggest that the inherent difficulty of a new technology is not what determines the success of a firm in the face of technical change. Rather, it is the kind of value network to which the firm belongs, and the performance parameter ordering that addresses the value network, that determines success. A firm's success in adopting an innovation depends on how the firm's product attributes address the needs of the actors within its value network.
Incumbents perform better if the innovation addresses needs within their value network regardless of the intrinsic nature of the technology. They (incumbents) fail when the innovation addresses customer needs for emerging value networks, no matter how simple the technology is.

The discussion so far has assumed that every decision maker in each firm takes decisions to maximize the attainment of the firm’s goals. Often, however, parochial interests win over firm rational goals (Pfeffer, 1981; Pfeffer and Salancik, 1974; Eisenhardt and Zbaracki, 1992). If the new technology has a powerful proponent who can wield the necessary influence on investment decisions of the firm, it will have a better chance of succeeding, no matter whether the firm is an incumbent or new entrant.

Section III
RISC technology and computer workstations

To lay the groundwork for the exploration of the above hypotheses, I define RISC, and briefly outline some stylized facts about its adoption in the computer workstation industry. I also briefly discuss the data used in subsequent analyses.

RISC is a computer architecture innovation, a method of designing the central processing unit (CPU) of the computer. (The CPU is sometimes referred to as the brain of the computer because it does all the calculations and controls all the electrical signals of the computer). Compared to CISC (Complex Instruction Set Computers)—the old design methodology—RISC greatly improves computer performance, development times and costs.

i) Incumbents

So far, incumbents have been winning the RISC workstation market share battle. In this context, I define incumbents as firms that were already competing in the workstation market with CISC machines before introducing RISC; those who entered the workstations market for the first time using RISC technology are new entrants. As Table 1 shows, four of the top five RISC workstation makers in 1989 and 1991 were incumbents who had been leaders in CISC. Table 2 also shows that incumbents still maintain the overall lead in market share for all workstations, CISC or RISC. Sun Microsystems, an incumbent which adopted RISC in 1987 and licensed its SPARC (Scalable Processor Architecture) RISC technology liberally, has maintained the highest unit market share of all firms. Apollo, another incumbent and the workstation pioneer, introduced its RISC workstation in 1988, shortly after its rival Sun. Apollo's RISC technology, PRISM (Parallel Reduced Instruction Set Multiprocessing), gained very little market share and couldn't stop Apollo's already declining position in workstations or acquisition by HP in 1989. HP has now abandoned the PRISM technology for its own PA-RISC (Precision Architecture-RISC) technology. DEC, another incumbent, introduced its first RISC workstation in 1989 using MIPS microprocessors. The company stumbled along, losing market share over the years, and in 1992 introduced its own RISC design, ALPHA to replace the MIPS design. Intergraph, Sony, NEC and Silicon Graphics Inc. have also introduced RISC workstations using Clipper, MIPS, MIPS and MIPS RISC technologies respectively.
ii) New entrants

In 1986, eleven years after inventing RISC, IBM introduced the first\textsuperscript{1} RISC workstation—the PC/RT—to enter the computer workstation market\textsuperscript{2}. [In this context, I define a new entrant as a firm that is using RISC technology to enter a market in which it had no products before.] By most accounts, the PC/RT was a failure and IBM had to introduce another RISC design, the RS/6000 in 1990. This has been more successful. MIPS Computer Inc., a start-up company, introduced a workstation in 1988. Despite introducing some of the best-performing workstations, MIPS never really gained much market share and was running into some financial problems in 1991 when it was bought by Silicon Graphics Inc., another workstation maker. Dozens of other new entrants, many of them from Asia, have entered the market using RISC designs.

The data

The data for the paper were collected in a continuing field-based study of the workstation and microprocessor industries that started in March 1993. Revenue, units sold, workstation product attributes, and technological backgrounds for over two hundred RISC workstations formed the basis for the quantitative part of the analysis. For the qualitative part, detailed technological histories of eight major RISC technologies, and the adoption histories of key incumbents and entrants were constructed. Sources of data included in-person field and telephone interviews of RISC pioneers, architects and designers, industry experts, corporate annual statements, consulting reports, the Nexis/Lexis computer database, as well as such electrical engineering and computer science journals as ACM (Association of Computing Machinery) Communications, UNIX Review, Electronics, and IEEE Computer, IEEE Spectrum. Information providers like Dataquest, RISK Management, ICE (Integrated Circuit Engineering), and IDC (International Data Corporation) were also valuable sources.

RISC technology for the workstation industry was chosen because workstations use components (microchips) that are in themselves systems, their development requires a high degree of learning, and their use entails a high level of learning as well as depends on complementary products like software. Such

\textsuperscript{1}There is some disagreement as to who first capitalized on RISC. Pyramid Computers insists that its line of minicomputers which it developed in 1981 and duped VAX-killers, was the first commercialization of RISC. Most RISC experts don’t agree with Pyramid. Pyramid later adopted MIPS Computer Systems MIPS chips for its computers. The first major computer maker to introduce RISC computers was HP. In 1985, it announced to all its customers that it was converting all its computers to the RISC technology. It shipped its first minicomputers, based on its PA-RISC architecture, shortly thereafter. But it was not until 1991 that it shipped its first PA-RISC workstation.

\textsuperscript{2}It is difficult is difficult to classify IBM in the incumbent/new entrant dichotomy. On the one hand, it entered the workstation market for the first time, using a RISC processor which makes it a new entrant since it is using a new technology to enter a market that other firms had exploited using an older technology. On the other hand, it had been a dominant player in CISC technology for years and would be handicapped by the very assets and routines that it put in place to exploit CISC in other computer markets and should therefore be considered an incumbent.
technologies provide a richer setting for examining the role of both competence and network externalities along the value-added chain and their study strengthens both construct and internal validity of the research.

Section IV
THE EMPIRICAL ANALYSIS—qualitative

The hypotheses developed in Section II suggest that the success of incumbents (and failure of new entrants) in the face of radical technical change is better understood by examining the impact of the technology on the competence and network externalities of the firm's innovation value-added chain. In this section, I explore these hypotheses qualitatively. I establish first that RISC is an architectural innovation to workstation makers and thus incumbents should have difficulties exploiting it. Next, with the workstation maker as the unit of analysis, I examine the impact of RISC on the rest of the workstation innovation value-added chain and the implications for an incumbent's success. I show that RISC is an architectural innovation to the microprocessor chip makers who supply RISC chips to workstation makers. To workstation customers and complementary innovators, however, the impact of RISC on competence varies from incremental to radical depending on how workstation makers incorporate the technology into their new products. Finally, I present five case studies of incumbents and new entrants whose value-added chains experienced different levels of competence-destruction and obsolescence of network externalities. The results of the cases suggest that the incumbents who have the most success in adopting RISC are those whose RISC workstations have neither been competence-destroying for the value-added chain nor network externalities-obsoleting for customers and independent software vendors. The results also suggest that customer competence plays a larger role than do network externalities in determining the success of a workstation maker.

Impact of RISC on workstation makers' competence

RISC is an architectural innovation (Henderson and Clark, 1990) to workstation makers. According to Henderson and Clark (1990), an architectural innovation changes the way in which the components of a product are linked together while leaving the basic knowledge underlying the components unchanged. It changes the product's architecture but leaves unchanged the components and the core design concepts as well as the associated engineering and scientific knowledge behind these components. The firm-specific assets, routines, procedures and information filters put in place to exploit the old technology may not only be useless with the new one, they may be a handicap. Architectural innovation is competence-destroying to the adopting entity. It may be triggered by a change in a component that creates new interactions and new linkages with the other components of the product. RISC in workstations exhibits these properties.

Workstations typically consist of five components: the CPU (the microprocessor), the memory system, the input/output (I/O) subsystem, the graphics subsystem, and software. At first glance it may seem that designing a RISC workstation is just a matter of replacing the CISC microprocessor with a RISC one. However, because RISC triggers changes in some of these components and the
linkages between them, the design of workstations using RISC requires special attention to architectural knowledge problems. These changes result from several key properties of RISC. In the first place, a simplified RISC microprocessor design means shifting some of the tasks that CISC CPUs used to perform to software and other components of the workstation. For example, workstation design now depends more on compilers to optimally translate higher level languages like C to simple instructions that the RISC CPU can understand. In the second place, the faster RISC microprocessor requires substantial changes in the linkages among the CPU, memory, and input/output (I/O), as well as in some of the components. For example, the faster CPU with its simpler instructions has very high bandwidth requirements, i.e., data must be transferred to the I/O and memory subsystems at very high rates in order to fully take advantage of the faster CPU. These properties of a RISC microprocessor and their consequences for the linkages between the components of a workstation suggest that the routines, procedures and problem solving strategies as well as some of the knowledge used by incumbents to effectively design CISC workstations may be a handicap to designing optimal RISC workstations (Nelson and Winter, 1982; Henderson and Clark, 1990). The failure of HP in its first RISC workstation is but one example of the kinds of problems that architectural innovation can cause.

**Impact of RISC on competence and network externalities along the value-added chain**

RISC has been an architectural innovation to the chipmakers who supply microprocessors to workstation makers. To customers and complementary innovators, it has been anything from incremental to radical. In essence, suppliers of microprocessors who, in designing CISC microprocessors, closed the semantic gap between instruction set and programming language using hardware and complex instructions, must now keep instructions simple and use software rather than hardware to close the semantic gap. This effectively tilts the balance of power from hardware to software. The changes in the other components of the microprocessor and the linkages between them, triggered by the simple instruction set, present architectural knowledge problems (Henderson and Clark, 1990) for the microprocessor maker. And this, in turn has implications for the success of the workstation maker that they supply.

For workstation customers, the impact of RISC on their competence and network externalities depends on two factors: whether the operating system and graphical user interface (GUI) of the new RISC machines are the same ones that the old CISC machines used, and whether the old software that had been an integral part of customer routines, and on which competence had rested, can still run on new RISC machines. If both the operating system and graphical user interface for their RISC machines are different, that can be competence-destroying to customers. Customers will experience obsolescence of network externalities if the size of the RISC (with compatible operating system, GUI, and applications software) is smaller than the CISC, but will be better off if the RISC network is larger. Switching to an incompatible network, no matter how large, is still competence-destroying to the customer who has to switch.

To independent software vendors (ISVs), who develop and sell the software critical to the success of any workstation, a change in the operating system and/or graphical user interface can also be competence-destroying. Typically, the software
developed by ISVs is layered\(^1\) on the operating system and graphical user interface (GUI). Thus, in some ways, the OS and GUI become an integral part of their design, coding, testing and service of software. A change in either the operating system or GUI can therefore be competence-destroying to the independent software vendor. If the RISC systems cannot run the CISC applications software, a lot of it developed by the independent software vendors, the ISVs have to rethink how to develop the new software. This may require obtaining new technical and marketing skills, and even different organizational routines. ISV's don't exhibit network externalities effects.

The cases

Having explored the effects of RISC on competence and network externalities along the innovation value-added chain, the question now becomes: Is there any relationship between these effects and firm success? Better still, can the effects of competence on success be distinguished from those of network externalities? To answer these questions, I explore five cases (See Figure 2): The case of Sun, a successful incumbent, whose value-added chain suffered the least competence-destruction and obsolescence of network externalities at its customers and complementary innovators. The case of DEC, a less successful incumbent, whose customers and complementary innovators, in contrast to Sun's, experienced competence-destruction and obsolescence of network externalities. These two cases suggest that the difference in the success of the two firms may be attributable to the impact of RISC on competence and network externalities at their customers and complementary innovators. However, they do not separate the effects of competence-destruction from those of network externalities. For that, I turn to the case of the so-called Sun "cloners" whose products are compatible with Sun's products (and its large installed base) giving their potential customers a large network. Sun cloners have, however, not been very successful. This suggests that factors other than a large network are important—probably competence. The case of IBM, whose PC/RT failed despite its large expected future network size, illustrates the importance of competence along the entire innovation value-added chain. Finally, I present the case of MIPS, a new entrant, which had superb products—as expected of a new entrant in the face of competence-destroying technical change—but failed because of potential competence-destruction and obsolescence of network externalities at customers and complementary innovators.

**Sun Microsystems**

In adopting RISC, Sun's value-added chain experienced the least competence-destruction of all the major computer workstation makers, and this may be one reason why the firm has been so successful with RISC. Table 1 shows its RISC market share in 1989 and 1991, while Table 2 shows its overall market share (CISC or RISC) relative to that of its competitors since adopting RISC in 1987.

Sun's supplier of CISC microprocessors was Motorola. However, when Sun decided to adopt RISC, it chose to develop its own RISC rather than depend on

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\(^1\)Software A is said to be layered on B if A makes specific references to routines in B, and in essence, cannot function without B. A change in B can therefore drastically affect the performance of A.
Motorola or any other supplier of CISC microprocessors—for whose instruction set designers RISC would have been more competence-destroying. However, rather than develop design competence from scratch, Sun adopted the RISC and SOAR architectures developed by RISC pioneer Professor Patterson and his students at UC Berkeley (Garner, Agrawal, Patterson et al, 1988). Sun engineers added extensions\(^1\) to the Berkeley design and named it SPARC (Scalable Processor Architecture). Competence-destroying for RISC microprocessor suppliers is in the design, especially instruction set design. Therefore adoption was not as competence-destroying to Sun as it would be to a Motorola, or to a Sun if it had to do it from scratch. The microprocessor, while a RISC speed laggard, has been delivered on time, and new versions have been introduced on schedule until 1992.

When Sun introduced its first RISC workstation in 1987, the operating system running on it, SunOS, was the same operating system that its CISC workstations used. The GUI (graphical user interface) for its RISC workstations was also the same GUI, SunView, used in its CISC workstations. Sun's old CISC customers didn't have to learn a new operating system or GUI. To the automobile designer who had used SunOS operating system commands to manipulate his CAD (computer-aided design) software in his design routines, Sun's RISC was not competence-destroying since his skills, firm-specific assets and routines had not changed.

The RISC workstations were forward compatibility with the CISC ones; i.e., all the applications software that ran on its CISC workstations could also run on the new RISC machines—sometimes with minor recompilation. That meant the circuit designer (a customer) who had accumulated EDA (electronic design and automation) tools and other applications software and skills for CISC workstations as an integral part of her design routines could buy the RISC machines and keep performing well.

For independent software developers (ISVs), the fact that Sun retained the operating system and GUI in moving from CISC to RISC meant that the developer of CAD tools whose program modules had made references to the CISC operating system and GUI, could continue to use those modules. It also meant that the ISVs didn't have to learn how to use a new operating system and GUI, both of which can be difficult to learn but often are an integral part of the customer's skills. Forward compatibility of software meant that ISVs could continue to write software the way they did before, which can be important especially if they wrote their software before in CISC assembly language.

From an externalities point of view, forward compatibility of software had some important implications given Sun's large installed base of workstations. For one thing, it meant that Sun's new workstations enjoyed instant demand-scale economies of scale—the workstations were more valuable to customers than price/performance measurements would predict (Kartz and Shapiro, 1985). Sun's old CISC customers would not have to abandon the applications software collections that they had built-up over the years of using Sun CISC workstations. Since ISVs prefer to develop software packages only for platforms with large installed bases or expected large share

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\(^1\)Specifically, the extensions were to accommodate multiprocessors, floating point and tightly coupled coprocessors.
of future installations, Sun's large installed base of compatible systems encouraged more ISVs to develop applications software for SPARC systems.

**Digital Equipment Corporation (DEC)**

DEC's innovation value-added chain experienced considerably more competence-destruction than Sun's and that may explain the difference between the success of the two incumbents. DEC entered the workstation market in 1985 with its VAXStation, a CISC machine. It offered its customers the option to use VAX/VMS, DEC's proprietary operating system, or ULTRIX, its own version of AT&T's UNIX operating system. By a large margin, however, most of its customers preferred the former. After initially resisting to adopt RISC and especially the UNIX operating system—the preferred RISC and workstation operating system—DEC succumbed in 1988 and produced its first RISC workstation in 1989. It's earlier efforts to design its own RISC microprocessors for the workstation had failed and so it bought the microprocessors from new entrant MIPS Computers. (DEC had designed and produced the processors for its CISC workstations itself.) [As we see shortly, MIPS experienced minimal competence-destruction in its microprocessor design.]

At the customer level, it was quite a different story. Despite its large installed base of VAX/VMS customers, DEC decided not to offer the VAX/VMS operating system on its RISC workstations. Ultrix would be the operating system for all the RISC workstations. Moreover—and more critical—none of the accumulated CISC applications software would run on the new RISC machines without major modifications. For the engine designer whose CAD tools, simulation programs and technical management routines had been built on VAX/VMS, buying a DEC RISC machine was competence-destroying. They not only had to learn a new operating system right away, their competencies in design, testing and management which had been built on the old operating system and applications software were destroyed.

For the independent software vendor (ISV) whose talented programmer routinely referenced VAX/VMS commands, exploited its idiosyncrasies, or reused old program modules built on it, this was competence-destroying. Those who had programmed in assembly language now had to learn that of the RISC processor. Additionally, because their old programs could not run on DEC's new machines, the ISVs would have to produce new kinds of programs, possibly for a new kind of market.

Other activities may have also made it difficult for DEC to win new customers or keep old ones. DEC's CEO then, Ken Olsen, didn't think much about UNIX, once calling it "snake oil". To customers, who wanted to join only networks that they believe would be large in the future, such comments didn't help DEC's RISC cause.

Some of the critical mistakes that DEC made when it adopted RISC may have been behind its decisions when it developed its new RISC technology, ALPHA. ALPHA comes with both VAX/VMS and ULTRIX, and has the same graphical user interface as its MIPS-based workstations. For DEC's customers and complementary innovators, this is not competence-destroying. ALPHA can also run the huge installed base of VAX/VMS applications that DEC's customers have accumulated over the years. This also preserves the competence as well as the network externalities
of its customers and complementary innovators and provides ALPHA with large demand-side economies of scale.

The cases of Sun and DEC suggest that competence-destruction and obsolescence of network externalities at customers and complementary innovators play an important role in the success of the workstation maker. The question is, can the two effects be distinguished. The next case tries to do just that.

Sun "Cloners"

Ever since Sun announced in 1987 that it would license its SPARC technology to anyone who wanted it, and followed the announcement with a $99 license fee, at least twenty firms have adopted the SPARC technology and now offer RISC workstations. For each of these Sun "cloners", adopting SPARC has meant instant access to the huge installed base and network of Sun products—the largest such network in workstations. Since customers are better off with a larger network, one would expect these Sun clones to do very well. Potential customers should switch to their products for the benefits that large networks offer. So far, the cloners have not gained that much market share despite their low prices. Since 1989 when the first Sun clones were introduced in the market, Sun's market share has been rising while the clones have not made any substantial inroads into the RISC workstation market. Network externalities don't appear to be enough. Customers are not switching from other RISC technologies like HP's PA-RISC technology or IBM's RS/6000 to the cloners because they (the customers) would have to learn a new operating system, abandon their old applications software, or learn a new GUI (graphical user interface) in order to enjoy the benefits of a larger Sun "clone" network. On the other hand, customers may not be switching from Sun (to the cloners) because it has established distribution channels and brand name recognition that the clones don't yet have. Incumbents like Toshiba and Xerox who have distribution channels that they used to sell their CISC workstations, may be having problems selling SPARC clones because the clones are competence-destroying to these incumbents' established base of customers. Their CISC customers have to learn a new operating system in Solaris, and may have to abandon most of their old CISC-based applications packages.

Success, at least in the case of Sun clones, doesn't appear to depend as much on network externalities as it does on competence. The quantitative analysis of Section V further distinguishes between the roles of competence and network externalities.

IBM (a new entrant in the workstation market but an incumbent in CISC technology)

IBM was a new entrant in the workstation market when it entered with a RISC technology. It had no CISC workstations. From a technology point of view, however, it was an incumbent that had designed CISC processors and computers for years. Its case illustrates how competence-destruction along the whole value-added chain can make a firm fail despite positive network externalities effects. Network externalities alone are not enough.

IBM, which invented RISC, is also credited with introducing the first RISC workstation, the PC/RT in February of 1986. That workstation used the ROMP (Research/Office Products Division Microprocessor) RISC chip designed by IBM's
office products division. Since RISC processors are very fast, and need to transfer instructions and data to and from memory and I/O at very fast rates—they require very high data bandwidths. While other RISC makers used data and instruction caches to provide the fast transfer rates, IBM chose to use a memory bus—a routine design solution in designing CISC processors. The result was an extremely slow processor that didn’t deserve the name RISC. IBM used it to build the PC/RT workstation, which would be withdrawn from the market some years later because of very poor performance.

At the workstation design level, IBM also suffered from architectural knowledge problems. This is reflected in its use of the 16-bit PC/AT bus in the RT design instead of the 32-bit bus that UNIX prefers since it manipulates data in 32-bit chunks, and 16-bit data slows it down considerably. This suggests that IBM may have been using CISC problem solving strategies where hardware is designed first and software is an afterthought. Interaction with the software groups, especially the UNIX group could have eliminated the problem. In any case, the design resulted in a very slow bus that, added to the already slow ROMP microprocessor, made for a very slow PC/RT. While Sun’s first SPARC workstation, introduced a year later in 1987, boasted 10 MIPS (million instructions per second), the PC/RT was only 3 MIPS.

IBM may also have experienced market competence problems at the workstation level. It viewed the workstation market as an extension of the personal computer market which it served at the time with its PC/AT. Thus, instead of making the workstation compatible with some of its minicomputers—the market from which potential workstation buyers were migrating—it provided it with a PC/AT bus believing that workstations were an extension of the PC market. The machine had no GUI, a key distinguishing feature then between PCs and workstations. Even the machine’s name, the PC (personal computer)/RT (RISC technology) signaled that its was earmarked for the PC market. IBM may have misread the market for workstations and designed a PC instead of a workstation.

For potential customers, the PC/RT was competence-destroying. It came with the AIX (Advanced Interactive eXecutive) operating system, IBM’s version of UNIX that was new to customers. It also ran none of IBM’s huge installed base of applications software.

For complementary innovators, it was also competence-destroying. Independent software vendors who wanted to develop software for the new machines had to learn a new operating system. Moreover, their old programs would not run on it.

The PC/RT enjoyed some positive network externalities. Since customers and ISVs who are choosing a network today, care about what the size of the network will be tomorrow (Kartz and Shapiro, 1985), IBM’s size and reputation in establishing large networks previously may have convinced customers and ISVs to adopt the RT or write software for it, respectively. It can be argued that these externalities effects are what gave IBM the 3-1% market share in workstations from 1986 to 1990 (See Table 2). These externalities didn’t save the RT.

---

1 IBM’s size, among other factors, was instrumental in establishing its mainframe computers as a standard, and its personal computer, the PC, as a standard.
In 1990, IBM introduced a different RISC workstation, and like DEC, corrected most of the problems of the PC/RT. At the supplier level, IBM provided the processor with both data and instruction caches to solve the bandwidth problem. At the workstation level, it eliminated the 16-bit bus, replacing it with a UNIX-compatible interface. Upon introducing the product in 1990, IBM’s market share rose from 1% in 1989 to 5% in 1990, rising to 9% in 1991 (see Table 3).

Alternate explanations have been given for the PC/RT’s failure. Morris and Ferguson (1992) suggest that IBM’s powerful minicomputer and mainframe groups, which feared that fast RISC workstations would cannibalize their lucrative products, were responsible for the RT’s failure.

**MIPS Computers**

MIPS was a new entrant in the workstation business and its story further illustrates how competence-destruction and obsolescence of network externalities at customers and complementary innovators can make new entrants (who are expected to thrive) with the best products—price/performance-wise—fail in the face of a radical technical change.

MIPS’s microprocessor instruction set architecture—the heart of the microprocessor RISC design and the potential source of competence destruction—came from the MIPS (Microprocessor without Interlocked Pipelining) RISC project at Stanford university that had been led by RISC-pioneer Professor John Hennessey and his students. He took the design with him when he took a leave of absence to found MIPS. Thus RISC was not as competence-destroying to MIPS as it was to incumbent CISC microprocessor makers like Motorola and Intel. Recall that competence-destruction in RISC at the supplier level lies largely in the instruction set architecture design.

MIPS also used some of its own chips to build workstations. The performance of these workstations was phenomenal. Commented, Workstation Laboratories, an independent test house that evaluates UNIX-based systems, "Wow! Terrific performance, outstanding price/performance ratio, . . ." (Wilson, 1988). This performance didn’t translate into sales. When MIPS introduced its first workstation in 1988, it had no installed base of workstations and no-one was familiar with its UNIX operating system, RISC/OS, and graphical user interface (GUI), RISC Windows. Potential customers who evaluated the system found it potentially competence-destroying since they would have to learn a new operating system, GUI, and replace any applications software that they may have accumulated. Having to replace three components—each of which has different attributes from prior ones—is, as demonstrated earlier competence-destroying to customers.

For complementary innovators, writing software for MIPS systems would also be competence-destroying since it would require inserting new components with different attributes in their repertoire of firm-specific assets, routines and relationships.

From an externalities point of view, customers who were already using other operating systems and GUIs, and also had their own software were reluctant to obsolete their old network and join a network as small as MIPS’s. MIPS didn’t have the size or reputation that would convince potential customers to expect its future
network to be large and therefore join it now. Even a large network, as we saw in the case of Sun clones, may not overcome the effects of competence.

Summary and conclusions from the cases

In introducing its RISC workstations, Sun maintained the same operating system and GUI (graphical user interface) that its CISC customers had grown accustomed to. Sun's CISC applications software could also run on its new RISC workstations. DEC, in introducing its own RISC workstations, did just the opposite. I suggested that Sun's superior performance compared to DEC could therefore be attributed to competence-destruction or obsolescence of network externalities at customers and complementary innovators. To distinguish between the effects of competence and those of externalities, I used the case of Sun clones. I showed that Sun clones are not doing well, despite the benefits of Sun's large installed base, because customers care more about their competence than network externalities. The lackluster performance of HP and IBM from 1986 to 1991 also confirms that positive network externalities alone may not be enough to make a firm succeed; competence destruction along the value-added chain matters. The case of MIPS illustrated why new entrants have difficulties succeeding despite superior products. Their products are competence-destroying, and externalities obsoleting to customers and complementary innovators.

Figure 3 summarizes the effects of RISC along the innovation value-added chain for each of the cases. It also illustrates the danger of trying to explain the success of firms in the face of competence-destroying technical change by focusing only on the impact of the change on the competence of the innovating entity. In the figure, looking at the innovating entity alone tells us that new entrant MIPS should succeed while Sun shouldn't. However, looking at the impact of the innovation on the whole value-added chain reveals a different picture.

Alternate explanations have been given for DEC's failure to capitalize on RISC workstation technology. Sanderson (1992) suggests that Sun has been more successful in RISC workstations than DEC because Sun made a clean break in switching from CISC to RISC, making sure that it had nothing more to do with CISC once it had switched, and also focusing on one product line—workstations. DEC, on the other hand, had both CISC and RISC products in the market, and also considered workstations as an integral part of its networked computer systems instead of a separate workstation business.

Section V
THE EMPIRICAL ANALYSIS—quantitative

The case studies explored in depth the impact of RISC on competence and network externalities of the innovation value-added chain of five workstation makers and the consequences for their success in adopting RISC. The purpose of this quantitative analysis is threefold: to extend the exploration to the dozens of other firms that have adopted RISC for their workstations, and thus strengthen the external validity of the study; to examine the effect that such control variables as time of adoption have on the effect of competence and network externalities on the success of firms; and to further explore the distinction between the effects of competence and network externalities on success.
Accordingly, I specify and test an empirical model. The results suggest that, as with the case studies, success is a function of competence-destruction along the value-added chain. I distinguish between the effects of competence and those of network externalities, showing that success is more a function of customer competence than it is of network externalities. I also show that the innovating firm's competence (as measured by its products' performance) and that of its suppliers play a role in explaining its success.

**Specification of the empirical model:**

The underlying hypothesis of this paper suggests that a firm's success in adopting a new technology is a function of the level of competence-destruction and obsolescence of network externalities inflicted by the new technology along the firm's innovation value-added chain. For workstation makers, this relationship can be expressed as:

\[
\text{Log}_e (\text{MARKET\_SHARE}_i) = \alpha_0 + \xi_1 \text{Log}_e (\text{PERFORMANCE}_i) + \xi_2 \text{Log}_e P_i + \\
\xi_3 \text{Log}_e (\text{OWN\_INSTALLED\_BASE}_i) + \xi_4 \text{Log}_e (\text{INSTALLED\_NETWORK}_i) + \\
\xi_5 \text{Log}_e \text{MHZ}_i + \xi_6 \text{DM}_i + \xi_7 \text{CV}_i + \epsilon_i \quad \text{Equation 1}
\]

where \text{MARKET\_SHARE}_i is the market share of workstation i, a proxy for its success; \text{PERFORMANCE}_i is the performance of workstation i, a proxy for the workstation maker's competence; \text{P}_i is the price of i; \text{OWN\_INSTALLED\_BASE} is each firm's own installed base of workstations with which workstation i is compatible, a measure of customer and complementary innovator competence; \text{INSTALLED\_NETWORK}, a measure of customer network externalities, is the total installed base of workstations that are compatible with i, i.e., compatible products from the firm that owns i, and those from any other firm with which i is compatible; \text{MHZ}_i is the speed of the RISC microprocessors used in i, a measure of supplier competence; \text{DM}_i is a vector of firm dummy variables; \text{CV}_i is a vector of control variables; \epsilon_i is a random variable that for the moment, is assumed to be iid (identically and independently distributed); and \alpha, and \xi, are constants. The definitions of these variables are summarized in Table 3.

In Equation 1, \text{P}_i is also a function of \text{PERFORMANCE}_i, and \text{PERFORMANCE}_i is in turn a function of \text{MHZ}_i so that:

\[
\text{Log}_e (\text{P}_i) = \gamma_0 + \beta \text{Log}_e (\text{PERFORMANCE}_i) + \chi_1 \text{CV}_i + \epsilon_i \quad \text{Equation 2},
\]

\[
\text{PERFORMANCE}_i = \text{MHZ}_i + \text{OV}_i + \epsilon_i \quad \text{Equation 3}
\]

where \text{OV}_i is a vector of the other variables like cache memory that impact workstation performance. Thus estimation of the effects of competence and network externalities on success consist of estimating the above system of simultaneous equations. This version of this paper uses the reduced form of equation 1.

**Results**

OLS (ordinary Least Squares) estimates of Equation 1 are summarized in Table 4. In model M2 of that table, the coefficient of
\( \log_e(OWN\_INSTALLED\_BASE) \) is highly significant \((p=0.00)\). Recall that \( OWN\_INSTALLED\_BASE \) for each workstation represents the number of customers who have learned the workstation's operating system and graphical user interface (GUI), and who have accumulated applications programs, all of which form an integral part of their competence in what it is that they use workstations for. This high level of significance suggests that competence and/or network externalities play a key role in the success of workstations. The question is which one plays the more significant role—competence or network externalities. Model M3 of Table 4 provides some insights to this question. There, \( OWN\_INSTALLED\_BASE \) has been replaced by \( INSTALLED\_NETWORK \), the installed base to which a firm's workstations are compatible (its own and that of other firms). \( INSTALLED\_NETWORK \) is always greater or equal to \( OWN\_INSTALLED\_BASE \). For example, a firm that has just entered the RISC workstation market with a Sun-compatible workstation has an \( INSTALLED\_NETWORK \) equal to Sun's installed base but an \( OWN\_INSTALLED\_BASE \) of zero. Hence, for each workstation, \( INSTALLED\_NETWORK \) is always larger than or equal to \( OWN\_INSTALLED\_BASE \) and therefore constitutes a larger network. If network externalities are what determine the success of a workstation, the coefficient of \( INSTALLED\_NETWORK \) should be significant since customers should prefer the larger network. In Model M3 of Table 4, the coefficient of \( \log_e(INSTALLED\_NETWORK) \) is not significant. In fact, \( R^2 \) drops by .277. If network externalities were the primary reason for customers choosing a new RISC workstation, \( \log_e(INSTALLED\_NETWORK) \) would be significant. The firms that build workstations that are compatible with Sun's or IBM's or HP should have market shares that reflect the sizes of their networks. Instead, it is the coefficient of \( OWN\_INSTALLED\_BASE \) that is significant suggesting that customers prefer to preserve their competence.

The coefficients of \( \log_e(MHZ) \) and \( \log_e(PERFORMANCE) \) are not significant suggesting that supplier competence and workstation maker competence, respectively, don't play a key role in determining workstation success. However, as Model M6 of Table 4 shows, the coefficient of \( \log_e(PRICE/PERFORMANCE) \)—a popular measure of technical performance in the computer industry—is negative and highly significant suggesting that the lower the price per MIP or per SPECmark of a workstation, the more likely it is to succeed. In the next version of this paper, I use a better measure of microprocessor supplier competence than clock speed in Megahertz (MHZ). I will also estimate the system of simultaneous equations of the model specified above.

Section V

SUMMARY AND CONCLUSIONS

This paper has suggested that the success of incumbents and failure of new entrants in the face of radical technical change can be explained by two factors: On the one hand, an innovation that is radical to the innovating entity may not be radical to the members of its innovation value-added chain. Therefore, to understand the success or failure of firms in adopting technologies, one must examine not only the effects of the technology on the adopter's competence, one must also examine its effects on the competence of the firm's innovation value-added chain of suppliers,
complementary innovators and customers. On the other hand, what organizational theorists see as competence-destruction may be regarded as obsolescence of network externalities by economists. Therefore success is better understood using the combined multidisciplinary approach of exploring both competence and network externalities effects along the value-added chain.

Using detailed field-based data on the adoption of RISC (Reduced Instruction Set Computers) by computer workstation makers, I showed that an incumbent's success (or new entrant's failure) is explained by the extent to which the firm's innovation value-added chain experiences competence-destruction and obsolescence of network externalities. In particular, I used both case studies and econometric analysis to distinguish between the effects of competence and network externalities, showing that customer competence explains success to a larger extent than do network externalities. I also showed that a workstation maker's competence also explains its success in adopting RISC.

The role of supplier and complementary innovator competence, in explaining firm success needs further exploration.
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TABLES AND FIGURES

Table 1: Incumbents have dominated the RISC Workstation Market (Source: IDC for 1991 data and Infocorp for 1989 data)

<table>
<thead>
<tr>
<th>Firm</th>
<th>RISC share</th>
<th>Incumbent?</th>
<th>RISC</th>
<th>RISC Adopted in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>54.8%</td>
<td>Incumbent</td>
<td>SPARC</td>
<td>1987</td>
</tr>
<tr>
<td>Intergraph</td>
<td>15.6%</td>
<td>Incumbent</td>
<td>Clipper</td>
<td>1986</td>
</tr>
<tr>
<td>DEC</td>
<td>9.6%</td>
<td>Incumbent</td>
<td>MIPS</td>
<td>1988</td>
</tr>
<tr>
<td>Silicon Graphics</td>
<td>8.1%</td>
<td>Incumbent</td>
<td>MIPS</td>
<td>1988</td>
</tr>
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<td>IBM</td>
<td>4.5%</td>
<td>New Entrant</td>
<td>PC/RT</td>
<td>1986/1990</td>
</tr>
<tr>
<td>HP</td>
<td>11.1%</td>
<td>Incumbent</td>
<td>PA-RISC</td>
<td>1986</td>
</tr>
<tr>
<td>Other</td>
<td>7.4%</td>
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Table 2: Workstation market shares of the major players—RISC and CISC. (Source: IDC)

<table>
<thead>
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<tr>
<td>Sun</td>
<td>28%</td>
<td>33%</td>
<td>27%</td>
<td>32%</td>
<td>33%</td>
<td>37%</td>
<td>38%</td>
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<tr>
<td>HP/Apollo</td>
<td>52%</td>
<td>47%</td>
<td>34%</td>
<td>27%</td>
<td>25%</td>
<td>21%</td>
<td>18%</td>
</tr>
<tr>
<td>Digital</td>
<td>12%</td>
<td>8%</td>
<td>20%</td>
<td>21%</td>
<td>22%</td>
<td>17%</td>
<td>14%</td>
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<tr>
<td>IBM</td>
<td>3%</td>
<td>3%</td>
<td>2%</td>
<td>1%</td>
<td>5%</td>
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<tr>
<td>Intergraph</td>
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<td>3%</td>
<td>5%</td>
<td>4%</td>
<td>4%</td>
<td>3%</td>
<td></td>
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<tr>
<td>Sony</td>
<td>4%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NeXT</td>
<td></td>
<td>2%</td>
<td>3%</td>
<td>5%</td>
<td></td>
<td></td>
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<tr>
<td>Silicon Graphics</td>
<td>4%</td>
<td>3%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
<td></td>
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<tr>
<td>MIPS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1%</td>
<td>1%</td>
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<tr>
<td>NEC</td>
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<td></td>
<td></td>
<td>2%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td>4%</td>
<td>6%</td>
<td>5%</td>
<td>6%</td>
<td>6%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
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<tr>
<td>Variable</td>
<td>Definition</td>
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<tr>
<td>MARKET_SHARE</td>
<td>Each RISC workstation's market share in units shipped</td>
<td></td>
<td></td>
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<tr>
<td>PRICE</td>
<td>Average Price of a workstation in 1992 dollars</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>PERFORMANCE</td>
<td>The performance of each workstation in MIPS (million instructions per second) or SPECmarks</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PRICE/PERFORMANCE</td>
<td>Price per MIP or Price per SPECmark. Widely used measure of performance</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>OWN_INSTALLED_BASE</td>
<td>The firm's own installed base of products to which the workstation is compatible</td>
<td></td>
<td></td>
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<tr>
<td>INSTALLED_NETWORK</td>
<td>The installed base of all the products with which the workstation is compatible. Includes products from the firm that produces the workstation and the installed base of any other firm to which the workstation is compatible.</td>
<td></td>
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<tr>
<td>DG</td>
<td>Dummy variable for Data General (DG)</td>
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<tr>
<td>DEC</td>
<td>Dummy variable for Digital Equipment Corporation (DEC)</td>
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<tr>
<td>HP</td>
<td>Dummy variable for Hewlett Packard (HP)</td>
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<tr>
<td>IBM</td>
<td>Dummy variable for IBM</td>
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<tr>
<td>INTERGRAPH</td>
<td>Dummy variable for Intergraph</td>
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<tr>
<td>MIPS</td>
<td>Dummy variable for MIPS Computer Corp.</td>
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<tr>
<td>SGI</td>
<td>Dummy variable for Silicon Graphics Inc. (SGI)</td>
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<tr>
<td>SOLBOURN</td>
<td>Dummy variable for Solbourne</td>
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<tr>
<td>TATUNG</td>
<td>Dummy variable for Tatung</td>
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</table>
Table 4: Effects of competence and externalities on success. The coefficient of $\log(\text{OWNINSTALLED\_BASE})$ is highly significant while that of $\log(\text{INSTALLED\_NETWORK})$ is not (or has the wrong sign). This suggests that customer competence, more than externalities, determines success.

Sun Microsystems is the base firm dummy.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>M1=</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
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</thead>
<tbody>
<tr>
<td>$\log(\text{MARKET_SHARE})$</td>
<td></td>
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<tr>
<td>n=95</td>
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<tr>
<td>CONSTANT</td>
<td>16.36*** (7.04)</td>
<td>10.83*** (5.28)</td>
<td>14.69*** (4.73)</td>
<td>14.15*** (5.74)</td>
<td>19.67*** (6.11)</td>
<td>8.97*** (3.87)</td>
</tr>
<tr>
<td>$\log(\text{PERFORMANCE})$</td>
<td>0.49 (1.43)</td>
<td>0.11 (0.41)</td>
<td>0.42 (1.19)</td>
<td>0.23 (0.81)</td>
<td>0.55 (1.64)</td>
<td>_</td>
</tr>
<tr>
<td>$\log(\text{PRICE})$</td>
<td>-1.15*** (-4.49)</td>
<td>-1.18*** (-5.67)</td>
<td>-1.09*** (-4.08)</td>
<td>-1.33*** (-6.24)</td>
<td>-1.47*** (-5.48)</td>
<td>_</td>
</tr>
<tr>
<td>$\log(\text{PRICE/PERFORMANCE})$</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>-1.04*** (-4.74)</td>
<td>_</td>
</tr>
<tr>
<td>$\log(\text{OWNINSTALLED_BASE})$</td>
<td>0.68*** (6.94)</td>
<td>_</td>
<td>0.79*** (7.40)</td>
<td>0.73*** (2.70)</td>
<td>0.69*** (6.07)</td>
<td>_</td>
</tr>
<tr>
<td>$\log(\text{INSTALLED_NETWORK})$</td>
<td>0.12 (0.81)</td>
<td>-0.29** (-2.32)</td>
<td>_</td>
<td>-0.60* (-1.90)</td>
<td>-0.25* (-1.87)</td>
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<tr>
<td>DG</td>
<td>_</td>
<td>-1.82** (-2.40)</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
<tr>
<td>DEC</td>
<td>_</td>
<td>-1.41** (-2.28)</td>
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<td>_</td>
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<td>_</td>
</tr>
<tr>
<td>HP</td>
<td>_</td>
<td>-1.38** (-2.37)</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
<tr>
<td>IBM</td>
<td>_</td>
<td>-1.00* (-1.73)</td>
<td>_</td>
<td>_</td>
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<td>_</td>
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<tr>
<td>MIPS</td>
<td>_</td>
<td>-3.18*** (-3.64)</td>
<td>_</td>
<td>_</td>
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<td>_</td>
</tr>
<tr>
<td>SGI</td>
<td>_</td>
<td>0.53 (0.49)</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>SOBOURN</td>
<td>_</td>
<td>-1.06 (-0.85)</td>
<td>_</td>
<td>_</td>
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<td>_</td>
</tr>
<tr>
<td>TATUNG</td>
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<td>-0.43 (-0.30)</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
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<tr>
<td>INTERGRAPH</td>
<td>_</td>
<td>-1.19* (-1.73)</td>
<td>_</td>
<td>_</td>
<td>_</td>
<td>_</td>
</tr>
</tbody>
</table>

Adjusted $R^2$:

0.165 0.448 0.161 0.473 0.538 0.377

* significant at the 10% level
** significant at the 5% level
*** significant at the 1% level
* Significant but has the wrong sign
Figure 1a: The DSK keyboard was an incremental innovation to its innovator but a radical innovation to customers. The Cray-3 was an incremental innovation to Cray Computer Corp. but a radical innovation to its silicon semiconductor suppliers who now faced GaAs, an unproven technology. It remained an incremental innovation to its customers and complementary innovators.
Figure 1b: Faces of an Innovation along the value-added chain. The innovation is radical to both firms; but incremental to Firm A's customers and complimentary innovators while radical to Firm B's customers and complementary innovators. Focusing on the impact of the innovation on the competence of the innovating firm alone would suggest that both firms have an equal chance of failing; but focusing on the impact on the whole innovation value-added chain shows that B is more likely to fail, ceteris paribus.
![Figure 2: The cases of DEC and Sun demonstrate the importance of competence and network externalities at customers and ISVs, while that of Sun clones tries to distinguish between externalities and competence. The case of IBM demonstrates the effects of competence at suppliers and the rest of the chain while that of MIPS shows why a new entrant might fail in the face of radical change.]

<table>
<thead>
<tr>
<th>Incumbents</th>
<th>Competence</th>
<th>Externalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEC</td>
<td></td>
<td></td>
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<tr>
<td>Sun compatibles</td>
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<tr>
<td>Entrants</td>
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<td></td>
</tr>
<tr>
<td>IBM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIPS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- □ Competence-destroying
- □ Network externalities obsoleting
- □ Not competence-destroying
- □ Not Network externalities obsoleting
Figure 3: Competence-destruction along the workstation innovation value-added chain, and success. IBM (PC/RT), MIPS, and DEC (MIPS) were relative failures, while Sun and IBM (RS/6000) have been relatively successful. The jury is still out on DEC (ALPHA).

Note on construction of this chart:
Relative competence-destruction at the supplier and workstation maker levels is proxied by the relative performance of microprocessors and workstations respectively. At the customer and complementary innovator levels, competence-destruction is proxied by whether the operating system and GUI were the same for CISC and RISC workstations, and if a firm's CISC applications software could run on its RISC machines.
Figure 3: Comparison-derivation along the production isometric with the added dimension and interest. IBM (PC/KT), MIPS, and DEC (MDP) were relatively uninteresting in the last 5 years and IBM (308/6000) have been relatively successful. The index is self-contained D,E,C,E,A,F,A (A).