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The Temporal Dynamics of Knowledge Creation in the Information Society

MARTIN KENNEY

> In 1993, Gates melodramatically told his software developers "there's not a single line of code here today that will have value, say, in four or five years time"
>
> Randall Stross, *The Microsoft Way* (1996)

Knowledge creation is playing an ever more central role in capitalist economies, and business organizations must constantly create new knowledge to guarantee survival. To be a competitive firm in the contemporary economy it is necessary to continually innovate. Industries and firms that formerly were in comfortably protected, slowly evolving markets are being swept into accelerated change. Nonaka and Takeuchi (1995) were, perhaps, the first authors to reflect on how knowledge is created, but, equally important, they zeroed in on the fundamental importance to today's firms of creating new knowledge or, put differently, of innovating. To compete, a firm must be transformed into an organization mobilized for knowledge creation. This paper reflects on the changing temporal dynamics of innovation on products, which are crystallizations of the state of knowledge in the firm at a particular moment. Products, released from the knowledge-creation process, become static, while the firm rushes into the future.

With knowledge in its various manifestations as the increasing arbiter of value, innovation (i.e., new knowledge creation) has become the key to success in the global marketplace. The dedication of organizations and the increase in the number of organizations dedicated to continuous innovation are having profound effects on the world economy. Product development cycles are being shortened, and there is an acceleration of new product introduction. In the process, the market value of products is increasingly transient, and the length of the commercial usefulness of products is declining. At the heart of the transience of a product's value is the growing centrality of knowledge creation and innovation in the value-creation process. In the contemporary world economy, the value of the purely physical components and inputs such as raw materials is dropping while the value component, consisting of design and "software," is correspondingly increasing. As a result of this tendency, products are becoming "dematerialized." This tendency is most apparent in the electronics-related industries, such as personal computers, software, and data communications, but is no longer confined to high-technology sectors.

The result is that a number of manufacturing sectors have temporal dynamics that resemble the rate of change in the high-fashion garment and shoe industry. This essay argues that these temporal dynamics are intimately connected with the increasing application of electronics and, more precisely, information processing to other industries. Electronics, or the provision of information-processing power, is the vehicle for something more significant, that is, the increasing importance of creating new products. The routinized portions of intellectual activity are being turned over to the computer. This unleashes a powerful tendency to delegate routine calculations to machinery. In the same way that power machinery earlier freed humans from the limits of their muscles, thereby speeding production, information-processing power is freeing the human mind to become more active in the knowledge-creation process.'

This essay examines the implications of the acceleration of knowledge creation and its impacts on business. The remaining sections briefly examine the contemporary dynamics of capitalism, arguing that the acceleration is embedded within the increasing importance of knowledge creation. The second section describes the impact of changing temporal dynamics on the producer goods industry, a critical sector because of its central role in manufacturing, where rapid change has become the norm. The third section describes the supercharged pace of change in the personal computer (PC) industry. The fourth section examines the quintessential knowledge-creation industry, computer software. In software, product physicality is rendered virtually nil, while the knowledge component is nearly total. The fifth chapter speculates on the applicability of the knowledge-transience linkage to the transmutation of computer networks into the Internet. The concluding section discusses the implications of the increasing centrality of knowledge creation and the temporal dynamics of firms.

Knowledge Creation and the Contemporary Economy

The importance of knowledge creation in what many have termed the Information Age is recognized by many scholars (Nonaka and Takeuchi, 1995; Leonard-Barton, 1995). Drucker (1993) argues that we are now in a postcapitalist society in which knowledge and creativity have replaced labor and capital as the source of value. Beyond these theoretical treatments, some empirical research on the implications of these developments is being done. For example, Zuboff (1988) points out that today's automated machinery creates information constantly, yet it is the work of human beings to transform this into knowledge. Put more properly, only human beings can transform information into knowledge. In the transformation of information, people are actually involved in analyzing symbols. Reich (1991) called the persons involved in these activities symbolic analysts. This formulation captures an important component of the changing nature of work. Frenkel and colleagues (1995) argue that more and more workers as part of the work process are dealing with "symbolic and systematic representation(s) of material reality." These representations are attributable to their use of software that models reality on the basis of algorithms.2

In the 1990s, there has been an explosion of interest in the innovatory process. And yet, only a few explicitly consider the temporal aspects of the innovation process. The one that pays the greatest attention to the innovation process has developed a stylized account of a cyclical innovation process that begins with a technological discontinuity, which results in great uncertainty and ferment (Anderson and Tushman, 1990). Eventually, the period of ferment ends, and a dominant design emerges (Suarez and Utterback, 1995). With the emergence of the dominant design, innovation does not end, rather the trajectory shifts into more predictable paths, including incremental product and process innovations, until another technological discontinuity emerges. This model provides a convenient and useful stylized history of technological development.

Explanations of technology *cycles* was pioneered by Abernathy and Clark (1985) and Clark (1985), who generalize from a case study of the automobile to argue that innovations can usefully be thought of as belonging to four innovation cells: architectural, niche, regular, and revolutionary. In these schema, hereafter model 1, the types of innovations are classified on two axes: whether they conserved or disrupted a firm's existing competencies and whether they conserved or disrupted the firm's relationships with its customers. Later, Henderson and Clark (1990) modified this schema (model 2) to classify innovations on the basis of whether the innovation reinforced or overturned core design concepts or changed the linkages between core concepts and components. In the earlier formulation the focus was on the firm, internally or externally. In the second formulation the focus changed to the product and tried to understand the implications of changes in the product for the firm. In model 2 an architectural innovation was redefined as an innovation that "changes the way in which the components of a product are linked together, while leaving the core design concepts untouched." With the emergence of this architectural innovation, evolution usually continues along an incremental process and product improvement cycle. In addition to their new concept of the architectural innovation, Henderson and Clark (1990) added two other types of innovation. The first, which they call radical innovation, is the complete substitution of one genre of products, such as horse-drawn buggies, with another—automobiles. In the second, modular innovation, the core design concept is changed, for example, the substitution of the digital for the analog telephone receiver set, but this does not disrupt the relationships between the different parts of the phone system (though here it is not clear that this was not a radical innovation, because it unleashed the ability to transform the phone into a much more powerful instrument). Model 2 has some elements of a technology cycle in it; however, it is not nearly as explicit as in the dominant design literature or in model 1. Model 2 explicitly considers the impact of the innovation on a firm's knowledge.

Whereas the dominant design literature described a cyclical motion, model 2 is not nearly as deterministic as Model 1 in temporal evolutionary terms. On the other hand, it does bring the firm as a repository of knowledge back into the discussions of innovations and the effects of innovations on the knowledge. However, in another sense, these models seem somewhat lacking when describing the contemporary competitive environment. The accelerated pace of change can mean that the concatenation of simple incremental product innovations can destroy a firm's competencies just as surely and perhaps more quickly than an architectural or radical change. This paper, while not contradicting these models, aims to return the dynamic of knowledge creation to the center of the discussion rather than treating knowledge as a passive component.

To build another basis of understanding the acceleration, it is necessary to recognize that products have an intellectual component and a physical component. The relative balance between the physical value added and the intellectual value added is shifting inexorably toward the intellectual. Many of the fastest growing firms, such as Microsoft, Intel, Oracle, and Cisco, are so successful because their businesses are based much more on the knowledge intensity than on the physical content of their products. In quite another way, retailers such as the Gap are delivering a fashion look that people want. In effect, they are creating knowledge about what the market wants. In yet another way, the value that the shoemaker Nike adds is in the knowledge of shoe design and marketing. The materiality of the shoe is almost less relevant. The "goods" these companies produce are largely dematerialized, in the sense that the value of the material component is relatively minor compared to the value attributable to the knowledge embedded in the product.

To illustrate the importance of the knowledge and the accelerated temporal dynamic, an example from the semiconductor industry is interesting. A semiconductor sold in 1999 will, by the middle of 2001, have lost more than 50 percent of its value. Some semiconductors will no longer be available, having been replaced by improved products with much greater functionality. According to an article in *Electronic News (1996),* "[t]he life span of an IC [integrated circuit] made by a big player is short. There's only about 18 months to four years while a firm like Motorola ramps up production, places a circuit in a system and manufactures the circuit at volumes high enough to keep it profitable." After four years, the market value of the knowledge congealed in the semiconductor will be only valuable as a replacement part.

The unusual aspect of these knowledge-intensive products is their extreme transience. A semiconductor is extremely resistant to physical degradation but not temporally based obsolescence. Because of the speed of new knowledge creation, the market demand for a particular semiconductor model is transient; as a commodity having market value, it is here today and gone tomorrow (for an excellent discussion of this, see Hutcheson and Hutcheson, 1996). The semiconductor soon becomes worthless even though it retains full functionality.

In the early twenty-first century, the fastest growing industrial sectors are the ones in which knowledge creation is most central. The Fordist period, in which consumer durables manufacturing, that is, of highly physical products, was the leading sector is giving way to an environment in which the focal economic sectors are those based on the creation and manipulation of information. When purchasing an automobile, its physical function of transporting you is of great interest, that is, you expect it to convey you somewhere, safely and reliably. In the case of computer software, you expect it to manipulate symbols in a virtual spreadsheet (it is not a physical spreadsheet) or a virtual document or a virtual game or to direct a device to perform functions such as printing letters or spreadsheets. Another task might be to order metal-cutting equipment to undertake a particular cut and send visual representations of the cutting to a monitor. Software is, in a sense, ethereal; it (in itself) does not do anything physical. In contrast to the automobile, software is immaterial and thus very easy to communicate, improve, and so on.

The distinction between a product's physicality and its embedded knowledge is, of course, artificial, for these are but two perspectives on a product's fundamental unity. Even the most disembodied product, computer software, to be transmitted and used requires the physical flow of electrons, magnetic impulses on a hard or floppy disk, or pits on a CD ROM sensed by a laser beam. Thus, though the software's physicality is minimal, its physicality still exists—for human knowledge and creativity must be transmitted and actualized in the physical world or, put differently, embodied in a medium.

Traditional Producer Goods Industries

It was for the traditional complex assembled product industries that dominant design and models 1 and 2 were created. However, more recently these industries have also been drawn into the knowledge-creation dynamic. The increasing significance of the intellectual component of products is having an important effect on the rate of change in traditional industries such as machine tools and producer goods. The market value of these goods is increasingly dependent on the software and integrated circuitry components, though the product is not yet treated as a modular assemblage, as in the case of the PC.

The normally staid world of producer goods is experiencing a change in the locus of value in its highly complicated and expensive machinery. Historically, these machines had life expectancies measured in decades and were considered durable assets. Thirty years ago, these machines were freestanding and used little or no electronics. Change was gradual and confined to steady incremental improvements. The knowledge of how to create value with these machines was located in the machine operators. The knowledge embedded in the machines was increasing, but at a rather slow rate.

The linkage of the machines with the information-processing ability of electronics transformed the economics of owning manufacturing machines. The electronics and software permit a more rapid improvement in machine performance than was possible when improvements were based on redesigning only the physical features of the machine. This means that newer models are being introduced more quickly and have significantly more functionality than their predecessors. John McDermott, vice-president of Rockwell Automation's standard drive business, described the changes in the industrial motor starter business, which until the recent application of semiconductors had changed only very slowly for nearly one hundred years:

> As the technology changes faster, the life cycle of our products drops. . . . Both features and costs are impacted so greatly by technology that if you don't have a new product within four years, you're not competitive. . . . If you have a three-year development window and four-year product life cycle, you're in tough shape. (Bassack, 1996:30)

Though not yet accelerated to the speed of change in the electronics and software industry, these mundane businesses are also experiencing a pervasive acceleration.

The ubiquity of distributed computing power has transformed an important part of the machining industry into an extension of the electronics and software industry. Machining centers are a large machines containing many components and materials, all of which, of course, are embodiments of human knowledge. For example, extremely sophisticated bearings capable of continuous speed when the 15,000 rpm cutting tool goes from air to cutting metal embody enormous amounts of knowledge (Lee, 1996). It was the application of integrated circuits in controller boxes that changed the development pace of the machine tool industry (Yamazaki, 1995).[3] This application of electronics to machine tools, or what the Japanese call mechatronics makes it possible to update a machine by rewriting the software (Schodt, 1988; Kodama, 1991), Integrated circuitry and software are becoming ever more significant value-added components of a machine tool. For example, at Mori Seiki, one of the largest machine tool builders in the world, the value of the software and electronics in the machines has increased from 20 percent of the total value to a current 30 percent (Mori, 1996). The important point here is that the software and the computer controller are the most knowledge-intensive components (but, emphatically, not the only components that have significant amounts of embodied knowledge) of the machine tool.

As more and more of the operations of the machine tool are automated, they also produce data in an electronic form. This provides opportunities of on-line computer monitoring. Now the machine tool has two outputs: the work piece and electronic data. Recently, Mori Seiki developed a system whereby information from the user's machine can be communicated to a computer, which can transfer information regarding malfunctioning to Mori Seiki's technical center for problem diagnosis or to another point for remote machining control. This means that the most knowledgeable people in the world, the tool's producers and designers, can participate in trouble-shooting. Moreover, it makes the user-designer relationship, which von Hippel (1988) argues is so important for improvement, even closer.[4] However, there are possibilities to go even further; for example, now software could be downloaded to the user's machine from anywhere, including third party vendors. With the increasing ability to quickly provide new software, change in the machine tool industry can be expected to become increasingly rapid.

Rapid change is not confined to the traditional machining industries. It is pervasive. For example, printed circuit board (PCB) component insertion machines are so fast that the insertion head is merely a blur as it inserts components fed from a tape reel (Mody, Suri, and Tatikonda, 1995). In this segment, the rapidity of improvement in insertion machines and the shrinking size of the components means that the machines also rapidly lose value (Kawai, 1992). The result is that designers must constantly develop new and improved models.

The importance of time is reflected by Douglas Elder, the Singapore-based managing director of Asia operations for the U.S. semiconductor test equipment maker Teradyne, when he said that price and quality were no longer the main sales features in the electronics industry; rather "the differentiating value is now cycle time.

. . . Many sales are now made on the basis of how soon the product can be delivered" (Bordenaro, 1996). Price, which used to be an all-important criteria, is no longer entirely central.

Production equipment loses its market value so quickly that it is becoming an ever greater business cost. Profits must be made quickly before the equipment has lost its value. This gives real meaning to the term "speed-based" competition. The introduction of electronics has made machines more productive, but simultaneously, due to accelerating technological change, productive life decreases. Factories are under extraordinary pressure to operate constantly, because physical depreciation no longer bears any relationship to obsolescence. Interestingly, this is matched by an environment in which markets often emerge and either disappear or explode in very short periods. In periods of slower change, depreciation and obsolescence had a relatively tight linkage, simplifying management decision-making about timing the replacement of capital goods. Now, the previous relatively stable linkage has been broken, and intensifying competition forces all companies to accelerate the introduction of new capital equipment.

The integration of electronics into production machinery increased functionality and speed; however, its pervasive effect on the rest of the economy simultaneously operated to decrease the machine's effective productive life. Even for the rather traditional industries such as machine tools, time has become an ever more central facet of the competitive environment. These developments are placing ever greater pressure on managers to actively manage the one-way arrow of time.

Personal Computers

Of all the products of the information age, the personal computer is probably definitional. The power of the PC is its neutrality—it can host many different functions. It can be an entertainment vehicle, a controller for machine tools, an information storage device, a switchboard router, a television receiver, a word processor, a spreadsheet, a telecommunications device, and/or a database manager. It is not imprinted in necessarily deterministic ways. It is universal receptacle, into which human creativity can pour the software concretizations of various ideas.'

Of all the products consumers and businesses purchase, the PC is the one that becomes obsolete most quickly. The pace of change in PCs is so rapid that it is nearly impossible to have a state-of-the-art machine. Time, in the PC world, is measured in months and even in weeks.

An important reason that the PC can change so quickly is that it is extremely modularized (Langlois, 1992). The various components that make up a PC can be mixed and matched in an enormous number of combinations from a wide variety of vendors. The result is that the PC's evolution is driven by change in each of its major components, and many of these are evolving at breakneck speed. As a result, the PC is also evolving at an exceptionally rapid rate. Moreover, as one component evolves it quickly makes the other components, in Thomas Hughes's terms, a reverse salient providing significant profitability for the product that ameliorates the salient (Hughes, 1983). As an illustration, the average life of a PC model is approximately three months, after which its price is dramatically reduced so as to remove it from the retailer's inventory.6

The PC is fascinating case study because it is ubiquitous. Moreover, because of the PC's modular construction, it is possible to see quite plainly the components that are rapidly changing and those less rapidly evolving. As table 6.1 indicates, certain components such as the case, the mouse, and the keyboard exhibit minimal improvement and negligible price decreases. The price/performance changes are concentrated in the components that have the highest value added and the least materiality and require the most R&D.

The innovations in the electronics industry are incessant and cumulatively dramatic. For example, the areal density of information storage in Winchester hard disk drives is increasing at 50 percent per annum. For example, in 1989, 40-megabyte hard drives were standard; in 2000 five-gigabyte hard drives are considered small. Semiconductor memory capacity doubles even more rapidly, every eighteen months. However, the price per chip or disk drive remains roughly constant. As a result, price per bit of information processed or stored decreases exponentially, and consumers can purchase ever more powerful information systems at a roughly constant price.

As I mentioned earlier, not all PC components experience such rapid price evolution. For example, monitors evolve somewhat more slowly, even though new programs such as Windows 95, 3–D graphics, desktop publishing, and CAD-CAM applications are driving a move to larger, better resolution monitors. The other force that is beginning to force the rather sedate pace of the monitor industry is the rapidly evolving flat panel display industry. In flat panel displays, technological innovation and product introduction more resembles the integrated circuitry industry than the tube-based monitor industry. The picture tube is the last major tube still being produced in the electronics industry.

The PC industry is the quintessential example of an industry in which time has become an absolutely critical component of the industrial dynamics. Accelerated knowledge creation is directly coupled with rapid price declines. Any specified model is a perishable item. Steve Haslett, Hewlett-Packard's Asia Pacific marketing director for servers, PCs, laptops, and related products, uses a graphic analogy to indicate the growing importance of logistics to PC sales.

> In this industry there is a horrendously short life cycle—if a product doesn't move from the chip to the customer in ninety days, like a banana, it goes rotten very fast. . . . It is estimated that computer products lose 1 percent of their value every day they sit on a warehouse shelf or a retail shelf. . . . If we can put the high-value parts in at the last minute, we will be able to help retain value and reduce costs. (Bordenaro, 1 9 9 6)

Each company must try to decrease its cycle time to remain competitive. The rapidity of price declines in computers has created a situation in which personal computer producers often cannot assemble and sell the systems before some components decrease in value. To cope, computer assemblers are reorganizing their global production networks to maximize proximity to customers. Ten years ago, personal computer motherboards were often completely assembled in then low-wage Asian

Table 6.1. Value of the Components of a Personal Computer, 1990 and 1996

PCs Circa December 1990

COMPAQ 389/33	Price	Build Your Own PC	Price
Motherboard	$ 1,100	Motherboard	$ 1,100
2MB RAM	$ 100	2MB RAM	$ 100
VGA Monitor - 14"	$ 350	VGA monitor - 14"	$ 350
2MB memory board	$ 375	2MB memory board	N/A
Video board	N/A	Video board	$ 135
84MB hard drive	$ 275	80MB hard drive	$ 550
1.4MB floppy drive	$ 58	1.4MB floppy drive	$ 70
Keyboard	$ 45	Keyboard	$ 68
Mouse	N/A	Mouse	$ 50
Case	$ 53	Case	N/A
Power supply	$ 135	Power supply	$ 61
Total parts cost	**$ 2,491**	**Total parts cost**	**$2,484**
List price	**$10,698**		

Source: Info world 1990

PCs Circa December 1996

Dell 200 MHz Pentium Processor (bundled)		Build Your Own PC	Price
Pentium Pro motherboard		Pentium Pro motherboard	$ 809
64MB RAM		64MB RAM	$ 549
SVGA trinitron monitor 17"		SVGA trinitron monitor 17"	$ 995
2MB video card		2MB video card	$ 239
4.2 GB hard drive		4.2 GB hard drive	$ 899
8X CD-ROM drive		8X CD-ROM drive	$ 99
28.8 fax modem		28.8 fax modem	$ 149
Various software		N/A	
		Power supply	$ 49
		Case	$ 51
		Keyboard	$ 59
		Mouse	$ 35
		Floppy drive	$ 28
Total cost	**$3,449**	**Total cost**	**$3,961**

Compiled from various vendors
Source: Computer Shopper 1996

countries such as Taiwan. The completed boards or even completed PCs were shipped to the United States. Recently, because microprocessors (MPUs), disk drives, and dynamic random access memory (DRAM) decline in value so rapidly, firms are altering their production location decisions. They still insert more slowly evolving components onto the motherboard in Asia, but now they add the MPUs and DRAMs near the customer right before shipment. Even more recently, because of increasing automation, the obsolescence of even more traditional components, and the rapidly changing marketplace, some firms have begun assembling the entire motherboard close to the final customer. For example, Intel has recently become the largest motherboard producer in the world, doing much of its assembly in the Portland, Oregon, area. The reason for Intel's decision is that the evolution of other components such as Basic Input/Output System (BIOS) chips and graphics chips is also quickening, and it is no longer much more economical to use low-cost labor.

Intel can achieve savings by inserting its newly made MPU right onto the board, thereby eliminating a sales step. This is because in the three to four weeks it takes to ship a completed motherboard or completed PC to the United States from Asia, it may have lost 20 percent of its total value.' Michael Dell, the president of Dell Computers, described the situation his company faces.

> The equipment to build the machines is relatively indiscriminant [sic]. It doesn't care where it sits, and time-to-market is really important. Labor is not a really important factor in the production of motherboards, particularly in high-end machines. If you're talking about low-end machines, which we don't participate in, you might have to build them in Taiwan to get the cost ratio. But then you have the question of, if you put it on a boat for thirty days and have the devaluation of materials, it's going to be much worse than if you built it close to the market. (Dell 1996)

The rapidity of change and the corresponding devaluation of their product means that the transience of value has become a central concern for PC industry managers.

Software and Value Creation

Software is an interesting commodity, because the physical portion of its value is trivial, and this makes the material component of production trivial. But timing in the software industry is critically important; missing a generation can place a software company so far behind the market that it is very difficult to recover. As a result, from one perspective, software appears to be a service, while from another it clearly is a product. Software (like musical recordings) need only be produced once; further reproduction is trivial. More than any other product, the relative cost difference between production and reproduction is the greatest in software. Normal goods require significant quantities of capital and labor to produce more units. Most other products, though not all—exceptions are recorded music and books—are "consumed" upon usage.8

Software, as a set of instructions that direct a machine to undertake a sequence of actions or, put differently, a tool that can be loaded onto a computer to perform various activities such as processing words or numbers, has its value almost entirely embodied in its code. The disk (or media) on which the software is imprinted is only a very small portion of its total value.

Software operates forever—but it is very time sensitive, in contrast with machines, which have a discrete life expectancy in the sense of how many production cycles can be performed before they wear out. In other words, a machine has physical constraints. In contrast, software has virtually none. Software, therefore, should be timeless. However, in the marketplace it has only a limited life expectancy, before it is replaced by an upgrade with greater functionality.

The speed of change is astonishing. For example, Microsoft operates on a one-year cycle for minor upgrades and a two-year cycle for major feature and architectural changes. Operating systems are scheduled for major changes on a three- to four-year cycle (Cusumano and Selby 1985:191). Semiconductor design software is on six-month major upgrade cycles.

The cost of software applications has also decreased dramatically. For example, word processing was first available as part of a dedicated system for about $7,000 to $10,000 per machine in the 1970s. It was also available from an extremely expensive mainframe or minicomputer terminal. In the mid-1980s a superior word processing system was available for approximately $500 on a PC costing approximately $5,000. In the 1990s, word processing has been reduced to a function in a suite of productivity applications worth approximately $100 and operating on a $2,500 machine. One observer believes the next step is that "the word processor is likely to become a feature in the operating system with almost no explicit economic value (Mcnamee, 1996:76)." In word processing software, little new knowledge is being created. Word processing programs are now products containing largely old knowledge, with new releases providing limited further functionality.

It is in software that the most purified form of mental labor is expressed. The physical aspect has been reduced to a minimum and may even be reduced further, if the current discussion of delivering software over the Internet actually comes to fruition. It may no longer be necessary to go to a store to purchase a CD ROM; the software could be downloaded directly from the Internet to your computer. This is the goal of the current discussions of building an information appliance. Instead of an appliance dedicated to a single function, such as a toaster connected to a power delivery network, the information appliance would be connected to an information delivery network. The acceleration of change that is so prevalent in the electronics world would now be linked directly to the home consumer. Software upgrades would be delivered directly to the end-user's computer as they become available—further quickening the pace in the industry.

Software is characterized by extremely short product cycles. This is possible because its creation is largely free of material constraints in its production. However, software quickly falls prey to obsolescence. Entire product categories such as word processing software lose value as they become old knowledge available nearly for free.

Knowledge and the Internet

In 1993, Bill Gates, the Rockefeller of the late twentieth century, thought that the Internet was not of critical importance to Microsoft. Then in 1995 he wrote his famous "Internet tidal wave" memo, and Microsoft was completely reoriented to participate in and capture the dominant spot on this tidal wave (Stross, 1996). That Microsoft, a veritable monopolist, could become concerned indicates how inherently fluid positions are in economic sectors based on knowledge creation.

The Internet forms the core of a significant new economic space in the continuing movement of the global economy from a physical basis to a knowledge and information basis. It is simultaneously contributing to an important new acceleration. The Internet is a vast unregulated, uncontrolled mass of information, images, and opinions accessible almost immediately to any computer owner with a connection (that can be had at quite low cost). Through the Internet, information that would have taken much time to find is now quickly available. Much of these materials are not for sale—they are provided for free. For example, many major companies put their press releases directly onto their Internet servers so that anyone can access them. This means that a computer can have access to press releases and corporate earning reports nearly simultaneously with reporters and professional analysts.

There are also many commercial sites on the Internet that cost money to access. Given the relative immaturity of the Internet, it is hard to draw any firm conclusions about its future, but some tentative observations are possible. Even though no one can be sure what the system will look like when it is mature, businesses such as stock trading, bookstores, and computer stores have already gone on-line. [9] This dramatically accelerates the process of acquiring many goods, and such products can then be drop-shipped from anywhere in the world using the various courier services. Market barriers are often also eased by the minimal startup costs, here again contributing to an acceleration of the realization of an idea.

The dematerialization that the Internet represents is extremely powerful. It is no longer necessary to disseminate information in the physical medium of paper, floppy disks, or CDs. Information can now be communicated through electronic impulses or beams of light (fiber optics). This availability of information accelerates the information flow and communication that can facilitate new knowledge creation.

Software firms using the Internet have developed a new business model. The companies with the most used Internet software, Netscape (Navigator) and Microsoft (Explorer) initially provided their software free to users in an effort to capture market and "mind" share (Lewis,19 9 6:70). Similarly, the "search engine" companies, such as Yahoo! Lycos, and DEC Altavista also provide their software and databases for free. From the perspective of traditional economics, this practice seems foolhardy and even perverse, though recently some economists, such as Arthur (19 94, 199 6), have begun a rethinking of traditional economic concepts to encompass the value added from knowledge creation and the increasing returns in information- and communication-intensive industries.

Companies are giving the software away because of the need to quickly establish a market presence and capture market share. If their product becomes a standard, adopters become customers for the rapidly arriving upgrades or spinoff products. This business model is possible because as Jim Clark, the chairman and founder of Netscape, said,

> [t]he Internet is low cost. We proved that by using the Internet to distribute our first product, and we were able to build a customer base of ten million users in just about nine months. Our only expense was the engineering cost of making the program. . . . So we see this potential for low-cost distribution of any kind of intellectual property—whether software, or pictures, or movies, or compact disks, or anything that can be represented as bits. (1995:70)

As the product is dematerialized, the costs of distribution drop dramatically, while the speed increases markedly.

The Internet also gives companies such as Netscape a route to users that circumvents traditional channels. Knowledge creation has spread to a "virtual" community, because of the practice of posting experimental versions of new software on the Internet. Then the consumers actually create knowledge by using it and communicating the results back to the company. Here, the community of users actually creates knowledge for the firm. This speeds the testing process, while simultaneously creating a market for the finished product. This integrates a subset of customers directly into the product development process.

Distributing software gratis over the Internet was pioneered by John McAfee with his antivirus software. McAfee has said, "If you give software away and assist people as well, you're almost bound to make money" (Leon, 1997). His strategy is to capture users and lock them in. After McAfee's companies get five million users, they change their "marketing" and start to charge for upgrades and add-ons. Since computers and networks are constantly evolving, the customers actually evolve with the software in the form of upgrades. The tempo of the users merges with that of the software developers. This occurs because the software soon becomes obsolete. The value created by this model is enormous. In the case of the McAfee antivirus product, the venture capital firm Summit Partners invested $5 million in his first company and took out $100 million.

In the Internet market space, product evolution has been extremely rapid. For example, Netscape Communications, the main provider of Internet software, was established only in February 1993 but already by June 1996 had already issued its third full upgrade of its Navigator software. Netscape develops a new product generation annually. This is also true of its Internet server software. Moreover, it has already made four acquisitions of other software companies to broaden its product line (Netscape Communications Company, 1996).

It is not only the data communications software industry that is evolving extremely rapidly. The increased number of Internet users has accelerated the pace of change in data communications hardware as well. New switches, routers, and data servers are released constantly (Burg and Kenney, 1995). Though these companies appear to be hardware companies in that they deliver physical products, the bulk of the value is embedded in their integrated circuits and the product design. Switches installed two years ago are already overloaded and need to be replaced by those with higher capacity. With the increasing communication of data, system overloads constantly pressure users to upgrade to keep the performance of their networks from degrading.

The acceleration in the amount of data being communicated over networks is so powerful, and change occurs at so many levels, that even the most sophisticated hardware firms find it difficult to innovate rapidly enough. In response, as table 6.2 indicates for Cisco Systems, the largest computer networking company, the larger companies purchase firms to secure access to new knowledge. Upon purchase, it is the larger firms' interest to drive that technology into the mainstream as quickly as possible. Eric Benhamou, the president and CEO of 3Com Corporation, another major computer networking company, believes that

Table 6.2. Cisco's Acquisitions, 1993-1996

Company	Date	Purchase price ($millions)
N etsys	1996	79
Granite Systems	1996	220
Telebit	1996	200
Nashoba Networks	1996	100
Stratacom	1996	4,000
TGV Software	1996	115
Grand Junction	1995	348
Network Translations	1995	N/A
Combinet	1995	114
Internet Junction, Inc.	1995	6
Kalpana	1994	204
Newport Systems Solutions	1994	91
Lightstream Corp.	1994	120
Crescendo Inc.	1993	95

Source: Cisco Systems Inc. 1996.

> [i]f all [change] was fairly static, if the pace of change was relatively slow, you wouldn't have to buy companies to create this integration. You could rely on third-party integrators whose job it is to take products from different companies and make them work together. The problem is that these networks grow and change so fast that even if you manage to freeze different vendors in one moment in time and get their products to interoperate well, two years downstream, each one of the products may have evolved on its own vector and the whole infrastructure [would] no longer be coherent. (Benhamou, 1995:46)

In an industry in which the product's value is so knowledge-intensive and changing so quickly, companies can be formed to create discrete pieces of knowledge-intensive (in this case, usually software-intensive) hardware. The value is so high and the pressure of change is so overwhelming that startups are purchased by the larger companies to secure control of the product and gain a few months. For example, the computer networking applications area not only is changing fast but also is expanding in so many directions that even firms in the center of its development cannot internally pursue all the possible expansion paths.

> "It's weird," said Joe Kennedy, cofounder of the five-month-old startup Rapid City Communications, a developer of gigabit intranet switches in Mountain View, California. "What used to be two-and-one-half years for a startup's business *cycle* is now being condensed to between six and nine months." For instance, Rapid City accelerated its plans to hire a VP within the first six months of being in business. The company will announce its new VP at the end of the month. (Bournellis 1996:1)

Competition is so intense and the technology is changing so rapidly that a startup must be jumped up even more quickly or it might miss the market. There can be little doubt that the Internet/data communications field is experiencing the rapid growth characteristic of a Schumpeterian new economic space. It seems possible that it will settle into the more stable phase that Abernathy and Clark (1985) identify as occurring after an architectural innovation becomes established. However, thus far there seems to be one fundamental difference from earlier periods; namely, the technical change in underlying industries of integrated circuitry, communications bandwidth, and data storage continues at logarithmic rates. The current acceleration gives little signs of slowing. The Internet provides every indication of continuing this process as ever more activities move on-line.[10]

Discussion

This essay explored some of the interconnections between knowledge creation and temporal dynamics. The dominant design and architectural innovation models provide insights into the phases of the innovation process. Model 2 posed the question of how a particular innovation might affect the core competencies of a firm. Model 2 distilled the dynamism of knowledge creation into the more static concept of effect on a core competency. Neither Model 1 nor Model 2 fully captured the temporal dynamics of highly knowledge-intensive industries. In many of the industries that are critically concerned with knowledge creation, the boundaries between users and producers are eroding. Moreover, some of the innovation dynamics operating are so accelerated that it is difficult to separate the incremental from the modular and architectural.

As knowledge creation becomes the focal point of our thinking about economic activity, managers face an environment with two attributes: increased emphasis on knowledge creation and a transience of existing products and knowledge. The acceleration in new knowledge creation speeds up the devaluation of the concrete results of knowledge creation, the products. In electronics and computer networking, knowledge creation is rapid and the pace of change is dramatic. For managers, understanding and operating at the industry's speed is the difference between success or extremely rapid failure.

Often management is simply riding on the tiger's back. Even industry leaders such as Intel and Microsoft have every reason to be paranoid (Grove, 1996), as the pace of change is engulfing all firms. For the more slowly evolving sectors of the economy, innovations such as the Internet may accelerate and transform their businesses (witness the case of on-line bookstores). Firms face unique challenges, as management of labor and capital is as critical as the management of knowledge and time.

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Notes

1. It is important to be careful not to assume that humans need no longer be concerned with the material. As material beings, we must continue to work with the material, but it is our minds working through our hands that is the critical feature. When the mind is no longer working through the hands, that is, mindless labor, the work is now suitable for machines. For a further discussion of this, see Kenney (1996).

2. For an insightful discussion of the tradeoffs between computer modeling and physical prototyping, see Thomke herein.

3. For an examination of the creation of computer numerically controlled (CNC) machine tools in the United States, see Noble (1984).

4. At higher speeds these tools become more efficient and accurate.

5. Charles Babbage was perhaps the first economist to see this (Rosenberg, 1994).

6. The fashion industry has similar turnover cycles. In this industry product life-cycles are notoriously short. The value-added is clearly in the design (creativity), and that is devalued extremely quickly, as cheap copies are created and the new season's fashions are released.

7. It is interesting to note that four to six weeks it takes to deliver a computer ordered from a mail order firm such as Dell or Northstar provides them with a significant competitive advantage because of the decrease in component cost between order and payment and delivery.

8. Musical recording is fascinating because two tendencies have been at play in its technological evolution. The first tendency has been toward ever greater fidelity, for example, from records to CD ROMs. The second tendency has been toward increased ease of copying.

9. For the package delivery firms, such as Federal Express, the changes in purchasing facilitated by the Internet create a burgeoning market (Lappin, 1996).

10. An interesting example of the Internet's acceleration of information flow is the rapidity with which Intel was forced to recall the flawed Pentium in 1990 (Uzumeri and Snyder, 1996).

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