Strategic Management Journal
Strat. Mgmt. J., **21**: 387–404 (2000)

HOW MUCH DO YOUR *CO-OPETITORS'* CAPABILITIES MATTER IN THE FACE OF TECHNOLOGICAL CHANGE?

ALLAN AFUAH*
University of Michigan Business School, Ann Arbor, Michigan, USA

Firms often lose their competitive advantage when a technological change renders their existing capabilities obsolete. An important question that has received little or no attention is, what happens to these firms' competitive advantage when the technological change instead renders obsolete the capabilities of their co-opetitors—the suppliers, customers, and complementors whose very success may underpin that of the firm and with whom it must collaborate and compete. This paper explores the effects on a firm of the impact of a technological change on its co-opetitors*. It argues that a firm's post-technological change performance decreases with the extent to which the technological change renders* co-opetitors' *capabilities obsolete. It uses detailed data on the adoption of RISC (Reduced Instruction Set Computer) technology by computer workstation makers to demonstrate the need to view resources as residing in a network and not in the firm alone.* Copyright © 2000 John Wiley & Sons, Ltd.

INTRODUCTION

One central theme in strategy argues that a firm should view its suppliers, customers, rivals, and potential new entrants as competitors, and design its strategies so as to attain a product-market position that allows it to exercise bargaining power over suppliers and customers while keeping out new entrants and rivals from its product-market positions (Porter, 1980). Another argues that competitive advantage comes from owning unique, valuable, inimitable, nonsubstitutable capabilities that allow the firm to offer its customers better value than competitors (Lippman and Rumelt, 1982; Wernerfelt, 1984; Barney, 1991; and Peteraf, 1993). In any case, a competitive advantage—whether from distinctive capabilities or an attractive product-market position—can be eroded by technological change (Tushman and Anderson, 1986; Henderson and Clark, 1990; Leonard-Barton, 1992). It has also been recognized that a firm's competitive advantage may rest on tacit, inimitable collaborative relationships with and the success of its *co-opetitors*[1]—the suppliers, customers, complementors and alliance partners with whom it must collaborate and compete (Brandenburger and Stuart, 1996; Moore, 1986; Singh and Mitchell, 1996). *Co-opetitors* are critical sources of innovations (Allen, 1984; von Hippel, 1988; Ahuja, 1996), of organizational learning (Kogut, 1988), of complementary products (Grove, 1996), of critical resources (Bower, 1970), of learning and capabilities (Kogut, 1988; Dyer, 1996; Gulati, 1998; Khanna, Gulati and Nohria, 1998; Dyer and Nobeoka, 2000; Gulati and Lawrence, 1999), and of lead users (von

Key words: co-opetitors, networks, competitive advantage, capabilities, competences

*Correspondence to: Professor Allan Afuah, University of Michigan Business School, 701 Tappan Street, Ann Arbor, MI 48109-1234, U.S.A.

---

[1] In using the word *co-opetitor*, I am not trying to burden the reader with one more term. It is easier to use it in place of the phrase 'suppliers, customers and complementors'. The term *co-opetition* was coined by Nadar, CEO of Novell and introduced to strategy research by Brandenburger and Stuart (1996).

CCC 0143–2095/2000/030387–18 $17.50

Hippel, 1986), making relationships with them sometimes critical.

Such dependence on co-opetitors suggests that a technological change that impacts the capabilities of a firm's co-opetitors ought to have an impact on the performance of the firm. Yet, major research streams on technological change have focused on the impact of change on a firm and its fellow incumbents, paying very little attention to the impact of the change on its suppliers, customers and complementors, and the consequences for the firm. One established research stream, for example, argues that incumbent firms are often displaced by entrants at times of radical technological change because such a change renders their capabilities obsolete (Tushman and Anderson, 1986; Leonard-Barton, 1992; Henderson, 1993), or because they do not have the incentive to invest in the radical change for fear of cannibalizing their existing products (Reinganum, 1983, 1984; Gilbert and Newberry, 1982, 1984; Henderson, 1993). Another argues that it takes both technological and market competences to exploit an innovation. Thus while a radical technological change may render an incumbent's technological capabilities obsolete, the firm can still excel in exploiting the change if its marketing capabilities are intact and such capabilities are important and difficult to imitate (Abernathy and Clark, 1985; Teece, 1986; Mitchell, 1989; Tripsas, 1997).

This paper takes a different perspective in exploring post-technological change competition. It focuses on the impact of change on the capabilities of co-opetitors. If a firm has come to depend on its co-opetitor's capabilities, obsolescence of such capabilities can result in lower performance for the firm. Such a reduction in a co-opetitor's performance, for example, can force the co-opetitor to exit its market or find another partner, in turn, reducing the performance of the firm (Singh and Mitchell, 1996). Moreover, collaborative relationships with co-opetitors which are usually a source of competitive advantage can become a handicap when a technological change renders co-opetitors' capabilities obsolete. What may be seen as an 'incremental or competence enhancing' technological change to a firm because it leaves its technological capabilities intact may actually render those of its suppliers, customers, complementors or alliance partners obsolete thereby reducing the performance of an unsuspecting firm that only looks out for those technological changes that potentially have a direct impact on its own capabilities (Afuah and Bahram, 1995). The paper uses detailed data on the adoption of RISC (Reduced Instruction Set Computer) technology by computer workstation makers to explore how the impact of a technological change on a firm's co-opetitors, in turn, impacts the firm's performance. It shows that supplier and customer capabilities obsolescence adversely affected workstation maker performance in the transition from CISC (complex instruction set computer) to RISC technology.

LITERATURE REVIEW AND HYPOTHESIS

Co-opetitors' critical role

Co-opetitors play critical roles during innovation. First, suppliers, customers, and complementors can be as good a source of innovations as firms and their competitors (von Hippel, 1988; Freeman, 1991; Hagedoorn and Schakenraad, 1994). And even when they are not the sources of innovations, co-opetitors still play a substantial role in the information sharing that takes place during the refinement and shepherding of new ideas and their commercialization (Allen, 1984). Moreover, some customers often play a critical role as lead users and work with firms to 'discover' customer needs, acting as beta sites, before the larger customer base decides to adopt (von Hippel, 1986). In industries where standards and network externalities are important, a firm may need alliance partners to help it win a standard or dominant design (Katz and Shapiro, 1985; Utterback, 1994). Also, firms often seek co-opetitors to provide complementary assets when such assets are important but difficult to acquire (Teece, 1986). Finally, co-opetitors can be the source of critical resources such as financing without which firms cannot successful carry out innovation (Bower, 1970; Christensen and Bower, 1996).

Impact of innovation on the capabilities of a firm

Despite these critical roles of a firm's co-opetitors, research in technological change has concentrated on the firm, leaving the impact of change on co-opetitors and the resulting consequences for the firm largely unexplored. Two research streams best illustrate this focus. One argues that a firm's ability to exploit an existing technology is a function of its capabilities or competences (Henderson and Clark, 1990; Leonard-Barton, 1992; Tripsas, 1997). In the face of a technological change, a firm's ability to embrace and exploit the change becomes a function of the extent to which the change renders the firm's existing capabilities obsolete (Tushman and Anderson, 1986; Henderson and Clark, 1990). If the change is competence-destroying in that the skills and knowledge required to exploit it are very different from existing ones, incumbents may have difficulties exploiting it since the old skills and knowledge embedded in their organizational routines and procedures are not only useless, but can also handicap them in their attempts to exploit it (Nelson and Winter, 1982; Abernathy and Clark, 1985; Henderson and Clark, 1990; Leonard-Barton, 1992; Utterback, 1994). The other stream argues that incumbents may underinvest in technological changes that render their existing products non-competitive for fear of cannibalizing their existing positions thereby leaving them more vulnerable to new entrants (Reinganum, 1983, 1984; Gilbert and Newberry, 1982, 1984; Henderson, 1993).

Impact of technological change on *co-opetitors'* capabilities

Such a focus on firms alone may be myopic given that technological change usually has an impact on the capabilities or incentives to invest of suppliers, customers and complementors (Afuah and Bahram, 1995), and that these co-opetitors can be critical to the success of many firms (Brandenburger and Stuart, 1996; Singh and Mitchell, 1996; Galaskiewicz and Zaheer, 1999). The electronic point of sale cash register, for example, rendered obsolete not only the capabilities of makers of mechanical cash registers but also those of suppliers of the ratchets, gears and levers that went into the mechanical machines since components now had to be electronic, requiring fundamentally different underpinning knowledge. Change can also be capabilities enhancing to a firm but capabilities obsoleting to some of its co-opetitors. David's (1985) discussion of the continued dominance of the QWERTY keyboard is a classic example of this. The Dvorak keyboard featured a different arrangement of keys, permitting a roughly 20–40% increase in typing speed. To manufacturers of keyboards, the Dvorak was competence enhancing since all they had to do, in producing the new keyboard, was rearrange the keys. To customers who had learned to touch-type with the QWERTY keyboard, however, adopting the new keyboard meant having to relearn how to touch-type again. It was therefore competence destroying to these customers. Additionally, because there was a large number of typists trained with the QWERTY and employers with an installed base of QWERTY machines, people learning to type preferred to go with the established QWERTY machines.

If innovations can have such an impact on the capabilities of a firm's *co-opetitors*, the question becomes: what kind of an effect would the impact on co-opetitors' capabilities have on the firm itself? This is a function of whether the co-opetitor is a supplier, customer, or complementor and of the type of collaborative relationship between the firm and its co-opetitor.

Suppliers: Extensive research has shown that in many industries, tight links to suppliers are critical to the success of manufacturers (Clark, 1989; Cusumano and Takeshi, 1991; Helper, 1987; Dyer, 1996; Dyer and Nobeoka, 2000). Thus, if a technological change renders the capabilities of suppliers obsolete, firms are faced with a difficult choice: They can stay with their current supplier or switch to a new supplier whose capabilities have not suffered from obsolescence. Staying with the old supplier means that the manufacturer can build on existing close relationships but must grapple with the problems that the supplier faces in making the transition to the new technology. If the change is radical enough to suppliers, they may not be able to supply components with the type of quality that the firm needs to be competitive with the new technology. Moreover, since suppliers can be a source of innovations (von Hippel, 1988), having a supplier with obsolete capabilities deprives the firm of vital sources of innovation. Switching suppliers means having to build new relationships and, in doing this, a firm may be handicapped by the organizational procedures and routines that it developed in its old relationships (Tushman and Anderson, 1986;

Henderson and Clark, 1990). Thus, in those cases in which relationships to suppliers are important and difficult to establish:

> *Hypothesis 1a: The more a firm's suppliers' capabilities are rendered obsolete by a technological change, the poorer the firm will perform.*

> *Hypothesis 1b: In the face of a technological change that is capabilities obsoleting to suppliers, firms that switch to new suppliers perform better than those that stay with old suppliers.*[2]

> *Hypothesis 2: Incumbents who are vertically integrated backwards will perform worse than those who are not, in the face of a technological change that renders the capabilities of the supplier obsolete.*

Customers: A firm's installed base and relationships with its existing customers can be a source of competitive advantage (Rothwell *et al*., 1974; Langlois, 1992). However, this advantage can become a handicap or be rendered useless by a technological change that renders existing customers' own capabilities obsolete. There are two ways in which this can happen. First, the technological change can result in a product that does not fit in the firm's existing customers' application. Christensen and Bower (1996) offer a good example in disk drives. The change from the 8-inch disk drives that were used in minicomputers to the 51/2-inch disk drives earmarked for desktop computers constituted a different application or 'value network' (Christensen and Rosenbloom, 1995) since users of minicomputers had very little use for the new drives. Organizational capabilities developed to sell to such customers may make it difficult to understand the ways in which the technological change alters the industry 'value network' and respond effectively to the change. Incumbents may have the technical competencies necessary to produce the new technology but tight, often tacit, links to existing customers may blind them to the new patterns of value creation made possible by the new technology. Second, the product from the technological change can fit in existing customers' value network but still be competence destroying. The DVORAK keyboard discussed earlier, for example, did not create a new value network but required new typing skills. In this second case, a firm's existing customer base may not want the new product because it renders its capabilities obsolete. Even if customers want such a product, their performance may be decreased (Henderson and Clark, 1990), indirectly impacting the performance of the firm (Singh and Mitchell, 1996). Thus:

> *Hypothesis 3: The more a firm's customers' capabilities are rendered obsolete by a technological change, the poorer the firm will perform.*

Network externalities and *co-opetitor* competences

Customer value is sometimes a function of network externatilities. A product or technology exhibits network externalities if the more customers that use it or a compatible one, the more valuable it is to each user (Katz and Shapiro, 1985; David, 1985; Farrell and Saloner, 1985, 1986; Baum, Korn and Kotha, 1995). This increasing value comes from the fact that the more customers that use a product, the more complementary products that will be developed for it and the more complementary products, the more valuable the product is to customers. Network externalities also arise from two other sources. First, there is the direct effect of network size where the more people that use the same product or technology, the more valuable it is to customers (Katz and Shapiro, 1985). The quintessential example is the telephone network. A phone line that is connected to just one other person is not as valuable as one that is connected to everyone else. Second, products or technologies that require specialized learning by customers can also exhibit network externalities since the more products that are available, the more opportunities there are for the customer to apply his or her learned skills (David, 1985; Hartman and Teece, 1990). For example, personal computers with Microsoft's Windows operating system are more valuable to their owners than those with a UNIX operating system since the former has many more users.

---

[2] Special thanks to one of the referees for suggesting this hypothesis.

Some products or technologies possess all three network externalities-endowing characteristics, making it difficult to distinguish between competence destruction for customers and complementors, and network externalities obsolescence. Computers are a good example. The more software that is available for them, the more valuable they are. Also, the more people that own a compatible computer system, the more valuable (beyond more software) each computer is to its owner since he/she can share computers and user information. For example, if a user's computer breaks down, the user's chances of finding another system that he/she can use are better if many other people own a compatible system. Computers also require users and complementors to acquire certain skills and knowledge that may be idiosyncratic to the computer system and compatible ones, making these skills more useful, the more other people that have acquired the same skills and knowledge. Thus, in the face of a technological change that is competence destroying to users and complementors, it is difficult to tell if a firm's performance deterioration is due to the direct effect of the obsolescence of skills or the indirect effect from the reduced network.

We use RISC technology to explore the hypotheses.

RISC TECHNOLOGY AND COMPUTER WORKSTATIONS

Technology and industry background

The adoption of RISC (reduced instruction set computer) technology by computer workstation[3] makers offers a good vehicle for testing these hypotheses because RISC was a technology that had an impact on workstation makers as well as their co-opetitors. The suppliers in this context are makers of the microprocessor chips that computer workstation makers use to build workstations, customers are the firms that buy computer workstations for use in designing products, and complementors are the independent software vendors (ISVs) who sell software directly to users of workstations. Before we get into how RISC impacted the capabilities of workstation makers and their co-opetitors, let us very briefly describe RISC, the technological change. (Appendix provides a more detailed description of the technological change.)

RISC is an innovation in the instruction set architecture of a microprocessor, a method of designing the central processing unit (CPU)[4] that considerably increases the speed of processors. An instruction set is a menu of commands that the CPU understands. Before RISC, there was CISC[5] (Complex Instruction Set Computer). In the design of CISC processors, a primary goal in instruction set design was to have so-called semantically rich instructions—instructions that get the hardware of the CPU to do as much as possible per instruction, moving as much of the burden of programming—of closing the semantic gap between human and computer—as possible from software to hardware. RISC technology calls for the opposite—simple instructions that get the hardware to do less per instruction thereby moving the programming burden from hardware back to software. With their simpler instructions, RISC microprocessors take up less chip real estate, ceteris paribus. This simplicity, coupled with the space saved, allows designers to take advantage of incremental design innovations to build RISC processors that are faster than their CISC predecessors.

Table 1 summarizes the impact of RISC on workstation makers and their co-opetitors. To makers of the CISC chips which workstation makers had used until the invasion by RISC, this technological change was an architectural innovation in the Henderson and Clark (1990) sense. In designing CISC processors, the mindset had been one of 'the more semantically rich the instruction (and therefore complex), the better' with as much of the burden of programming as

---

[3] The definition of a workstation has evolved over the years, with the line between them and personal computers diminishing every year. Earlier definitions (International Data Corporation, 1988) defined it as a 32-bit, single-user, multitasking, compute intensive system with large memory, high-resolution graphics, windowing capability, and networking capability. The definition has changed over the years reflecting advances in technology and evolution of user needs.

[4] 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.

[5] Although so-called Complex Instruction Set Computers existed a long time before RISC, the acronym CISC was coined by Professor David Patterson of UC Berkeley and his students *after* they had started pushing 'RISC' in the computer architecture community.

Table 1. Impact of RISC on a firm (workstation maker) and its *co-opetitors*

	Supplier	Firm	Customer	Complementors
Who	Makers of microprocessors such as Motorola and Intel	Makers of computer workstations such as Sun Microsystems, HP and DEC	Companies such as Boeing and Ford which use workstations to design airplanes and cars	Independent software vendors (ISVs) such as Autodesk who develop and sell software directly to the Boeings
Impact of RISC	RISC was an architectural innovation (Henderson and Clark, 1990): one component of the microprocessor—the instruction set—changed, triggering changes amongst different components. The other components, and the core concepts that underpin them, remained largely unchanged. It was both capabilities obsoleting and enhancing. The first commercial RISC microprocessor was introduced by a new entrant	RISC was an architectural innovation to workstation makers. One component—the microprocessor—had changed, triggering the changes in the linkages between the different components of a workstation. Many incumbents stumbled in their first RISC workstation offerings	RISC was capabilities destroying to users who had invested in learning proprietary operating systems and developing software for those systems	RISC was capabilities obsoleting to those ISVs that had invested in skills and development systems for proprietary workstation operating systems and instruction sets
Potential consequences for workstation maker	Workstation makers risk ending up with inferior RISC microprocessors if they are supplied by a RISC maker who used to make CISC microprocessors. Incumbent workstation makers may be handicapped by their relations with CISC suppliers	Capabilities obsoleting portions of the innovation may hamper incumbent ability to exploit the new technology	Incumbents with CISC proprietary operating systems that must switch to UNIX stand to lose their customers to whom UNIX is capabilities obsoleting	May lose ISVs who must now switch to UNIX and new instruction sets

possible put on hardware. RISC called for ‘the simpler the instructions, the better’ and for moving the burden of closing the semantic gap from hardware back to software. Effectively, although the key components of the microprocessor had not changed in moving from CISC to RISC, the linkages between these components had changed, making the change an architectural innovation. Like many architectural innovations (Henderson and Clark, 1990), RISC was both competence-enhancing and competence-destroying. It was enhancing in that knowledge of components and the core concepts underpinning them had remained the same. It was competence-destroying in that knowledge of the linkages had changed considerably. The reversal in the direction of thinking made it difficult for many CISC designers to understand the rationale behind RISC. The first commercial RISC microprocessor was from a new entrant, MIPS Computer Corp. As of 1997, more than ninety percent of the RISC microprocessors earmarked for computer workstations were also from new entrants (MIPS, Sun, IBM, and HP).[6] This is in keeping with Henderson and Clark's (1990) prediction.

At the computer workstation level, RISC was also an architectural innovation (Henderson and Clark, 1990). It was both competence-enhancing and competence-destroying to workstation makers. Some of the core concepts that underpin one of the components—the microprocessor—had changed, triggering changes in the linkages between it and other components of the workstation. Many CISC workstation makers failed to understand the implications of RISC for the linkages between the microprocessor and other components of the workstation such as the memory system, input/output components, graphics subsystems and software. Some incumbent workstation makers thought that designing RISC workstations was just a matter of replacing the CISC microprocessors in their CISC workstations with a RISC one without paying much attention to other components. That was a mistake. HP, for example, announced in 1983 that the processors in all its workstations and minicomputers were going to be RISC. But it had so much trouble implementing its decision that it did not ship its first RISC workstation until 1988. Even then, the price/performance of the workstation was so poor that HP had to keep shipping CISC workstations until 1991 when it took into consideration the impact of RISC microprocessors on other components of its workstation.

RISC was competence destroying to the installed base of CISC workstation users that had proprietary operating systems. Most workstation makers had provided their own proprietary operating systems with CISC machines.[7] However, when the first RISC microprocessors were being designed, there was a free and readily portable operating system in UNIX that was available to anyone who wanted it. So most RISC workstation makers chose to use the free operating systems, forcing users who had learned proprietary operating systems to relearn a new operating system in UNIX and to rewrite their non-UNIX applications software to run on the new machines. Independent software vendors who had developed software for proprietary systems also had to develop new skills for writing applications for the new operating systems.

Sample and data collection

Data were collected in field-based research between December 1992 and April 1994 in California's Silicon Valley and Massachusetts' Route 128. Since the technological change is the displacement of CISC by RISC in computer workstations, I started the study by constructing a technical history of RISC from its invention in 1975 at IBM to 1992 when 95% of all workstations being introduced were RISC. For the first pass of the technical history, I used archival data from major electrical engineering and computer science journals, and pilot interviews. My first stop for data was a *Lexis/Nexis* search for articles with the keyword 'RISC' in their titles and from these articles, I identified the firms that had adopted or were about to adopt RISC technology for workstations. I also noted the names of the individuals who had invented RISC, written the first journal articles explaining the rationale behind the concept, started the first firms using the technology, or had undertaken some of the first RISC-based workstation projects. From the journal and magazine articles (see Appendix 2 for their names), and preliminary phone interviews with these key individuals, I constructed the technical history. In the history, I paid particular attention to those differences between RISC and CISC that promised to have an impact on

---

[6] There are two key points to note here. First, although Sun, IBM, and HP were in the computer business before the advent of RISC, they never made commercial CISC microprocessors and are therefore new entrants in the microprocessor market. Second, Intel's microprocessors that are used in most personal computers are CISC although the company has been adding RISC-like features to the architecture over the years. The tasks normally performed on personal computers are not as compute-intensive as those on workstations and as such, personal computers do not need the speed of workstations. That is one reason why RISC found its way into workstations faster than it did into personal computers. In 1998, only Apple's personal computers used RISC chips. Moreover, Intel had the huge installed base of CISC-based software PCs that it could exploit by adhering to CISC technology.

[7] An exception was Sun which had, from day one, used UNIX.

the capabilities developed by CISC workstation makers and their CISC *co-opetitors*.

I began in-person interviews after I had finished the first draft of the technical history. In all the interviews, I used the same interview protocol and either had the interviewees read the technical history or described it to them noting their reactions and corrections. From these interviews, the consensus was that *UNIX Review* was the magazine in which key RISC news was reported. I combed through all the issues of the magazine for any stories that I might have missed in the *Lexis/Nexis* search. The differences between the data from *UNIX Review* and those from the *Lexis/Nexis* searches were few and insignificant. Finally, I checked my list of projects with International Data Corporation's (IDC) computer workstation census and their list was a subset of mine. IDC is a market research firm that collects data on computer makers.

In all, I conducted a study of 67 RISC workstation development projects by 23 firms, especially their development histories using in-person plant and telephone interviews, as well as corporate and consulting reports. Appendix 2 provides some details on which companies I visited for in-person interviews and which ones I interviewed over the phone.

Workstation revenues, units sold and technological backgrounds for over a hundred RISC workstations from the 67 projects form the basis for the quantitative analysis. I obtained the revenue, prices and units sold primarily from International Data Corporation (IDC), and Workstations Laboratories, an independent test laboratory. These data were augmented with data from corporate annual statements and interviews with industry experts and consulting reports.

VARIABLES

The variables and their measures are shown in Table 2.

Dependent variables

The dependent variable is a firm's performance in developing and marketing a RISC workstation. This is measured by dollar market share for each workstation for each year that the product is in the market in the period studied, from 1988 to 1992. Revenue market share captures two key outcomes of successful exploitation of technological change to offer new products. First, it captures the ability to sell more units as the innovation offers better value, attracting more customers.

Table 2. Variables and measures

Variable	Measure
Dependent	
Firm performance	Workstation revenue market share in each year
Independent	
Supplier capabilities obsolescence	Dummy variable that is 1 if a firm's supplier of RISC microprocessors had been a supplier of CISC microprocessors and 0 otherwise
Switched suppliers	Dummy variable that is 1 if, in adopting RISC technology, an incumbent switched from the supplier who had supplied it with CISC microprocessors to a new entrant RISC microprocessor and 0 otherwise
Backward vertical integration into CISC	Dummy variable that is 1 if firm had been vertically integrated into CISC microprocessors and 0 otherwise
Customer capabilities obsolescence	Dummy variable that is 1 if firm changed its operating system in moving from CISC to RISC, and 0 otherwise
Control	
Incumbents	Dummy variable that is 1 if the firm offered CISC workstations before adopting RISC, and 0 otherwise
Competition	Number of workstations in the market that year
Growth rate	Percentage growth in workstation sales from the year before
First product	Dummy variable that is 1 if the product was the firm's first RISC workstation

Second, the resulting product differentiation also allows the firm to charge premium prices. Revenue market share captures both.[8] Empirical studies have demonstrated high correlation between revenue market share and profitability (e.g., Buzzell and Gale, 1987; Jacobsen and Aaker, 1985). Thus, since profitability data were not available, revenue market share is a good proxy for the performance of a workstation maker adopting RISC technology.

Independent variables

Obsolescence of a RISC microprocessor supplier's capabilities is measured by whether the RISC supplier had been a CISC supplier before or was a new entrant in the RISC market. The rationale here is that firms which supplied this old technology are more embedded in the systems, routines and procedures (Nelson and Winter, 1982) of CISC than new entrants. Former CISC suppliers must unlearn the CISC skills and learn RISC ones while new entrants do not have to unlearn any (Bettis and Prahalad, 1995). According to Hypothesis 1a, we can expect firms that buy from suppliers with CISC experience to perform worse than their counterparts who buy from suppliers with no CISC experience. The variable, *Supplier capabilities obsolescence*, assumes a value of 1 if the RISC microprocessor supplier had offered CISC microprocessors before, and 0 otherwise. To measure the impact of switching suppliers on a firm's performance, the variable *Switched suppliers* was used. It assumes the value of 1 if, in adopting RISC, a workstation maker switched from its supplier of CISC microprocessors to a new entrant supplier, and 0 otherwise. *Backward vertical integration into CISC* captures the fact that the tacit relations that a firm may have cultivated with its in-house CISC suppliers can now become a handicap in evaluating RISC chip makers and establishing new relations with them. Backward vertical integration into CISC is measured by whether the workstation maker was vertically integrated into CISC microprocessor design and development before adopting RISC or not. The variable *Backward vertical integration into CISC* assumes the value of 1 if a firm had been vertically integrated into CISC and 0 otherwise. *Customer capabilities obsolescence* is measured by whether customers have to change from the operating system that they used with their CISC workstations to a new incompatible one when they buy RISC workstations. A new operating system is not only competence destroying to customers who must learn how to use it. Often, it also means that customers may not be able to use the applications programs that they had accumulated with the old operating system. If a firm introduced a new operating system, one can expect its market share to be lower, all else equal. *Customer capabilities obsolescence* assumes the value of 1 if a firm offered a new operating system with its RISC workstations, and 0 otherwise. Finally, the ability of a workstation maker to exploit a technological change also depends on whether it is an incumbent or new entrant. The variable, *Incumbent*, assumes a value of 1 if the workstation maker had offered CISC workstations before the arrival of RISC and 0 if it entered the workstation market for the first time using RISC technology.

Control variables

We control for several effects, the first of which is *Competition*. This is measured by the number of products in the market in the year in question. The higher the number of competing products, the lower should be the market share for a product. The next control variable is *Growth rate*. Market growth usually means that there are newer customers, increasing the chances of a new product gaining some ground. Old customers who have to make more purchases also give new products a better chance of gaining market share too. Thus the higher the growth rate, the higher should be the market share of new products. Growth rate was measured by the annual percentage increases in revenue dollars for RISC workstations. Many firms stumble when they introduce their first product in the face of a technological change. The dummy variable *First product* is used to isolate this effect. We can expect each firm's product to have a lower market share than other products.

---

[8] Elegant models exist for exploring the relationship between the demand generated by an innovation and the ability to charge more for it (see, for example, Griliches, 1971; Berry, 1991; Hartman and Teece, 1990). However, our goal here is to measure the combined effect and so revenue market share is used.

Statistical methods

Following previous studies that explore the impact of technological change on performance and proxy performance with revenue market share (e.g., Tripsas, 1997), I used the semi-Log (also called Log-Linear) functional form. In particular, I used the expression $\mathrm{Log}(\mathrm{SHARE}_i) = \beta Y_i + \epsilon_i$ where SHARE is the dollar market share, Y is the vector covariates of independent and control variables described above with β as coefficients, and ϵ, the error term. Dollar market share and corresponding vector covariates are for each year that a workstation is in the market.

RESULTS

The means, standard deviations and bivariate correlations for key variables are shown in Table 3. The independent and control variables all have the expected signs with respect to market share. The estimates of the determinants of a workstation maker's performance in the face of the change from CISC to RISC are shown in Table 4. Model M1 is the basic model with control variables. The coefficients of all the variables are significant and have the expected signs. That of *Competition* is negative suggesting that the more products in the market in any one year, the smaller the market share of each product is likely to be. The coefficient of *Growth rate* is positive also suggesting that the higher the growth rate of the market, the better the chances of a new product gaining market share. The coefficient of *First product* is negative suggesting that since firms often make mistakes in their first attempt at new products, the market share of first products is likely to be lower.

Model M2 introduces the variable *Supplier capabilities obsolescence* to test Hypothesis 1a which predicted that the more a firm's suppliers'

Table 3. Means, standard deviations and bivariate correlations for study variables (n = 328)

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10
1. Log (Revenue Market share)	–5.91	2.03	1.00									
2. Competition	90	30	–0.40	1.00								
3. Growth rate (%)	106	134	0.39	–0.83	1.00							
4. First product	0.27	0.44	–0.07	–0.25	0.21	1.00						
5. Supplier capabilities obsolescence	0.30	0.46	–0.14	–0.13	0.05	0.14	1.00					
6. Customer capabilities obsolescence	0.53	0.50	–0.40	0.21	–0.17	0.21	–0.13	1.00				
7. Incumbent	0.67	0.47	0.36	–0.26	0.19	–0.04	0.44	–0.63	1.00			
8. Incumbent* Backward vertical integration into CISC	0.31	0.46	–0.03	–0.01	–0.07	–0.01	0.66	0.02	0.46	1.00		
9. Incumbents* **Not** backward vertical integration into CISC	0.37	0.48	0.38	–0.24	0.25	–0.03	–0.21	–0.63	0.53	–0.51	1.00	
10. Incumbents* Switched suppliers	0.47	0.50	0.34	–0.11	0.10	–0.13	–0.20	–0.28	0.66	0.10	0.55	1.00
11. Incumbents* **Not** switched suppliers	0.20	0.40	–0.01	–0.17	0.09	0.11	0.77	–0.38	0.35	0.42	–0.07	–0.48

Table 4. Dependent variable is Log(Dollar market share) (n = 328)

	M1	M2	M3	M4	M5	M6
Constant	−4.14***	−3.64***	−5.47**	−5.33**	−5.38**	−5.57**
	(−6.44)	(−5.59)	(−8.18)	(−8.05)	(−8.19)	(−8.45)
Competition	−0.02***	−0.02***	−0.002***	−0.02***	−0.02***	−0.01**
	(−3.56)	(−4.08)	(−2.61)	(−2.90)	(−2.76)	(−2.54)
Growth rate	0.25*	0.20	0.28**	0.25*	0.22*	0.26**
	(1.85)	(1.49)	(2.14)	(1.95)	(1.69)	(1.49)
First product	−0.86***	−0.78***	−0.73***	−0.65***	−0.70***	−0.54**
	(−3.68)	(−3.35)	(−3.22)	(−2.89)	(−3.12)	(−2.34)
Supplier capabilities obsolescence		−0.74***				
		(−3.34)				
Incumbent			1.13***			
			(5.24)			
Incumbent*Switched suppliers				1.35***		
				(6.01)		
Incumbent***Not** switched suppliers				0.57**		
				(2.04)		
Incumbent*Backward vertical integration into CISC					0.69***	
					(2.85)	
Incumbent***Not** backward vertical integration into CISC					1.53***	
					(6.39)	
Incumbents*Customer capabilities obsolescence						0.57**
						(2.12)
Incumbents***Not** customer capabilities obsolescence						1.42***
						(6.17)
Adjusted R^2	0.198	0.223	0.259	0.277	0.285	0.280

***Significant to less than 1% level
**Significant to less than 5% level
*Significant to less than 10% level

capabilities are rendered obsolete by a technological change, the poorer the firm will perform. The coefficient of the variable is negative and significant supporting the hypothesis. Thus, firms that use RISC microprocessor suppliers who had been CISC suppliers before, on the average, perform worse than firms that chose suppliers who had no CISC experience. Hypothesis 1b predicted that in the face of a technological change that is capabilities obsoleting to suppliers, incumbents that switch to new entrant suppliers perform better than those that stay with their old suppliers. In the RISC context, we want to see if there is a significant difference between the performance of incumbent workstation makers who, in adopting RISC, switched suppliers of microprocessors and those who did not. That is, we want to find out if there is a significant difference between *Incumbent*Switched suppliers* and *Incumbent**Not** switched suppliers* of Model M4. To do so, we perform an F-test (difference of R^2 test), with M3 as the restricted model and M4 as the unrestricted model. (Model M3 introduces the variable *Incumbent*.) $F_{1,322} = 12.81$ is greater than the F_c of 6.63 at a 1% level of significance. This suggests that there is a significant difference between the performance of those incumbents who switched microprocessor suppliers and those who did not. Moreover, the coefficient of *Incumbent*Switched suppliers* is greater than that of *Incumbent**Not** switched suppliers* suggesting that those incumbents who switched suppliers performed better. This supports Hypothesis 1b.

To test Hypothesis 2 which predicted that firms which were vertically integrated backwards will perform worse than those that were not, in the face of a technological change that renders the capabilities of the supplier obsolete, we turn to Models M3 and M5. Our goal here is to see if there is a significant difference between the performance of incumbents who had been vertically integrated into CISC during the CISC era and those who had not been. Following the method that we used to test Hypothesis 1b, we want to see if there is a significant difference between *Incumbent*Backward vertical integration into CISC* and *Incumbent**Not** backward vertical integration into CISC* , with the latter being more positive. An F-test with M3 as the restricted model and M5 as the unrestricted model results in $F_{1,322} = 9.04$ which is greater than the F_c of 6.63 at a 1% level of significance, with *Incumbent****Not*** *backward vertical integration into CISC* being greater than *Incumbent*Backward vertical integration into CISC*. This supports Hypothesis 2.[9]

We now turn to Hypothesis 3 which predicted that the more a firm's customers' capabilities are rendered obsolete by a technological change, the poorer the firm will perform. We are concerned with whether those incumbents who were able to maintain the same operating system in the transition from CISC to RISC performed better than those who did not. As in Hypothesis 2, we perform another F-test with M3 as the restricted model and M6 as the unrestricted model. $F_{1,322} = 10.44$ is greater than the F_c of 6.63 at a 1% level of significance. This suggests that those incumbents who maintained the same operating system in going from CISC to RISC workstations, performed better than those who did not. This supports Hypothesis 3. The question still remains, how does a workstation maker's switching to a new operating system decrease its performance? I conducted detailed case studies of DEC and Sun and found that when workstation makers switched operating systems in moving from CISC to RISC, two factors contributed to their lower market share. First, existing customers delayed purchases of the newer RISC machines. Second, when these existing customers decided to buy the RISC machines, they turned to firms with larger networks. These firms with larger networks were those that had maintained the same operating system in moving from CISC to RISC. Sun was one of them and was quick to point out to customers how much of an existing UNIX installed base and applications software it already had, how 'open' its architecture was and how much bigger its installed base and complementary software developers were. DEC's CISC workstation customers switched in droves to Sun's RISC workstations. New customers buying their first workstation preferred the firm with the larger installed base and complementors.

Other explanations for success with RISC

The question at this point is: what is the relationship between the network resource-based view of explaining success with RISC that we have just explored and existing explanations? Khazam and Mowery (1994), and Garud and Kumaraswamy (1993) argue that Sun was more successful than DEC because it decided to give away both its RISC microprocessor and computer workstation technologies to build a network. Since customers' choice of a network today is a function of the expected future size of the network (Katz and Shapiro, 1985), Sun's strategy attracted many workstation makers as well as independent software vendors to develop products for Sun's SPARC architecture which emerged as the standard in the workstation industry. This is also a customer competence destruction and network externalities story. From the case studies that I performed, it was evident that one reason why many workstation makers and complementors joined the SPARC alliance was because Sun maintained the same operating system in going from CISC to RISC allowing its customers to maintain their old software and complementors to build on the skills acquired in developing software in the CISC era. Gomes-Casseres (1996) argues that success with RISC came to those who not only built the right allies, but also positioned themselves well within the alliance. As just argued, this is also a network externalities story. Finally, Sanderson and Uzumeri (1996) argue that Sun was more successful than DEC in RISC workstations because of its entry strategy. When it decided to switch to RISC, Sun did so cold-turkey and focused all its resources on RISC. DEC, in contrast, was less focused and maintained both RISC and CISC technologies, spreading its resources too thin. Again, this is a network externalities story. From the case studies, customers and complementors saw Sun's commitment to RISC and the compatible installed base of CISC as a signal that it would throw its weight behind its RISC products. This signal and the compatible installed base attracted many customers and complementors to Sun's workstations.

DISCUSSION AND CONCLUSIONS

This research's findings that the more a technological change renders obsolete the capabilities of

---

[9] According to Oster (1999: 211), 'The closest buyer-seller relationship is complete ownership integration.' This suggests that Hypothesis 2 can also be interpreted as: the closer the relationship between a firm and its supplier of CISC, the poorer the firm's performance with RISC technology.

a firm's suppliers or customers, the poorer the firm performs, underscores the importance of using the network as the lens when exploring the impact of a technological change on firm competitive advantage. A lot of attention has been given to the direct impact of technological change on the firm itself, asking the question: How much does a firm's performance deteriorate as a result of the impact of technological change on the firm's *own* capabilities and incentives to invest in the technological change. This paper's primary argument is that the question ought to be: How much does a firm's performance deteriorate as a result of the impact of technological change on the firm's *co-opetitors'* capabilities? This question was explored using the adoption of Reduced Instruction Set Computer (RISC) technology by computer workstation makers.

The paper showed that firms whose suppliers of RISC microprocessors had previously made CISC microprocessors performed worse than those firms whose suppliers were new entrants in RISC microprocessors. Those incumbent workstation makers who, in adopting RISC, switched suppliers performed better than those who did not. Moreover, firms that were vertically integated into CISC, performed worse than those that were not. These results suggest that a firm's ties with suppliers that may be a source of advantage in exploiting an existing technology, can become a handicap in the face of a technological change that renders suppliers' capabilities obsolete. The study also showed that incumbents who, in introducing RISC workstations, maintained their old operating systems performed better than those who did not. This suggests that a technological change that renders customers' capabilities obsolete reduces firm performance. However, this poorer performance can also be the result of two other factors. First, it can be a result of complementor capabilities obsolescence. When a workstation maker changes its operating system, the change is also competence destroying to independent software developers who must also learn how to use the new operating system. This can delay the introduction date and quality of the software that these complementors develop, indirectly impacting the market performance of the incumbent workstation maker. Second, the poorer performance can also be attributed to network externalities. For one thing, if a firm switches operating systems, it is effectively creating a new network that keeps out some of its customers for whom the new operating system is competence destroying. This reduces the value that customers of the new system can expect from the new network. For the other, complementor competence destruction also means fewer complementary products and the fewer the number of complementary products, the less the value for customers. Thus, introducing a new operating system clearly impacts the performance of a firm. However, it is difficult to tell if the difference in performance is a result of complementor or customer competence destruction, or of network externalities obsolescence. In any case, it illustrates the importance of co-opetitors' capabilities in the face of a technological change. Future research could explore the differences between the impact of customer and complementor competence destruction on firm performance. It could also explore the differences between the impact of co-opetitor competence destruction and network externalities obsolescence on firm performance.

These results suggest that, in exploring technological change in some industries, the focus ought to be on the network of *co-opetitors*—the suppliers, customers, and complementors on whose capabilities and success a firm often depends. Co-opetitor-based competitive advantage may come from tight, often tacit links with suppliers, customers or complementors, or from knowledge of the co-opetitor's value network. In the face of a technological change that renders a co-opetitor's capabilities obsolete, such links or knowledge of the co-opetitor's value network may not only be useless, it may also become a handicap to the firm. If a supplier's capabilities are rendered obsolete, for example, a firm faces the dilemma of staying with the old supplier and using inferior components or switching to a new supplier and re-establishing new relations (while being handicapped by the old relations). If the change renders obsolete a customer's capabilities, the firm may be so blinded by its links to customers that it misses out on opportunities in new value networks. What is more is that a technological change that is capabilities enhancing to a firm may actually be capabilities obsoleting to one or more co-opetitors. Thus a firm that is myopic enough to focus only on the impact of technological change on its own capabilities can lose a competitive advantage that it derived from its relations with co-opetitors.

Given the lack of attention to using the network of co-opetitors as the lens for exploring technological change, this research's findings actually raise more questions for future research than they answer. First, research in technological change and strategy has explored the role of alliances that are formed *after* a technological change in exploiting these changes (e.g., Roberts and Berry, 1985). This paper's approach suggests that it would also be insightful to explore the impact of technological change on alliances that existed *before* the technological change, and how such alliances affect firm performance. Second, there is the question of *when*? As Hypothesis 2 suggests, the type of relationship that exists between a firm and its co-opetitors prior to a technological change may also play a major role in the extent to which a firm is hurt by its co-opetitor's competence destruction. What type of relationship matters the most—market exchanges, joint venture or vertical integration? Does the balance of power in the firm-co-opetitor relationship matter? That is, does a co-opetitor's capabilities obsolescence matter at all times or only when the co-opetitor dominates. This is also a starting point for more empirical work.

Finally, recall that in the RISC case, those incumbents who switched suppliers in moving from CISC to RISC performed better than those who did not. An important research question would be why some incumbents were able to switch while others were not.

ACKNOWLEDGEMENTS

I would like to thank Rebecca Henderson, Will Mitchell, Dick Schmalensee, Jim Utterback, the editors of the special issue of SMJ on *Strategic Networks*, and two anonymous referees for useful comments and suggestions. I am, however, responsible for any errors.

REFERENCES

Abernathy, W. and K. B. Clark (1985). 'Mapping the winds of creative destruction', *Research Policy*, **14**, pp. 3–22.

Afuah, A. N. and N. Bahram (1995). 'The hypercube of innovation', *Research Policy*, **24**, pp. 51–76.

Ahuja, G. (1996). 'Collaboration and innovation: A longitudinal study of interfirm linkages and firm patenting performance in the global advanced material industry', dissertation, University of Michigan Business School.

Allen, T. (1984). *Managing the Flow of Technology*. MIT Press, Cambridge, MA.

Barney, J. B. (1991). 'Firm resources and sustained competitive advantage', *Journal of Management*, **17**(1), pp. 99–120.

Baum, J. A. C., H. J. Korn and S. Kotha (1995). 'Dominant designs and population dynamics in telecommunications services: Founding and failure of facsimile transmission services organizations, 1965–1992', *Social Science Research*, **24**, pp. 97–135.

Berry, S. T. (1991). 'Discrete choice models of oligopoly product differentiation', Yale University and NBER mimeo.

Bettis R. A. and C. K. Prahalad (1995). 'The dominant logic: Retrospective and extension', *Strategic Management Journal*, **16**(1), pp. 5–14.

Bower, J. (1970). *Managing the Resource Allocation Process*. Irwin, Homewood, IL.

Brandenburger, A. M. and H. W. Stuart (1996). 'Value-based business strategy', *Journal of Economics & Management Strategy*, **5**(1), pp. 5–24.

Buzzell R. D. and B. T. Gale (1987). *The PIMS Principles: Linking Strategy to Performance*. Free Press, New York.

Christensen, C. M and J. L. Bower (1996). 'Customer power, strategic investment and failure of leading firms', *Strategic Management Journal*, **17**(3), pp. 197–218.

Christensen, C. M and R. S. Rosenbloom (1995). 'Explaining the attacker's advantage: Technological paradigms, organizational dynamics, and the value network', *Research Policy*, **24**, p. 233–257.

Clark, K. B. (1989). 'Project scope and project performance: The effects of parts strategy and supplier involvement on product development', *Management Science*, **35**(10), pp. 1247–1263.

Cusumano, M. A. and A. Takeishi (1991). 'Supplier relations and management: A survey of Japanese, Japanese-transplant, and U.S. auto plants', *Strategic Management Journal*, **12**(8), pp. 563–589.

David, P. A. (1985). 'Clio and the economics of QWERTY', *American Economic Review*, **75**, pp. 332–336.

Dyer, J. H (1996). 'Specialized supplier networks as a source of competitve advantage: Evidence from the auto industry', *Strategic Management Journal*, **17**(4), pp. 271–292.

Dyer, J. H. and K. Nobeoka (2000). 'Creating and managing a high performance knowledge-sharing networks: The Toyota case', *Strategic Management Journal*, Special Issue, **21**, pp. 345–367.

Farrell, J. and G. Saloner (1985). 'Standardization, compatibility and innovation', *Rand Journal of Economics*, **16**, pp. 70–83.

Farrell J. and G. Saloner (1986). 'Installed base and compatibility: Innovation, product preannouncements, and predation', *American Economic Review*, **76**, pp. 940–955.

Freeman, C. (1991). 'Networks of innovators: A synthesis of research issues', *Research Policy*, **20**, pp. 489–524.

Galaskiewicz, J. and A. Zaheer (1999). 'Networks of competitive advantage', *Research in the Sociology of Organizations*, **16**, pp. 237–261.

Garud R. and A. Kumaraswamy (1993). 'Changing competitive dynamics in network industries: An exploration of Sun Microsystems' open systems strategy', *Strategic Management Journal*, **14**(5), pp. 351–369.

Gilbert, R. J. and D. M. Newberry (1982). 'Preemptive patenting and the persistence of monopoly', *American Economic Review*, **73** , pp. 514–595.

Gilbert, R. J. and D. M. Newberry (1984). 'Uncertain innovation and the persistence of monopoly: Comment', *American Economic Review*, **74**, pp. 238–242.

Gomes-Casseres, B. (1996). *The Alliance Revolution: The New Shape of Business Rivalry*. Harvard University Press, Cambridge, MA.

Griliches, Z. (1971). *Price Indexes and Quality Change: Studies in New Methods and Measurement*. Harvard University Press, Cambridge, MA.

Grove, A. S. (1996). *Only the Paranoid Survive*. Double Day, New York.

Gulati , T. and P. Lawrence (1999). 'Organizing vertical networks: A design perspective', paper presented at the *SMJ* Special Issue Conference on Strategic Networks.

Gulati, R. (1998). 'Alliances and networks', *Strategic Management Journal*, **19**(4), pp. 293–317.

Hagedoorn, J. and J. Schakenraad (1994). 'The effect of strategic technology alliances on company performance', *Strategic Management Journal*, **15**(4), pp. 291–309.

Hartman, R. and D. J. Teece (1990). 'Product emulation strategies in the presence of reputation effects and network externalities: Some evidence from the microcomputer industry', *Economics of Innovation and New Technology*, **1**, pp. 157–182.

Helper, S. (1987). 'Supplier relations and technical change: Theory and application to the U.S. automobile industry', dissertation, Harvard University.

Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment industry', *Rand Journal of Economics*, **24**, pp. 248–270.

Henderson, R. and K. B. Clark (1990). 'Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms', *Administrative Sciences Quarterly*, **35**, pp. 9–30.

Hennessy, J. and D. Patterson. (1990). *Computer Architecture and Performance: A Quantitative Approach*. Morgan Kaufmann, San Mateo, CA.

International Data Corporation (IDC) (1988). *Report on Workstations*. International Data Corporation, Framingham, MA.

Jacobsen, R. and D. Aaker (1985). 'Is market share all that it's cracked up to be?', *Journal of Marketing*, **49**, pp. 11–22.

Katz, M. L. and C. Shapiro (1985). 'Network externalities, competition and compatibility', *American Economic Review*, **75**, pp. 424–440.

Khanna, T., R. Gulati and N. Nohria (1998). 'The dynamics of learning alliances: Competition, cooperation and scope', *Strategic Management Journal*, **19**(3), pp. 193–210.

Khazam, J. and D. Mowery (1994). 'Commercialization of RISC: Strategies for the creating of dominant designs', *Research Policy*, **23**, pp. 89–102.

Kogut, B. (1988). 'Joint ventures: Theoretical and empirical perspectives', *Strategic Management Journal*, **9**(4), pp. 319–332.

Langlois, R. N. (1992). External economies and economic progress: The case of the microcomputer industry', *Business History Review*, **66**, pp. 1–50.

Leonard-Barton, D. (1992). 'Core capabilities and core rigidities: A paradox in managing new product development', *Strategic Management Journal*, Summer Special Issue, **13**, pp. 111–126.

Lippman, S. and R. P. Rumelt (1982). 'Uncertain imitability: An analysis of interfirm differences in efficiency under competition', *Bell Journal of Economics*, **13**, pp. 418–438.

Mitchell, W. (1989). 'Whether and when? Probability and timing of incumbents' entry into emerging industrial sub fields', *Administrative Sciences Quarterly*, **34**, pp. 208–230.

Moore, J. F. (1986). The *Death of Competition*. HarperBusiness, New York.

Nelson, R. and S. G. Winter (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

Oster, S. (1999). *Modern Competitive Analysis* (3rd edn.). Oxford University Press, Oxford.

Peteraf, M. A. (1993). 'The cornerstones of competitive advantage: A resource-based view', *Strategic Management Journal*, **14**(3), pp. 179–191.

Porter, M. E. (1980). *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. Free Press, New York.

Reinganum, J. F. (1983). 'Technology adoption under imperfect information', *Bell Journal of Economics*, **14**, pp. 57–69.

Reinganum, J. F. (1984). 'Uncertain innovation and the persistence of monopoly: Reply', *American Economic Review*, **74**, pp. 243–245.

Roberts, E. B and C. A. Berry (1985). 'Entering new businesses: Selecting strategies for success', *Sloan Management Review*, **26**, pp. 3–17.

Rothwell, R., C. Freeman, A. Horsley, V. T. P. Jervis, A. B. Robertson and J. Townsend (1974). 'SAPPHO updated—Project SAPPHO phase II', *Research Policy*, **3**, pp. 258–291.

Sanderson, S. W. and M. Uzumeri (1996). *The Innovation Imperative: Strategies for Managing Product Models and Families*. Irwin, New York.

Singh, K. and W. Mitchell (1996). 'Precarious collaboration: Business survival after partners shut down or form new partnerships', *Strategic Management Journal*, Summer Special Issue, **17**, pp. 99–115.

Teece, D. J. (1986). 'Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy', *Research Policy*, **15**, pp. 285–306.

Tripsas, M. (1997). 'Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry', *Strategic Management Journal*, Summer Special Issue, **18**, pp. 119–142.

Tushman, M. L. and P. A. Anderson (1986). 'Technological discontinuities and organizational environments', *Administrative Science Quarterly*, **31**, pp. 439–465.

Utterback, J. M. (1994). *Mastering the Dynamics of Innovation*. Harvard Business School Press, Cambridge, MA.

von Hippel, E. (1986). 'Lead users: A source of novel product concepts', *Management Science*, **32**, pp. 791–805.

von Hippel, E. (1988). *The Sources of Innovation*. Oxford Unviversity Press, New York.

Wernerfelt, B. (1984). 'A resource-based view of the firm', *The Strategic Management Journal*, **5**(2), pp. 171–180.

APPENDIX 1. RISC TECHNOLOGY

To understand reduced instruction set computer (RISC) technology, it is important to start with a simple definition of a computer. In its most basic form, a computer consists of a Central Processing Unit (CPU)—often referred to as the brain of the computer because it does all the calculations (brainwork) and sends electrical signals to other components telling them what to do; the main memory—sometimes referred to as the gut of the computer because it usually contains the sequence of commands (see below) that the CPU reads in order to know what to do; and the input/output (I/O) unit that the CPU uses to communicate with the keyboard, printers, disk drives, modems, etc. (what are sometimes referred to as peripherals). The three components just described are usually referred to as the hardware of the computer because we can touch and feel them.

For the computer to perform any useful tasks, it must be provided with a well-ordered sequence of commands that the CPU can understand and carry out. This sequence of commands is called a program, and each of the commands, an instruction. Each computer has a menu of these instructions—called an instruction set—that a programmer can choose from. To be executed by the CPU, programs are usually loaded into the main memory (from, say, a disk). The CPU goes to the main memory, fetches each instruction, decodes it (to know what to do) and executes it. The speed of the computer (how fast it runs the program) depends on how quickly the CPU can fetch the instructions, decode and execute them. This sequence of actions—fetching, decoding and executing—is synchronized by clock signals that are released at equal intervals. Each of these intervals is called the cycle time of the computer, and the reciprocal of this cycle time is the clock frequency that most personal computer marketers are referring to when they talk of, say, a 600 MHz system.

What then is RISC?

In order to understand the nature of RISC and its impact on the computer innovation value-added chain, it is best to start with some technical history. In the 1960s and 1970s several factors, three of which are described here, influenced computer design. In the first place, main memory was very slow and expensive. Consequently, a primary goal for computer designers was to minimize how much of this memory was needed by any program during its execution, and how many times the (CPU) had to access the main memory for instructions during execution of the program (Hennessy and Patterson, 1990).

In the second place, most programmers used assembly language[10]—a somewhat awkward non-expressive computer language that uses a mnemonic for each instruction of the instruction set, and is difficult to program in (see the example below). To improve the efficiency of these programmers, computer designers shifted some of the programming burden from programmers to hardware by designing computers that did as much per command from the programmer (line of assembly language code) as possible. An example serves to illustrate the influence of these factors on computer design. To add two numbers **A** and **B**, the programmer could use the [one] complex instruction **Sum R3 A B** to perform the whole task, or the [three] simple instructions **MV R1 A** (move A to register R1), **MV R2 B** (move B to register R2) and **Add R1 R2 R3** (add the contents of Register R1 and R2 and store the sum in register R3) to achieve the same task. The outputs (end results) of the one complex

---

[10] This is a low level language (lower than, say, FORTRAN) that consist of mnemonics such as LDA (for Load Register A), and translates directly (on a one-to-one basis) to machine language code such as 082 which the computer's CPU recognizes.

instruction or the three simple ones are the same. But in the first case, the programmer only has to write one line of code which takes up one unit of main memory and the CPU only has to access the main memory once. The computer hardware is then charged with the rest of the job needed to give the end result. In the second case, the programmer has to write three lines of code which take up three units of main memory and the CPU must access the main memory three times. Given that memory was expensive and slow, and computer architects wanted to make life easier for programmers, it is easy to see why designers would choose the one complex instruction over the three simple ones. The one complex instruction is also said to be semantically rich since with just this one command, a programmer can tell the computer to do what would ordinarily take three instructions. Since, in issuing only one software command, the programmer charges the computer's hardware with the minute details that allow the computer to produce the same results as the three simple instructions, it is said that the burden of closing the semantic gap between programmer and machine is being moved from software to hardware. Effectively, semantically-rich instructions, the so-called 'complex instructions', were preferred in computer design. This resulted in a technological trajectory of sorts where the more complex (semantically-rich) an instruction, the better. Computers with such instructions are so-called CISC (Complex Instruction Set Computer).

Over the years, some of the factors that had perpetuated CISC technology were changing. First, main memory got cheaper and faster, relaxing the constraint on memory space and the need for semantically rich instructions. Second, systems programmers increasingly used higher level languages (as opposed to assembly language) which compilers translated into simple code, also reducing the need for semantically rich instructions. Third, advances were being made in some complementary computer innovations that have a direct bearing on instruction set design. For example, optimizing compilers[11] improved drastically, allowing higher level languages to be translated to very simple and efficient code. This includes efficiently replacing complex instructions with simpler and faster ones. Innovations like cache[12] memory also gained more acceptance, as its implementation became cheaper and more efficient. Thus, those portions of memory that the computer needed frequently during the execution of a program could be stored in cache, therefore reducing the need to access main memory and the need for semantically rich instructions. The combined effect of these factors had a clear impact on computer design. For example, cheaper and faster memory, coupled with the advent of cache technology, meant that computer designers were no longer as restrained by the length of code (and therefore memory space occupied by a program) as before. The increased preference for higher level languages by systems programmers coupled with the improvements in optimizing compilers called into question the need for semantically-rich instructions, the rationale behind CISC computer design. Computer scientists began to question the traditional approach to computer design that called for semantically-rich instructions. They suggested that computer design should use simpler instructions, not complex ones. This was a reversal in direction—from a core concept that had been 'the more semantically-rich an instruction the better', to one where the simpler the instruction, the better. The burden of closing the semantic gap between programmer and machine was being moved back from hardware to software.

With their simpler instructions, RISC microprocessors take up less chip real estate, ceteris paribus. This simplicity, coupled with the space saved, allows designers to take advantage of incremental design innovations to build RISC processors that are faster than their CISC predecessors.

---

[11] A compiler is a program that translates the high level languages most programmers use to the machine instructions that the computer hardware can understand. Some computer scientists don't like the term 'optimizing compiler', insisting that the word 'optimizing' be dropped since compilers have always been designed to be optimizing.

[12] Cache is another layer of memory between the CPU and main memory and that holds the most recently accessed code or data. It is usually physically located on the CPU chip itself and is extremely fast. The ideas behind cache go back, at least, to the 1960s. The first paper describing the concept of cache was published in England by Wilkes in 1965. The first implementation of cache was also in 1965 at the University of Cambridge.

APPENDIX 2. DATA COLLECTION

Table 2A. Journals and magazines used as sources for technical history

ACM Communications
Byte
Computer Architecture News
Computer Reseller News
Computerworld
Datamation
Digital News
Electronic Business
Electronic News
Electronics
High Technology Business
IEEE Computer
IEEE Spectrum
Infoworld
Microprocessor Report
UNIX Review
UNIXworld

Table 2B. Firms and institutions interviewed in-person

Firm	In-person interviews	Telephone interviews	Firm	In-person interviews	Telephone interviews
Apollo Computers	•		Samsung		•
Aries Research Inc.		•	Silicon Graphics	•	
Axil Workstations		•	Solbourne		•
Data General	•		Solflower Computer		•
DEC	•		Sony		•
Evans and Sutherland		•	Stanford University[1]	•	
Hewlett Packard	•		Stardent Computer		•
IBM		•	Sun Microsystems	•	
Intergraph		•	Tatung		•
Kubota		•	Tektronix		•
MIPS	•		Twinhead Corporation		•
Mobius Computing		•	UC Berkeley[2]	•	
Omron		•			

[1] The pioneering RISC research at Stanford was conducted by Professor John Hennessy who went on to found MIPS Computer Corporation which produced the first commercial RISC microprocessors.

[2] The RISC research at the University of California Berkeley was conducted by Professor Dave Patterson.

Although IBM invented RISC, Professors Patterson and Hennessy are normally credited with the commercialization of RISC—taking the idea, championing it and developing RISC products that customers wanted.