I. TECHNOLOGY COMPETITIVENESS—BUSINESS BASE OF INNOVATION

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TECHNOLOGICAL INNOVATION

INTRODUCTION

Technological innovation is, without doubt, the major force for change in modern society—a force of knowledge. There are two basic issues about knowledge: (1) creating knowledge and (2) applying knowledge. The first is the domain of science and the second is the domain of technology. This book focuses on the second domain, technology—the application of knowledge.

But there is a difference between technology and scientific technology. The world has had technology since the dawn of the Stone Age—when humanity's predecessors, the hominoids, chipped stones into tools. In fact, the history of humanity may be classified into ages of technologies—the Stone Age, the Bronze Age, the Iron Age. But what age shall we call our age, the modern age? As a reflection of its influence on society, a most descriptive term would be the age of science and technology. In historical fact, the transition from antiquity to modern arose from the origin of science and from thence all the technologies derived from science—scientific technology. Technologies are the "how" to do something; science is the "why" of something. So scientific technologies are both the how and why something can be done in nature. Science understands nature. Scientific technology manipulates nature. And this is good or bad—depending what we do to nature.

> The basis for our modern age, characterized by so many new technologies and rapid technological progress, is the science base of modern technologies—scientific technology.

These are the modern connections—from science to technology to economy. Scientific technologies provide the basis for new high-tech products, services, and processes of modern economic development. The study of these connections is the focus of the topic of *technological innovation*. The field of management of technology (MOT) studies the principles of innovation, which describe the general patterns and principles in technological progress—the *theory of innovation*. As in any social theory, the *context* of the application of the theory affects the *generality and validity* of theory. So, too, with innovation theory, successful innovation is context dependent, and that theory needs to be illustrated and bounded by the contexts of actual historical examples of innovation. The first cases we will examine are the innovations of the Internet, Google, Xerography, and the Altos PC.

There is a "big picture" of innovation—science and technology and economy—and the historical industrialization of the world. There is also a "smaller picture" of innovation—businesses and competition and high-tech products/services. Innovation operates at two levels: macro and micro. We begin by looking at the macro level by asking the following questions:

- How does innovation create wealth?
- How does innovation transform scientific nature into economic utility?
- Who makes innovation?

TIMELINE OF SCIENCE, TECHNOLOGY, AND INDUSTRIALIZATION

Historically, the grand theme of innovation has been the invention of major new technologies and their dramatic impacts—changing all of a society and all societies. This story of the modern world has been both dramatic and ruthless. The drama has been the total transformation of societies in the world from feudal and tribal to industrial. The ruthlessness in technological change has been its force, which no society could resist and which has been called a *technology imperative*. Technological change has been irresistible—in military conflict, in business competition, and in societal transformations. (The latest of these imperatives is the globalization of the world, driven by the Internet. For example in 2010, the government of China decided that it would control Google in China or Google would have to leave China.)

Going back to the 1300s and 1400s in Europe, there were two technological innovations that provided the technical basis for the beginning of our modern era: the gun and the printing press. They were not scientific technologies, but only technologies; as scientific technologies were to begin later in the 1700s with the steam engine and the Bessemer steel process. The technologies of the gun and printing press had been *invented* in China, but were *innovated* in Europe. This is an important distinction between invention only and innovation as both invention and commercialization. The gun was improved and commercialized in Europe, and it was so potent a weapon that the gun ended the ancient dominance of the feudal warrior—a military technology imperative. In parallel, the improvement and commercialization of the printing press made books relatively inexpensive and fostered the secularization of knowledge. This combination of the rising societal dominance of a mercantile class (*capitalist*) and the deepening secularization of knowledge (*science*) are hallmarks of a modern society. After the fifteenth century, the political histories of the world became stories of the struggles between nations and peoples, wherein the determining factor has been the military and economic superiorities made possible by new *scientific technologies*.

When and how did scientific technologies begin? Figure 1.1 summarizes the major historical milestones of changes in science, technology, and economy.

Science began in European civilization in the seventeenth century, when Isaac Newton combined new ideas of physics (from Copernicus, Brahe, Kepler, and Galileo) with new ideas in mathematics (from Descartes and others) to develop the mathematical theory of space, time, and forces, the Newtonian paradigm of physics. In the next eighteenth century, these new ideas were further developed into the new scientific disciplines of physics, chemistry, and mathematics. The nineteenth and twentieth centuries had dramatic advances in these disciplines, along with the founding of the scientific discipline of biology By the end of that twentieth century the physics of the small parts of matter and the largest spaces of matter was established, the chemistry of inanimate and animate matter was established, the

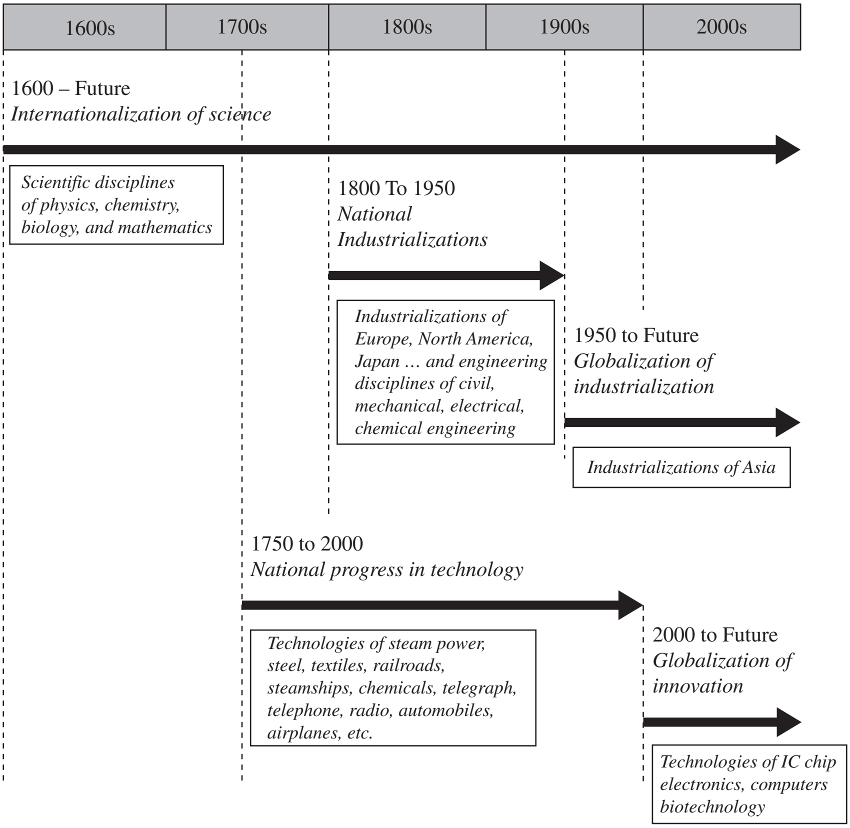

Figure 1.1 Timelines of science, technology, and economy

molecular biology of the inheritance of life was established, and the computational science of mind and communication was being extended. All this began in and took place in an international context from its very beginnings, so that one can see the four hundred years of the origin and development of science as a period of the *internationalization of science* as well.

In contrast to this international context of science, the economic and technological developments occurred within purely national contexts. Each nation industrialized on a national basis and in competition with other nations. From about 1765 to 1865, the principal industrialization occurred in the European nations of England, France, and Germany. From 1865 to about 1965 (the second hundred years) other European nations began industrializing, but the principal industrialization shifted to North America.

By the 1940s, the industrial capacity in the United States alone was so large and innovative as to be a determining factor in the conclusion of the Second World War. For the second half of the twentieth century, U.S. industrial prowess continued, and European nations rebuilt their industrial capabilities that had been destroyed by that war. From 1950 to the end of the twentieth century, several Asian countries began emerging as globally competitive industrial nations: Japan, Taiwan, South Korea, and Singapore.

After the economic reforms in China by Deng Xiaoping, China began to rapidly industrialize, quickly becoming a major manufacturing nation in the world in the twenty-first century. India also, throwing off decades of socialism, began to further industrialize, particularly in the information technologies. All other Asian countries were also moving toward globally competitive capability: Vietnam, Thailand, Philippines, Malaysia, and Indonesia. (Note that historically, Asian industrialization actually begun in Japan in 1865—but was diverted principally to a military-dominated society. After the Second World War, a reindustrialization of Japan occurred.)

In summary, we see a pattern of three hundred years of world industrialization in which different regions of the world began to develop globally competitive industrial industries:

- First hundred years (1765–1865)—Europe
- Second hundred years (1865–1965)—North America
- Third hundred years (1965–2065)—Asia

As with industry, the patterns of developing technological progress was also on a national basis, with technology viewed as a national asset. However, the pace at which modern technology was transferred around the world increased in the second half of the twentieth century, so that when the twenty-first century began, a new pattern of change in the modern world emerged, the beginning of the *globalization of technological innovation*.

Thus, by the time the twentieth century ended, there was worldwide appreciation that science and technology were critical to international economic competitiveness.

World markets and industrial production had become global affairs. In 1980, global trade had already accounted for about 17 percent of total economic activity, increasing by 2000 to 26 percent, worldwide (Kahn 2001). The economic mechanism of the global trade were multi-national firms: "Global trade increased rapidly throughout the 1990s, as multinational companies shipped products through a global supply chain that minimized costs and maximized efficiency with little regard for national borders (Kahn 2001, p. A4).

But while the entire world was industrializing, it is important to make clear the difference between globally effective and ineffective industrialization. For example, Michael Porter identified several factors in effective national competitive structures: political forms, national and industrial infrastructures, domestic markets, and firm strategies. Also, an effective national research infrastructure was necessary for effective industrialization. Elements of necessary national infrastructure include educational systems, police and judicial systems, public health and medical systems, energy systems, transportation systems, and communication systems. Economic development of all nations in this global context remains an important problem. Technological progress has enabled some but not yet all nations to develop economically.

One important research feature for national competitiveness lies in proper strategic interactions between universities and high-tech companies in the nation. For example, Peter Gwynne described some of the science and technology parks developed in Singapore, South Korea, and Taiwan to build their science and technology infrastructure for high-tech industries (Gwynne 1993). The model for such science and technology parks was the Silicon Valley in northern California in the United States for the building of the chip industry and personal computer industry. Stanford University and the University of California at Berkeley both played an important role in the rise of Silicon Valley, along with venture capital firms in growing high-tech industries there (e.g., computer chips, computers, and multimedia).

CASE STUDY:

Innovation of the Internet

Let look at our first case, the innovation of the Internet, a major technological innovation at the end of the twentieth century. The Internet is both an idea of a technology and an implementation of the technology as a connected set of businesses, as sketched in Figure 1.2. The Internet is constructed of many, many units that continually are connecting into or out of the network at different time—either as businesses directly connecting to the Internet or as home-based customers connecting to the Internet through connection services. The operations of this functional system enable users (as businesses or as consumers) to log onto the Internet through their respective personal computers or Web servers, and thereby communicate from computer to computer.

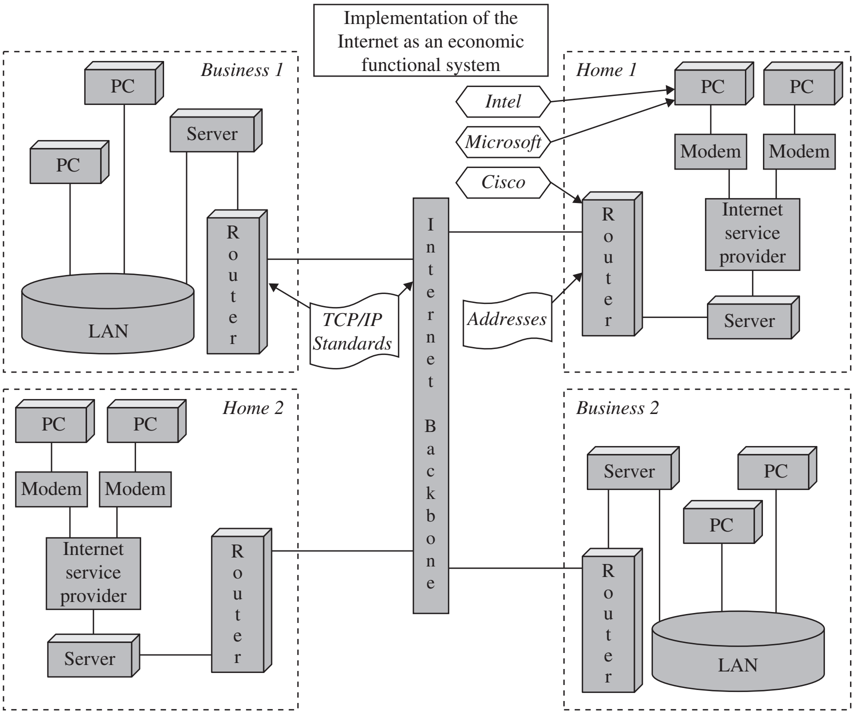

Figure 1.2 Architecture of the Internet

The technological innovation of the Internet was commercialized by a set of business:

- Sale of personal computers (e.g., Dell, Mac), containing a microprocessor (e.g., Intel CPU), an operating system (e.g., Microsoft Windows), and a modem
- An Internet service provider (e.g., AOL, Vodaphone, Comcast, etc.)
- A server and router (e.g., Cisco, Dell, IBM)
- A local-area network or wide-area network in a business (e.g., Cisco, Erickson)
- An Internet backbone communications system (e.g., AT&T, Sprint, Vodaphone)
- Internet search services (e.g., Google, Yahoo)

The invention of Internet technology can be traced to an earlier computer network then called ARPAnet. ARPAnet's origin, in turn, can be traced to Dr. J. C. R. Licklider. In 1962 Licklider was serving in the Advanced Research Projects Agency (ARPA), a government agency funding military research projects for the U.S. Department of Defense. At ARPA he headed research into how to use computers for military command and control (Hauben 1993). As an ARPA research program officer, Licklider began funding projects from ARPA on networking computers. He wrote a series of memos on his thoughts about networking computers, which were to influence the computer science research community.

About the same time, a key idea in computer networking was derived from research of Leonard Kleinrock. Kleinrock had the idea of sending information in packaged groups, or *packet switching*. He published the first paper on packet switching in 1962 and a second in 1964. Packet switching enabled computers to send messages swiftly in bursts of information—without tying up communication lines very long and thus vastly increasing communication capacities of network lines.

In 1965, Lawrence Roberts at the Massachusetts Institute of Technology (MIT) connected a computer at MIT to one in California through a telephone line. In 1966, Roberts submitted a proposal to ARPA to develop a computer network for a military need (defense) for protection of U.S. military communications in the event of a nuclear attack. This was called the Advanced Research Projects Administration Network, or ARPAnet, and was to develop, eventually, into the Internet.

Robert W. Taylor had replaced Licklider as program officer of ARPA's Information Processing Techniques Office. Taylor had read Licklider's memos and was also thinking about the importance of computer networks; and he also approved the funding of projects from ARPA on computer networks: "The Internet has many fathers, but few deserve the label more than Robert W. Taylor. In 1966 . . . (At ARPA), Taylor funded the project with the idea for Internet's precursor, the ARPAnet" (Markoff 1999).

Earlier, Taylor had been a systems engineer at the Martin Company and next a research manager at the National Aeronautics and Space Administration (NASA). There he had approved projects funded by NASA for advances in computer knowledge. Then he went to ARPA and became interested in the possibility of communications between computers. In his office, there were three terminals, connected to time-sharing computers in three different research programs that ARPA was supporting. He watched communities of people build up around each of the time-sharing computers: "As these three time-sharing projects came alive, they collected users around their respective campuses . . . [but] . . . the only users . . . had to be local users because there was no network. . . . The thing that really struck me about this evolution was how these three systems caused communities to get built. People who didn't know one another previously would now find themselves using the same system" (Markoff 1999, C38).

Taylor was also struck by the fact that each time-sharing computer system had its own commands: "There was one other trigger that turned me to the ARPAnet. For each of these three terminals, I had three different sets of user commands. . . . I said . . . It obvious what to do: If you have these three terminals, there ought to be one terminal that goes anywhere you want to go where you have interactive computing. That idea is the ARPAnet" (Markoff 2000).

In 1965, Taylor proposed to the head of ARPA, Charlie Herzfeld, the idea for a communications computer network, using standard protocols. Next in 1967, a meeting was held by ARPA to discuss and reach a consensus on the technical specifications for a standard protocol for sending messages between computers. The packet-switching node used to connect the computer network was called the *Interface Messaging Processor* (IMP).

Using these to design messaging software, the first node on the new ARPAnet was installed on a computer on the campus of the University of California at Los Angeles. The second node was installed at the Stanford Research Institute, and the ARPAnet began to grow from one computer research setting to another. By 1969, ARPAnet was up and running. Taylor left ARPA to work at Xerox's Palo Alto Research Center.

J.C.R. Licklider

Leonard Kleinrock

Robert W. Taylor

(http://en.wikipedia.org. 2009)

As the ARPAnet grew, there was the need for control of the system. It was decided to control it through another protocol, called Network Control Protocol (NCP); and this was begun in December 1970 by a private committee of researchers called the Network Working Group.

The ARPAnet grew as interconnected independent multiple sets of smaller networks. In 1972, a new program officer at ARPA, Robert Kahn, proposed an advance of the protocols for communication, as an *open architecture* accessible to anyone. It was formulated as the Transmission Control Protocol/Internet Protocol (TCP/IP), and became the standard upon which the Internet would later be based.

While the ARPAnet was being expanded in the 1970s, other computer networks were being constructed by other government agencies and universities. In 1981, the National Science Foundation (NSF) established a supercomputer centers program. The program funded computer centers at universities, which purchased supercomputers and allowed researchers to run their programs on these supercomputers. Therefore, researchers throughout the United States needed to be able to connect to the five NSF-funded supercomputer centers to conduct their research. NSF and ARPA began sharing communication between the networks, and the possibility of a truly national Internet was envisioned. In 1988, a committee of the National Research Council was formed to explore the idea of an open, commercialized Internet. They sponsored a series of public conferences at Harvard's Kennedy School of Government on the "Commercialization and Privatization of the Internet."

In April 1995, NSF stopped supporting its own NSFnet "backbone" of leased communication lines, and the Internet was privatized. The Internet grew to connect more than 50,000 networks all over the world. On October 24, 1995, the Federal Network Council defined the Internet as follows:

- Logically linked together by a globally unique address space based on the Internet Protocol (IP)
- Able to support communications using the Transmission Control Protocol/Internet Protocol (TCP/IP) standards

One can see in this case that the innovation of the Internet occurred at a macro-level of a nation—motivated by researchers seeking ways to have computers communicate with each other. This was a new kind of functional capability in computation. The invention of the computer networks required the creation of nine technical ideas, and together these constitute the *technology* of the Internet:

1. *Computer-to-computer communications*. Computers would be electronically connected to each other.
2. *Packet-switching*. Computer messages should be transmitted in brief, small bursts of electronic digital signals, rather than a continuous connection used in the preceding human voice telephone system.
3. *Standards*. Formatting of the digital messages between computers needed to be standardized to send message packets. These open standards became the Internet's (TCP/IP) standards.
4. *Routing*. A universal *address repository* would provide addresses so computers could know where to send messages to one another.
5. *HTML*. Web pages would be written in a language that allowed computers to link to other sites.
6. *www*. World Wide Web registration of directory of Web sites would allow sites to be connected through the Internet.
7. *Browser*. Software on computers would allow users to link to the World Wide Web (www) and find sites.
8. *Search engine*. Software would allow users to search for relevant sites and link to them.
9. *Web page publication.* Software facilitates the preparation and publication of sites on the Internet.

> A technology consists of the technical ideas that together enable a functional transformation. The functional transformation of the Internet technology provides communication between and through computers.

All these technical ideas together enabled the new Internet technology. Next commercialization of the new technology occurred when NSF transferred network management from the government to private companies. Thus, the innovation of the Internet did occur in a common pattern of technological innovation—first the *invention* of new technical ideas (as ARPAnet) and second the *commercialization* of new products and services embodying these new ideas (in the privatization of the Internet).

Technological innovation consists of both the invention and commercialization of a new technology.

INNOVATION PROCESS

How should we think about the process of innovation? In the "big picture," we start with the *nature* and them turn to transforming knowledge of nature into economic utility. The term *nature* is the scientific term for the entire observable world in which we exist. All technologies involve manipulating nature to create products and services useful in an economy.

For example, in the Internet innovation, a government agency, ARPA, funded university researchers, who used the nature of electronics (electrical signal propagation), the nature of information (communication standards), and the nature of logical computation (computers) in order to invent computer-to-computer communication technology. If one examines any technology, one will see that some kind of nature (material, biological, or social) is being used (manipulated). Accordingly, we can describe the innovation process as the way knowledge of nature (science) can be connected to technology (manipulation of nature), which then can be connected to use of nature (economy). This is sketched in Figure 1.3.

1. *Research*. In technological innovation, one begins with nature. Knowledge about nature—what it is (discovery) and how it operates (explanation)—is gained by *science* through act of *research. Scientists* are the principal kinds of people who as researchers study the knowledge of nature.

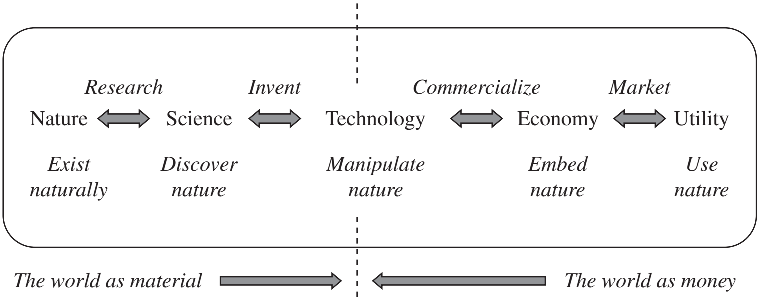

Figure 1.3 Innovation process

2. *Invent*. Scientific knowledge of nature is used as a *knowledge base* by technologists to create new technologies (manipulations of nature) through the act of *invention*. Technologists are usually scientists or engineers or other technical personnel.
3. *Commercialize*. Technical knowledge is *embedded* within a product/service/software through the act of *design*. In a business, engineers use technological knowledge to develop and design new high-tech products or services or processes. *Commercialization* is the act of connecting (embodying) technology into the products/services/processes. In the product/service development procedures of a business, technical and business personnel work together in innovation teams.
4. *Market*. A business competes by selling high-tech products/services in a marketplace, earning income—which become profits when the sales prices exceed the costs of producing products/services.

For this representation of the innovation process, we should formalize the definitions of the key term. We can do this in the following way, by carefully defining each term with regard to the idea of nature:

Basic Definitions for Innovation

1. *Nature* is the totality of the essential qualities of the observable phenomena of the universe.

   In the communities of scientists and engineers, the term *nature* is commonly used to indicate essential qualities of things that can be observed in the entire universe.
2. *Science* is the discovery and explanation of nature.

   The derivation of the term *science* comes from the Latin term *scientia,* meaning “knowledge.” However, the modern concept of scientific research has come to indicate a specific approach toward knowledge, which results in discovery and explanations of nature.
3. *Technology* is the knowledge of the manipulation of nature for human purpose.

   The technical side of the idea of technological innovation—invention—derives, of course, from the idea of technology. The historical derivation of the term *technical* comes from the Greek word, *technikos,* meaning “of art, skillful, practical.” The portion of the suffix *ology* indicates a “knowledge of” or a “systematic treatment of.” Thus, the derivation of the term *technology* is literally “knowledge of the skillful and practical.” This meaning of technology is a common definition of the term—but too vague for expressing exactly the interactions

(continued)

between science, technology, and economy. The “knowledge of the skillful and practical” is a knowledge of manipulation of the natural world. Technology is a useful knowledge—a knowledge of a functional capability. In all technologies there is nature being manipulated.

4. *Scientific* technology is technology invented upon a science base of knowledge that explains why the technology works.

   Not all technology has been invented upon a base of scientific knowledge. In fact, until science began in the world in the 1600s, all previous technologies—fire, stone weapons, agriculture, boats, writing, boats, bronze, iron, guns—were invented before science. Consequently, technical knowledge of these understood how to make the technologies work *but not why the technologies worked.* What science does for technology is explain why technologies work. After science, all the important technologies in the world have been invented upon a knowledge base of science.

5. *Engineering* is the design of economic artifacts embodying technology.

   Technologies are implemented in products and services by designing the technical knowledge into the operation of the products/services, and engineers do this design. Engineering designs enable businesses to use nature in adding economic value through its activities. What engineers design in the commercialization phase of technological innovation are new products or services or processes that embody the technical principles of a new technology.

6. *Economy* is the social process of the human use of nature as utility.

   The products/services provide utility to customers who purchase them. Through products/services, the concept of *utility* provides the functional relationship of a technology to human purpose. Thus, economic utility is created by a product or service sold in a market and that provides a functional relationship for its customer. For example, xerography products provided the functional relationship of copying (duplicating) the contents of printed papers, which is useful to the customer. Since in a society its technology connects nature to its economy, we will use a meaning of the term *economy* that indicates this. The common usage of the term *economy* is to indicate the administration or management or operations of the resources and productivity of a household, business, nation, or society. But we will use the term to mean the use of nature as utility.

7. *Management* is the form of leadership in economic processes.

   Business organizations provide the social forms for economic activities. The leadership in an economic organization is provided by the management staff of the business.

8. *High-tech products/services/processes* are commercial artifacts that operate on the principles of a new technology.

CASE STUDY:

Google Inc.

In our second case, we turn from the macro to the micro-level of innovation, how a new business develops and uses a new technology to compete and to create wealth for its entrepreneurs. A good example of this is the firm Google—which used the macro-level technology of the Internet to begin a new business in the micro-level technology of a search engine to find Web sites on the Internet. Google did not invent the search engine but improved it and learned how to make money from it. In the first decade of the 2000s, Google earned enormous revenue through advertising. Google incorporated in 1998 and by 2006 generated annual revenue of $7.4 billion, with a net income of $2.05 billion. It became the most-used search engine and one of the largest companies in the world.

Sandra Siber and Josep Valor summarized Google's early years (Sieber and Valor 2007). The founders of Google were Sergey Brin and Larry Page, and they met in 1995 as two PhD candidate graduate students in Stanford University Computer Science Department—working on a Stanford University digital library project. In 1996, Brin and Page began developing their own search engine, which they called Back Rub. It analyzed not only the content of pages in terms of key words but also counted the number of other links that pointed to these pages. They assumed that the importance of a page could be measured by the number of links pointing to it. They hosted the software on Stanford University servers, and students and professors tried it out.

In 1997, they renamed the search engine as Google (from the term *googol,* used in mathematics for quantities raised to the power, 10^{100}) and registered the google.com domain and informed the Office of Technology Licensing at Stanford of their technology. (As part of the U.S. national innovation system, normally the intellectual property rights of all research performed at a university are first invested in the university.)

Some offers were received to buy the technology, but Brin and Page decided to start their own company, licensing the technology from Stanford. In 1998, they were introduced to Andy Echtosheim, who had co-founded Sun Microsystems, Inc. and was then a vice-president of Cisco Systems. He invested $100,000. Google was established in a rented garage in which telephone lines and cable Internet access and DSL lines were installed.

In 1998, *PC Magazine* listed Google as one of its top 100 Web sites. By 1999, Google was handling 500,000 queries per day and moved to a new office in Palo Alto. Also in 1999, Google obtained its first revenues from license fees for its software from RedHat. Google continued to sell more licenses, and in 2002, America Online (AOL) adopted Google as its default search engine. From all these contracts, by 2003 Google had revenues of $961.8 million U.S. dollars with a profit of $105.6 million. Then in 2004, Google made an initial public offering (IPO)—offering shares at $85 per share—but with no voting rights on these shares. They raised $1.2 billion in the offering.

But if Google was free to use on the Internet, how was Google too earn "googol" amounts of money? Not just from licensing fees—increasingly from advertising. By 2005, advertising revenues at Google, at $6 billion, comprised 98.8 percent of its revenue.

While Google started out as a technology company earning money by licensing its software, it became an in effect an advertising company—to make *lots* of money. Google built its search engine with four criteria: accuracy, speed, ease of use, and objectivity. Yahoo! gained advertising revenue by listing its advertisers at the top of research results. Google always used objective relevance to order results. Although Yahoo! was the first search engine, increasingly users turned away from nonobjective ranking of results (listed by paid advertisers). And they turned to Google for objectivity. By 2001, Google was the most widely used search engine, with over 100 million queries daily. (This was 10^8—far from a googol at 10^{100}—but heading upward.)

Google's business challenge was to build advertising revenue but not to compromise objectivity. To do this, Google built two separate columns for its search-results page. The first column presented its objective ranking of relevant Web sites for the search. The second column presented a list of relevant advertisers to the research results. In that second advertisers' column, Google would charge an advertiser, but only if the user actually clicked through to its Web page, called *click-through*. The two marketing ideas were that (1) Google would maintain brand integrity for its search users, while (2) producing a higher probability of sales for an advertiser through click-through pricing.

Google maintained objectivity in the presentation of the ranking of relevance to sites, and Google also charged advertisers not on view but only on click-throughs.

The Google search-users were not Google's customers. Google provided a free and objective service to them. That free service was paid for by advertising. Google's customers were the companies who paid Google to list as relevant to the search on the advertising column. Therefore, Google had to provide two kinds of value: (1) search value to its users, as Google's market base, and (2) sales value to its advertisers, as Google's customers. This was called Google's *business model* (Sieber and Valor 2007).

Google continued to refine its business model as an advertising company. Google added services to its advertising customers to try to increase their utility from Google's services—as Google's Checkout program. Google understood that the real value from its advertising prices came to its customers when users not only clicked-through to the advertiser's Web site but also actually purchased from this Web site. To make this purchase an easier experience for the search user, Google added to their customer's Web site the image of a shopping basket (such as that used shopping in a supermarket)—Google Checkout. A user can buy a product from a company advertising on Google and purchase it by simply clicking on Google's payment technology, symbolized by its "shopping basket."

TECHNOLOGY AND WEALTH

With Google, wealth was created by developing new technology (a search engine) and providing it in a business (Google Inc.) as a service (browsing)—making money (wealth) from advertising in the service. The combination of invention and commercialization is the way that technological progress has become the major historical factor in enabling economic development in the modern world—technology creating wealth. Tarek Khalil expressed the relationship between technological innovation and wealth in Figure 1.4 (Khalil, 2000).

The process of technological innovation is generated by the science and technology infrastructure of a nation. This infrastructure provides new technical knowledge to the economic and financial infrastructure of the nation. All three infrastructures provide the bases for national wealth creation. Technological innovation is commercialized in economic systems to add value to markets and to international trade. Technological innovation provides a competitive advantage for exports and for the businesses in a nation, thus contributing to wealth creation.

Thus, to create wealth, two stages are necessary in innovation: (1) inventing new technology and (2) commercializing new technology in high-tech products or services. The development of the ideas for a new technology is called the *invention* of the technology. The embodiment of the new technology into high-tech products or services is called *commercialization* of the technology. These two parts of invention and commercialization are different processes and present different management challenges.

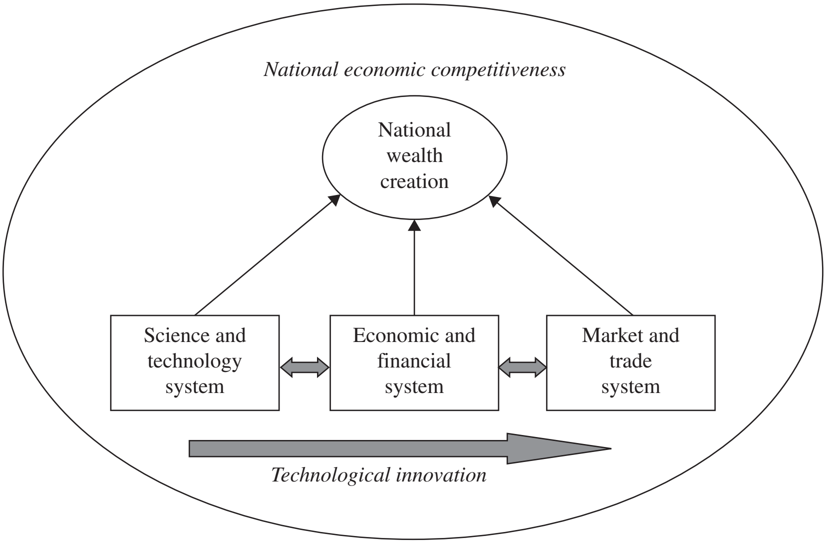

Figure 1.4 Technology and wealth creation

CASE STUDY:

Innovation of Xerography

To see the different management challenges in innovation, we next look at xerography. It was another and earlier case of a radical innovation at the micro-level that also launched a new business—Xerox. Here we will see that the two different roles—one of a technical talent and the other of a business talent—were both important. The inventor of xerography was a technical person, Chester F. Carlson, and the commercialization of xerography was accomplished by a businessperson, Joseph Wilson.

Dennis Hall and Rita Hall have summarized Carlson's life (Hall and Hall 2000). Chester F. Carlson was born in Seattle, Washington, on February 8, 1906. His father had tuberculosis and arthritis and for health reasons moved the family from Seattle to California. During high school in San Bernardino, California, Carlson worked in part-time jobs in a newspaper office and in a small printing business. He became interested in "the difficult problem of getting words onto paper or into print" (Hall and Hall 2000, p 15). After graduating from high school, Carlson attended the two-year Riverside Junior College and then the California Institute of Technology in Pasadena, California, graduating in 1930 with a bachelor's degree in physics.

While at Caltech, Carlson began to think of himself as an inventor: "I had read of Edison and other successful inventors and the idea of making an invention appealed to me as one of the few means to accomplish a change in one's economic status, while at the same time bringing to focus my interest in technical things and making it possible to make a contribution to society as well" (Hall and Hall 2000, p. 17).

Carlson found a job with the Bell Telephone Company in New York City, working in their patent department to assist Bell's patent attorneys. It was the time of the Great Depression in the United States, and Carson was laid off from Bell in 1933. He found a similar job in a New York law firm, and then a year later, another one in P.R. Mallory and Company. While at Mallory, Carlson entered and graduated from New York Law School. He became head of the Mallory's patent department.

Carlson had technical backgrounds in physics and in the chemistry of carbon (the powder that he was to use in his invention). As a patent lawyer, he understood a market need for copying. He had been frustrated by the errors in copying a patent for public dissemination and with the trouble with making large numbers of copies whose quality continually decreased with number.

In 1935, Carlson began experimenting in the evenings and weekends with ways to create a new copying process. His idea was (1) to project the image of a typed paper onto a blank sheet of paper coated with dry carbon, (2) to hold temporarily the carbon on spaces of letters by static electrical charges induced by light, and (3) finally, by baking, to melt the ink onto the paper in the patterns of the projected letters. This would produce a quick, dry reproduction of a typed page, which he would call xerography.

In the fall of 1938, Carlson moved his apparatus from his kitchen in his apartment to a one-room laboratory in Astoria on Long Island, New York. He hired Otto Kornie, a recent Austrian immigrant and a physicist, to help him in the invention. On October 22, 1938, they used static electricity and a photoconductive, sulfur-coated zinc plate to transfer a written phrase, "10–22–38 ASTORIA," from a glass plate to paper. It was the first demonstration of what would later become *xerography*. It was a crude image, but it reduced his idea to practice, and he filed for a patent.

Yet like all new inventions, it was still not commercially efficient, cost-effective, or easily usable. It required research and development. The development of a new technology usually costs a great deal of money, takes time, and requires skilled resources. All inventors face similar problems—first conceiving the invention, reducing it to practice, obtaining a patent, and then obtaining support for its development and commercialization.

From 1939 to 1944, Carlson went from company to company seeking support. He was turned down, again and again, by twenty major companies. Each company that turned him down missed one of the great commercial opportunities of that decade. (That story you may have heard about how the world will beat a path to the door of the inventor of a better mousetrap—not true! A newly invented mousetrap that uses new technology is seldom capable of catching a real mouse until after much costly research and development.)

Finally in 1944, Carlson's patent work for Mallory brought him into contact with Russell Dayton, who worked at Battelle Memorial Institute in Ohio. Some researchers in Battelle found Carlson's idea interesting and signed a development agreement with Carlson on October 6, 1944, in return for a share in royalties from the invention. Battelle Memorial was a nonprofit R&D organization, and proceeded to make several improvements in the technical process of the invention.

That same year of 1944, John Dessauer, director of research at Haloid Company, read an article about Carlson's patent. Dessauer told the President of Haloid, Joseph Wilson, about the invention. Wilson was looking for new technology for his company for new products. At the time, Wilson's main customer was the giant Kodak, who could at any time eliminate his small business if it chose. Wilson watched Battelle's research progress, and in 1947 signed a license agreement with Battelle and Carlson.

Finally, all the innovative pieces for Carlson had fallen in place—inventions, patents, R&D, commercialization. Wilson funded Battelle for the rest of the development and then commercialized the first copiers, which Wilson called Xerox. Wilson subsequently changed the name of his company to Xerox, and the rest became commercial history in the second half of the twentieth century. Xerox created a new industry in office copying and was one of the fastest-growing companies in the world for the decades of the 1950s and 1960s.

For technological innovation, two roles are always required: (1) an inventor (invention) and (2) an entrepreneur (commercialization).

Joseph Wilson (1909–1971) graduated from the University of Rochester in New York. He worked for his father's firm, Haloid Company, which made photographic paper for Kodak. Wilson became very wealthy. Carlson derived substantial income from Xerox from royalties, as did Battelle.

Chester Carlson

Joseph Wilson

(http://en.wikipedia.org, 2009)

TECHNICAL SAVVY AND FINANCIAL SAVVY

In the history of innovation, the hard fact is that relatively few managers have really successfully envisioned and run with a radical innovation. Managers with both technical vision and financial strategy have been rare. They are the exceptional managers who are savvy (clever) about both technical and financial issues. Joseph Wilson had both technical and financial savvy. Thus, interesting questions that can be asked about such cases of innovation:

- Why do many companies who are presented with a vision of a new technology not see its strategic importance?
- Why can some organizations with research capabilities have good technological vision but not be able to commercialize things themselves?
- What kind of leadership qualities do innovative, risk-taking managers possess?
- What was the power of the innovation that it enabled the newly large firm of Xerox to create and dominate an industry for fifty years?

These are some the kinds of questions we will pursue in studying technological innovation. We will learn that technical people, like Carlson, invent technology from a skilled base of knowledge in science and engineering. We will learn that a technological entrepreneur, like Joseph Wilson, is a manager who understands a technical opportunity and financially runs with it. What made Carlson an outstanding inventor was that he had two kinds of skills—an understanding of a technical need and the scientific background to invent a process to accomplish the technical goal. What made Wilson an outstanding business leader was that he had two kinds of skills—technical savvy and business savvy. A technically savvy manager, a clever manager, needs to know how to manage the business process of innovation—planning and financing and assembling a good technical team for innovation strategy.

A technically savvy manager may not fully understand the details of a given technology but (1) does appreciate technology and (2) can effectively organize technically skilled personnel for innovation.

CASE STUDY:

Xerox Invents the Altos PC System

Now it is useful to look at another case of radical invention in Xerox—but a problematic case in which Xerox succeeded at invention but failed in commercialization. This is the dramatic case of a second great invention made later by Xerox—but that created no wealth for Xerox. This is the case of the Xerox Altos Personal Computer System.

It was in the late 1970s and early 1980s when Xerox made the radical invention of the next-generation technology of personal computers. It was in the form in which today we know as the PC—with windows, icons, mouse, object-oriented operating system, networked, and laser-printing. But Xerox failed to commercialize—never making a dime from the invention.

In the 1960s, Xerox had acquired a mainframe computer company to enter the computer business, but its acquisition failed in competition against IBM. In response, Xerox turned back to innovation and established a new research laboratory for computer invention—the Palo Alto Research Center (PARC). The PARC laboratory was to pioneer new computational ideas for the Xerox's strategic technical vision of a "paperless office."

Xerox hired George Pake, a physicist, to head the new PARC laboratory. He located it next to Stanford University, which was strong both in electrical engineering and the then new discipline of computer science. Pake hired many bright young researchers, and an important one was Alan Kay. In the late 1960s, Kay as a student had been influenced by the ideas of an MIT professor, J. Licklider (and we recall that Licklider had once served in ARPA). Licklider envisioned an easy-to-use computer, portable and about the size of a book (Bartimo 1984). At Palo Alto, Kay and his colleagues further developed these ideas into the vision of the future computer system—personal computers linked in a communications network with laser printers, and operated with icons, windows, and a mouse. They called this the Altos system and built it in 1979 as an experimental computer test bed and prototype.

What did Altos look like then? It looked much like what we would see over a decade later, when others successfully commercialized the earlier Altos vision—offices with local area networks of Macintosh computers, hooked together with ethernet coupling, using icons, desktops, and mouse and object-oriented programming software. Altos was ahead of its time.

But did Xerox itself make wealth from its visionary investment in computer technology? No. Instead of producing the Altos system, Xerox instead produced a workstation that looked like a Wang word processor—which then was the technical vision of Xerox Office Products Division. The Wang word processor was a minicomputer programmed for the writing task—word processing. Wang produced it from 1978 to 1983. Then, after 1984, the personal computer took over the word processing application. The manager of the Office Products Division was looking backward at technology—in contrast to the forward-looking, technology vision of the Xerox PARC researchers. In 1980, he thought the Wang word processor was the latest thing in technology. But it wasn't. The PC was the future of computer technology.

Instead of an Altos PC, Xerox's Office Products Division put out a Wang look-alike product using only some of PARCs inventions. It was called the Star workstation, and was a commercial failure. This poorly conceived product cost Xerox its whole investment in personal computers. Xerox lost its opportunity to capture the then-new emerging personal computer market. Xerox might have become the future Microsoft and Intel combined!

This was a failure of a manager to properly use his researchers' capabilities for technology foresight. He was too much a short-term, money-oriented fellow and failed to appreciate the correct long-term technology vision of his technical personnel and likely emerging market.

Xerox's Office Products Division failed to properly integrate strategies of matter (technology) with strategies of money (markets).

In 1983, Bro Uttal commented: "On a golden hillside in the sight of Stanford University nestles Xerox's Palo Alto Research—and an embarrassment. For the $150 million it has lavished on PARC in 14 years, Xerox has reaped far less than it expected. Yet upstart companies have turned the ideas born there into a crop of promising products. Confides George Pake, Xerox's scholarly research vice president: 'My friends tease me by calling PARC a national resource'" (Uttal 1983, p. 97).

Eventually all of PARC's Altos system inventions were innovated—but by companies other than Xerox. In the early 1980s, Steve Jobs of Apple visited PARC and saw Altos. Rushing back to Apple, Jobs used PARC's vision to design Macintosh personal computers; and this Mac saved Apple in the 1980s. PARC's research had given Apple its technology lead in personal computers from 1985 to 1995. So it happened that in 1981, Xerox invented the personal computer that the world would not see for another decade. Xerox invented the ethernet-connected personal computer, along with the graphic interface and mouse and object-oriented operating system. Xerox's research was ten years ahead of Apple's Mac and twenty years ahead of Microsoft's Windows software. But then, Xerox never produced PCs and lost its future as a commercially dominant company.

It was in the late 1980s that Xerox management continued to look backward, trying to protect the Xerox market. It completely missed the evolving personal computer industry and next the Internet revolution of the 1990s. These later Xerox managers had failed in technical savvy. So by 2002, Xerox was deeply in debt and on the edge of bankruptcy. (Xerox then even offered PARC for sale. Also, a Xerox CEO was then under investigation by the ERC for fraudulent reporting of sales in the late 1990s.)

As a historical note—emphasizing the long-term impact of that failure of innovation strategy in Xerox in the1980s—even three decades later, when the 2010s began, Xerox was still struggling for its future. Then a new CEO, Ursula M. Burns, had just completed a major business acquisition of Affiliated Computer Services for $6.4 billion. Despite Xerox's research prowess of the 1970s to 1980s, Xerox had never been able to grow again by innovation but resorted to acquisitions of different businesses. Adam Bryant of the *New York Times* summarized: "For many years, Xerox dominated the copier market, helped by an unparalleled direct sales force, and was known as a technology innovator. But growing competition from low-cost computer printers, a failure to capitalize on its innovations and management missteps rocked the company a decade ago" (Brian 2010, p. B9).

The sequence of events in the two decades of the 1990s and 2000s unfolded as follows:

1. In 1997, Paul A. Allaire, Xerox's chief executive, hired G. Richard Thoman from IBM as president in hopes that he would help with new digital products and technologies and generally invigorate a stodgy culture.
2. Mr. Thoman, as chief executive, pared 14,000 jobs in two years and realigned the sales force twice. Then, in October 1999, warnings began that profits would tumble.
3. In May 2000, Mr. Thoman was ousted as C.E.O. Anne M. Mulcahy, a four-year Xerox veteran, was named president.
4. In June 2000, accounting issues were uncovered that later led to big restatements and an SEC fine.
5. With a steady hand, Ms. Mulcahy turned around Xerox, strengthening products and making it more competitive on cost. Ursula M. Burns, also a longtime Xerox veteran, succeeded her as chief executive in July 2009.

6. Xerox urgently needed to build revenue (sales dropped 14 percent to $15.2 billion in 2009) and perk up its stock price, which remained below $10 a share after spending a long stretch of the last decade (between $20 and $10 dollars a share) (Bryan 2010 p. B9).

This case is a cautionary tale of a great company, Xerox, which had been built on a radical invention, xerography. Xerox went on to strategically prepare its future by a second radical invention, the Altos PC system. But Xerox failed to properly commercialize its second radical invention. Thus, Xerox was a "once great" company—which became a "not-so great" company—continually needing fixing for three decades.

The long-term challenge of innovative high-tech companies is to keep innovative strategy going in a corporation through generations of leadership—in successive CEOs.

The failure of a big company by inventing but not commercializing, such as in the case of Xerox, turns out to be not infrequent in the history of innovation. Another dramatic example of such a failure can be found in the history of AT&T. AT&T had been established in the early twentieth century and granted a monopoly for phone service in the United States. AT&T established a research lab, Bell Laboratories (much earlier, but inventive like Xerox's PARC). Bell Labs made major inventions, including transistor in the 1940s. In the 1960s it invented the basic concepts of cellular phone systems. But then, AT&T did not commercialize and start a cellular phone business. AT&T top management was looking backward—at how to maximize profits from pricing local and long distance phone services. Managers got into legal arguments about AT&T's phone monopoly with the U.S. Department of Justice. Consequently, AT&T agreed to divide its fixed-line phone business between one long-distance phone company (AT&T) and several regional local-phone services. The regional phone services thrived but long-distance AT&T shrank. Eventually, AT&T went bankrupt. But two of the local phone services looked ahead and established cellular phone services as Verizon and Cingular. Then Cingular bought out the old AT&T and changed its name to AT&T. Reincarnated, the new AT&T is a cellular phone service.

It is one of the great ironies of big business that management has often looked backward to yesterday's technologies and focused only on maximizing short-term profits from these old technologies.

Even while their researchers might be envisioning and creating a new technical future, sometimes top executives have failed to look forward toward a strategic future of innovation.

TECHNICAL PERSONNEL AND BUSINESS PERSONNEL

How can one account for this backward-looking versus strategic forward-looking that has occurred at the executive levels in some very big companies at various times? To the point—if technological innovation is so important, why hasn't everyone done it successfully?

The reason lies in the differences in ways of thinking between technical and business personnel. As we saw in the case of Xerox's Altos invention, one difficulty in succeeding in innovation has often arisen in the differences between the two activities of innovation—invention and commercialization. Invention is principally a technical process (performing research) and secondarily a business process (funding research). Commercialization is a principally a business process (investing in product development) and secondarily a technical process (solving engineering problems).

Thus, to understand the whole of innovation, one needs to understand: (1) how engineers and scientists think and (2) how marketing, production, and financial managers think. And these groups think differently. Technical personnel primarily focus on technical effectiveness and business personnel primarily focus on financial effectiveness. For a successful high-tech business—a technology innovative business—scientists/engineers and business/managers must understand each other and work together as an innovative team.

Forming and leading integrated technical/business teams for successful innovation is one focus of management of technology.

But making effective teams is not easy to do in practice. This is because engineering and business personnel live in the two different worlds—worlds of matter or of money. The world of matter depends on the sciences of physics, chemistry, biology, and mathematics. The world of money depends on the social systems of economy and markets and on the practices of management. Their principles and theory and practice of the two worlds are very different—one dependent on physical nature and the other on social nature.

Inventors and designers of technology (scientists and engineers) are trained in a conceptually technical world—that one of physical and biological nature. They see the world as a material, physical world—a world of matter and energy and material life. In contrast, business people are principally trained in the financial world—focused on management, leadership, economics, and sales and markets. They see the world as principally driven by financial forces—an economic world of production, trade, and competition for goods and services and wealth.

Which is it? Is the world made of matter or of money?

Both, of course! Technology provides the capability to do things but not the wherewithal. Finance provides the wherewithal of action but not the technical capability.

Properly managing innovation, in both invention and commercialization (matter and money), continues to be a major long-term strategic challenge in large businesses.

LOOKING AHEAD

Innovation theory is complicated because of these two fundamental parts of innovation—invention and commercialization. We have emphasized how these are, respectively, principally technical or business processes. To clarify such complication, we will divide and explore innovation in the two groupings of ideas—a business side of innovation (commercialization) and a technical side of innovation (invention).

But one of the rewards for our facing this complexity is the really good stories that can be told about innovation—stories like the Internet, Google, Xerox, and so on. In the cases of innovation, one can see some of the most dramatic stories of modern times—the successes and failures of innovation—wealth creation and the technology imperative!

KEY IDEAS

In the case studies of:

- Invention of the Internet
- Google
- Invention of Xerography
- Invention of the Altos Personal Computer System

We have examined the key ideas of:

- Technology and wealth creation
- Innovation process
- Definitions of science, technology, and economy
- Technical savvy and financial savvy
- Two worlds of innovation—matter and money