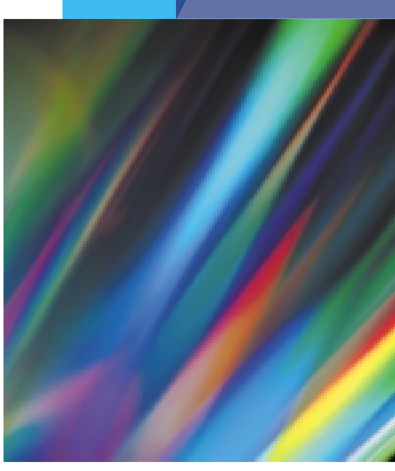
The Transformation of R&D:

Redefining Risk



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The Corporate Associates Program (CAP) is the Institute for the Future's flagship service. Focused on the strategic planning needs of organizations worldwide, CAP offers an ongoing examination of the international and domestic business environment. During the yearlong membership, program members receive practical, incisive, and up-to-date analysis of emerging trends and their likely consequences. Throughout its 25-year history, CAP has offered an unparalleled opportunity for senior corporate planners and strategic thinkers to interact effectively on key issues with CAP colleagues, Institute for the Future researchers, and leading experts.

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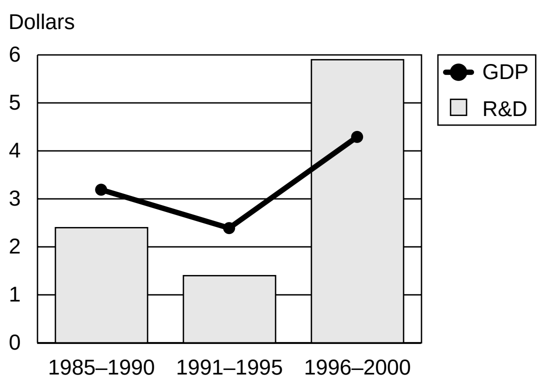
INTRODUCTION

More than the manufacturing might of its vast industries, more than its renowned marketing prowess, the critical growth engine of the U.S. economy is research and development (R&D)—the means by which knowledge capital is created. Indeed, R&D provides the basic ideas—the pure science—from which our scientists and engineers build the continual flow of innovative products that improve the standard of living worldwide and make more goods more affordable to more people. Effective R&D keeps the United States competitive in a world where more value is embedded in a wider range of products every day, the costs of production are falling, and production cycles are growing shorter.

A significant sign of the importance of R&D to the competitiveness of the U.S. economy is that in the past five years—at just that time when the global economy has been growing most quickly—R&D spending has surged dramatically in the United States. Indeed, U.S. spending on R&D has grown 50% faster than GDP (see Figure I–1), pushing the total spending on R&D as a percentage of GDP from 2.5% to 2.7%.

Is this upsurge in R&D spending merely an exuberant market response to the information revolution and the unprecedentedly strong economy of the late 1990s? Or does it reflect a fundamental shift in the United States' willingness to invest in the longer-term possibilities of R&D to transform society? At the Institute for the Future, we think the second choice is the answer. For reasons outlined below and set out in the rest of this report, *The Transformation of R&D: Redefining Risk*, R&D will continue to play an increasing role in the United States by providing a continual flow of benefits to its citizens and the world.

Figure I–1
R&D Spending Is Up
(Average annual rate of increase, in constant dollars)



Source: U.S. Department of Commerce, Bureau of Economic Analysis, *National Accounts;* National Science Foundation, *Science and Engineering Indicators,* 2000; National Science Foundation, *Survey of Research and Development*.

In the first chapter, we describe how the approach to R&D spending has changed in the United States in the past five years. Not only has the scale of R&D increased, but a number of other important shifts have taken place as well—the role of privately supported research has grown in importance; smaller firms have conducted more R&D; nonmanufacturing firms have conducted more R&D; and a greater emphasis has been placed on basic research throughout the economy.

In the next five chapters, we explore the drivers that will determine the depth and breadth of change in R&D in the United States, and whether R&D spending will continue to grow in the future. The major drivers are:

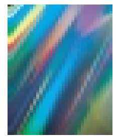
- The information revolution and the coming of age of the Internet had far-reaching impacts on R&D in the United States (Chapter 2).
- Science, technology, and innovation enjoy broad popular support in the United States (Chapter 3).
- Investors have found unique financial mechanisms to channel funds into R&D in a risk-adjusted fashion (Chapter 4).
- The U.S. intellectual property regime protects the rights of inventors while encouraging the rapid spread of ideas (Chapter 5).
- The United States spends more on R&D than the rest of the world, and has a stronger economy for that reason (Chapter 6).

Chapter 7 takes all of these drivers into account and presents our forecast for R&D in the United States in 2005 and 2010. And in the last chapter (Chapter 8), we identify the implications for business that follow from the forecast.

Part 1: Structural Shifts

Chapter 1

New R&D Players Bring Fundamental Change



An increase in overall spending in the United States has driven a surge in R&D spending in the past five years. But even more interesting structural changes portend fascinating consequences in the next decade for the who, what, where, and how of R&D. The four key changes are:

- The growth of private sector investment in R&D
- The increased funding of basic research
- The greater role of smaller firms in R&D
- The increase in nonmanufacturing firms conducting R&D

The Private Sector Moves into the Driver's Seat

Until recently, the private sector has been ambivalent toward R&D. On the one hand, R&D was an important means of providing innovative products that kept companies competitive. On the other hand, during the 1980s and early 1990s Wall Street and other investors had been loath to consider the importance of R&D in their calculations. Wall Street made it clear even to research-intensive companies that it was more interested in quarterly cash flows than in their capacity for R&D.

This approach has often made it difficult for private sector companies to support R&D, especially R&D that was not directly market-oriented. In the last five years, however, the Street's attitude toward R&D has loosened up, and the private sector has increased its commitment to R&D, in the amount of money invested, and widened its risk profile.

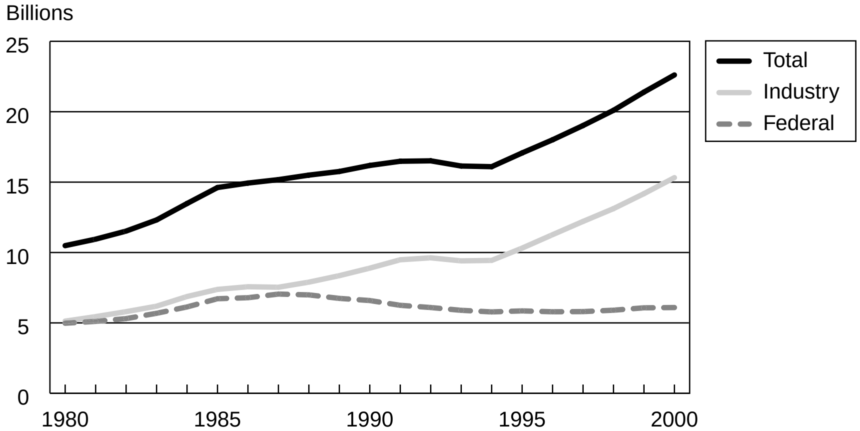
The Build-Up in Funding

In the past five years, the private sector increased its role in both funding and conducting R&D. In fact, increases in spending by private sector firms accounted for virtually all of the growth in R&D spending during that time (see Figure 1–1).

Although private industry's growing contribution to R&D funding was especially high during the past five years, this is really a longer-term trend. While federal spending has tended to be broadly cyclical, private funding has increased fairly steadily throughout the past five decades—despite the previously mentioned fact that the private sector has had to temper its funding of R&D in order to announce quarterly cash flows that please Wall Street. Under this regime it is truly noteworthy that private industry has accounted for a growing share of R&D over the longer term (see Figure 1–2).

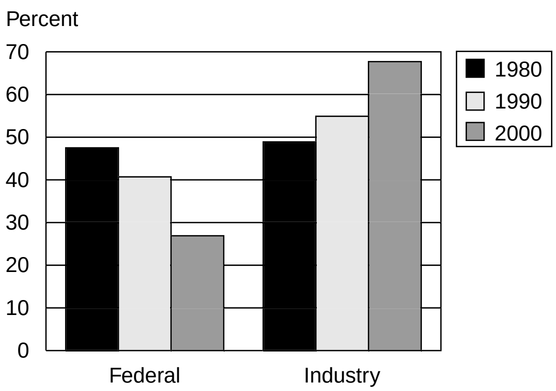
The shift to private sector spending on R&D also reflects changing social and political priorities. With the end of the Cold War, U.S. security needs took a somewhat less prominent place in the federal budget. Since a good amount of defense spending was focused on the R&D behind the development of defense systems, the warming of the Cold War has reduced federal R&D expenditures in this key sector.

Figure 1–1
Private Sector Spending Jumps Ahead
(Total spending on R&D, by source of funds)



Source: National Science Foundation

Figure 1–2
Huge Jump in Private Sector R&D
(Percent of total R&D expenditures)



Source: National Science Foundation

But the slowing growth of federal spending on R&D has been replaced by a huge jump in the private sector's spending in several new areas. In fact, the growth in private sector R&D (and R&D overall) is closely tied to the dramatic evolution of one sector of the economy in particular—information and communications technologies. As the price of information and communications hardware fell and the applications became richer and more affordable, investments by both businesses and households grew tremendously. Industry investment in these technologies increased almost 20% a year throughout the 1990s, for example; after 1995, the rate of increase was closer to 30%.

Developments in software went hand in hand with developments in hardware—private investment in software more than quadrupled in the 1990s, from $50 billion in 1990 to $225 billion in 2000. With developments in software came even more dramatic improvements in storage capacity, processing speed, data transmission, and user interfaces, which have made information and communications technologies even more invaluable, changing the course of business throughout the world. Across all industry sectors, and in the household as well, rising demand for information technologies created the opportunity for a cycle of rapid and continual innovation in products, applications, and new services—innovation driven by huge increases in private sector R&D.

Who Is Conducting the New R&D?

Who is doing all this new R&D? The government's role is pretty clear—it has traditionally paid for a significant share of the research done by others. As the defense imperative for R&D weakened, however, government defense-related R&D funding leveled off. Despite increases in areas like biomedical research, the total share of R&D funding accounted for by the government fell. And more government-funded research, now that less of it was highly classified, was done outside government labs.

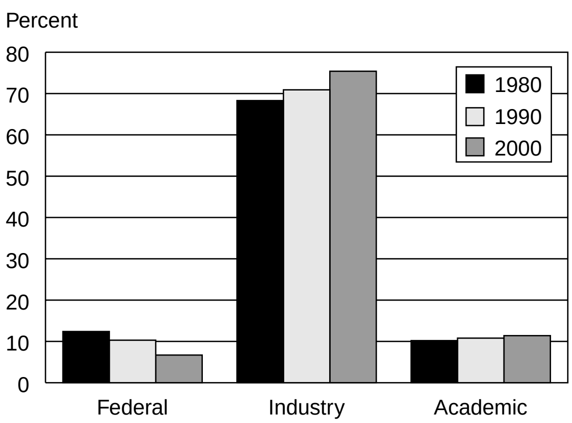
The private sector more than made up for this slowdown in government R&D spending. Most of the increase in private investing went directly into higher levels of industry research, though some went to universities in support of industry-sponsored R&D there. Led by information and communications technologies and biotech, business contributions to university research grew about twice as fast as federal contributions.

As industry funding increased sharply, the share of R&D performed by industry jumped accordingly. The federal government's share of R&D performance dropped by 35% in the past decade, while industry, and universities increased their share modestly (see Figure 1–3). In total, industry now conducts over 75% of all R&D, with universities a distant second at 11%.

Basic Research Is Up

Not only is more R&D being conducted in general but also more basic research is being conducted in particular. The purpose of basic research (also called "pure" research) is to gain more comprehensive knowledge in a subject area without specific applications or immediate commercial objectives. (In industry, of course, such research is likely to be conducted in fields with present or potential commercial interest.) This longer-term research now accounts for more than $45 bil-

Figure 1–3
Industry Performs Most R&D
(Percent of R&D performed)



Source: National Science Foundation

lion of spending and has been growing extremely rapidly in the past five years—well above the rate of overall GDP and other types of R&D. A huge share of the increase in spending on basic research has been funded by the private sector, a striking change from historical patterns.

Basic research accounts for only 17% of all R&D spending in the United States, but it is the key to the technological breakthroughs of tomorrow. Because basic research by definition does not have specific application, about half of it is done in universities. It is a long-term, high-risk investment for individual companies. A company must not only conduct the research, but sometime in the indefinite future it must also develop and market products based on that research to repay the cost and effort expended. Meanwhile, other companies are sometimes able to exploit the research without having to carry the burden of R&D costs, and thus can undercut the price of the original company. (Xerox, for example, is legendary for inventing technologies critical to the information revolution—including the mouse, the Ethernet, and the first PC—that other companies were able to turn into huge commercial successes.) Furthermore, lower prices and knowledge spillovers often benefit society at large but not the company that does the research. Thus, traditionally, companies have been wary of spending money on basic research that doesn't lead to a product that can be patented. That is why most basic research has been funded by the federal government and other noncorporate sources.

In the past decade, however, and especially in the last five years, the growth of spending on basic research by private companies has been quite dramatic (see Table 1–1).

The funding shift for basic research into the private sector is not so much a decline in the amount provided by the government but a sharp increase in the amount provided by the private sector. For example, private businesses are investing more in university research. These private companies are finding that direct collaboration with research universities can result in a faster spread of innovative ideas. The private sector has increased its share of funding of university research by 25% in the last two decades (see Table 1–2).

Table 1–1
Basic Research Exhibits Strong Growth
(Average annual growth rate, by funder)

	Total	*Federal Government*	*Industry*
1985–1990	5.3	4.4	6.3
1991–1995	2.0	1.0	4.2
1996–2000	7.4	4.2	15.3

Source: National Science Foundation

Table 1–2
Federal Dollars Decline as a Share of University R&D Funding
(Percent of all university R&D funding, by source)

	Federal	*Universities*	*Other**
1980	71	13	16
1998	62	17	20

*Other includes industry, nonprofits, and nonfederal governments.

Source: National Science Foundation

Overall, the amount of basic research performed by universities increased steadily throughout the last decade, at about 4% a year. As a result, more patents registered by companies today cite work done in universities than they did a decade ago.

It is surprising that basic research has experienced an increase in funding from the private sector. Because of the uncertain payoffs and the long time horizon, most academic literature until now suggested that the private sector would underinvest in basic research. Instead, the private sector today seems to have found that basic research, at least in some business areas, will lead to more innovative and more marketable products more quickly. This has been especially true in the information and communications areas associated with open networks and the Internet. Whole streams of new applications—database management, customer relationship management, streaming audio and video, tracking and monitoring, transaction flow, inventory monitoring, and enterprise management—have benefited from new basic research that can be applied to an existing market problem.

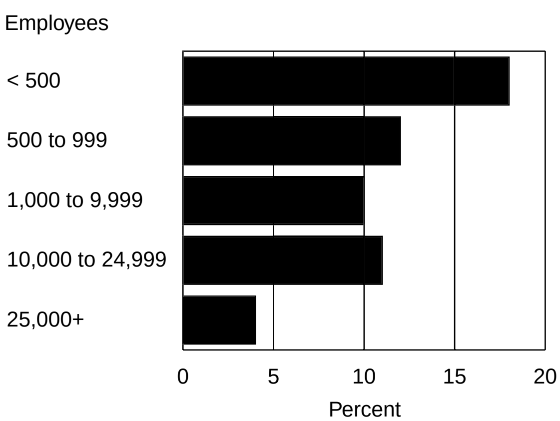
Small Companies Are Conducting More R&D

The amount of research done in small firms has been increasing steadily over the past decade as well. These small entrepreneurial firms have the ability to focus research on one specific opportunity and are staffed and funded by people who want to move a successful product into a market setting quickly.

The jump in corporate spending on R&D that began in 1995 was universal across companies of all sizes. The pace of change in R&D spending, however, was much more dramatic for firms with fewer than 500 employees than for larger firms (see Figure 1–4). In 1992, the earliest year for which we have comparable data, the largest firms (those with more than 25,000 employees) were responsible for 47% of industry spending on R&D. This share has been declining over the last decade, however, as small and medium-size firms increased their spending significantly. By 1999, these large corporations provided only 37% of all industry-based R&D money.

But the notable change has not been just the decline in very large companies' share of R&D expenditures but also the rapid growth in the amount of R&D actually conducted by very small firms. Although the data collected covers just a few years, we see that R&D spending by the smallest firms has been growing at huge rates (see Figure 1–5 on page 12). Businesses have found that R&D can be done effectively in small, focused entrepreneurial firms for the reasons listed earlier.

Figure 1–4
R&D Spending by Smaller Firms Increasing Faster
(Average annual percent growth in R&D spending, by number of employees, 1993–1999)



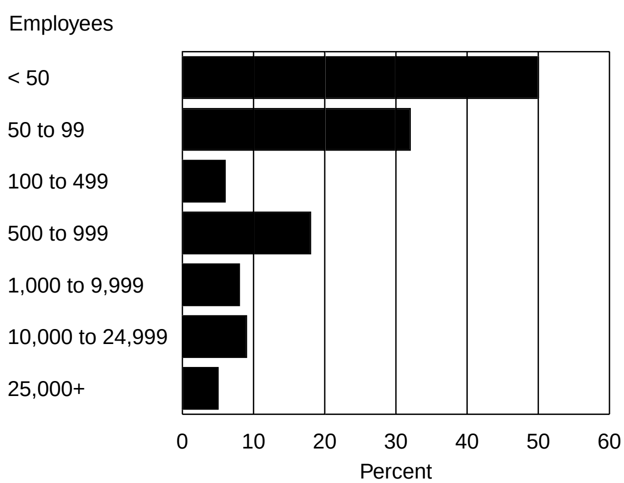
Source: National Science Foundation, *Research and Development in Industry,* 1999.

Nonmanufacturing Firms Are Conducting More R&D

Smaller firms are conducting more R&D, but so are nonmanufacturing firms. The nonmanufacturing sector's R&D performance has increased remarkably in the last two decades. In the mid-1980s, the nonmanufacturing sector accounted for only 10% of all industry R&D expenditures. Today, that share has grown to 36% of the total (see Figure 1–6).

The big emerging nonmanufacturing R&D players include companies from industries such as software development and small entrepreneurial firms that concentrate on developing a product for market rather than manufacturing and distributing it. R&D spending in these two industries grew by 50% in real terms in the last two years. Other big R&D

Figure 1–5
R&D Spending by Very Small Companies Increasing Even Faster
(Annual average percent growth in R&D spending, by number of employees, 1997–1999)



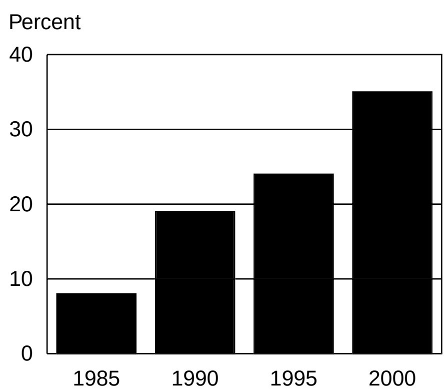
Source: National Science Foundation, *Research and Development in Industry,* 1999 (early release).

spenders among nonmanufacturing firms are, surprisingly, wholesale and retail trade companies. Funds from these industries lead to a focus on inventory management, logistics, and customer relationship management. The importance of these firms points to a theme common to the Corporate Associates Program literature—the impact on the economy of the revolution in retail, the place where companies actually meet up with their consumers.

The smallest nonmanufacturing firms, those with fewer than 15 employees, account for only a small portion of overall R&D. Yet they have increased their R&D expenditures tremendously over the last few years. In 1997, these firms spent $1.5 billion on R&D. By 1999, that number tripled to almost $5 billion.

This trend is very different from that of the manufacturing sector, which still performs more of its R&D in large companies. (Industries that tend to conduct R&D at large companies include aircraft and missiles, electrical equipment, professional and scientific instruments, and transporta-

Figure 1–6
The Rise of Nonmanufacturing R&D
(R&D expenditures by nonmanufacturers as a percent of all industry R&D spending)



Source: National Science Foundation, *Research and Development in Industry,* 1998.

tion equipment.) Still, the fastest-growing spending, even in the manufacturing sector, took place in firms with a greater range of sizes, such as computers, communications, and pharmaceutical firms.

The manufacturing sector still performs ten times more R&D per firm than the nonmanufacturing sector, but the shift toward conducting more R&D outside large research-intensive firms is notable. Investors are finding that some forms of R&D can be conducted in smaller, specialized firms that are not tied to manufacturing or production. Over the last few years, many large high-tech companies have been acquiring small innovative firms for their products and people. Cisco, for example, has acquired more than 70 smaller networking firms, including Kalpana, Precept Software, and StrataCom. Nortel Networks has taken over successful start-ups like Bay Networks, Qtera, and Sonoma Systems. These firms take some of the institutional burden of R&D costs from the larger firms, speeding up the development process and creating benefits for everyone in the marketplace.

Conclusion: R&D Can Be Done in the Private Sector

Because private businesses have learned the value of R&D spending in keeping them competitive, and more and more R&D can be done effectively in small and specialized entrepreneurial firms, the way R&D is conducted and financed is undergoing important changes.

We think there are five unique forces that converged during the late 1990s to drive these lasting structural changes, which will continue over the next decade. These drivers are the subject matter of the next five chapters. Together they explain why the United States emerged as the world leader in R&D activity and why the structural changes outlined in this first chapter bode well for future R&D in the United States.

Part 2: The Driving Forces

Chapter 2

New Technologies Find a Market

Just as a general increase in overall spending drove a surge in R&D spending in the United States in the late 1990s, so too did an explosion of R&D-related activity by small entrepreneurial firms. A good portion of this activity came from firms focusing on a single market area—the Internet. At the end of the decade, about 80% of investment in new R&D-based ventures came from Internet-related activities.

The huge growth surge was not an overnight phenomenon, although it may have seemed so. It was focused on a sector whose foundation was the core information revolution that had been building since the 1950s. The information revolution gradually transformed the business infrastructure, but it was the coming of the Internet in 1991 that seemingly galvanized the business world overnight. The Internet created a giant new market with a wide range of potential new commercial applications. Suddenly, the opportunity existed for new R&D activities that could extend and broaden uses in a market that had 200 million users.

The Information Revolution

The information revolution had a long gestation period. As the Institute for the Future's Paul Saffo puts it, "It takes 30 years to make an overnight success."

The information revolution began with the invention of the transistor in 1947, and continued with the integrated circuit in 1957 and the microprocessor in 1971. This triad formed the core technology of the revolution—the processing power of the chips at the heart of today's computers and communications devices.

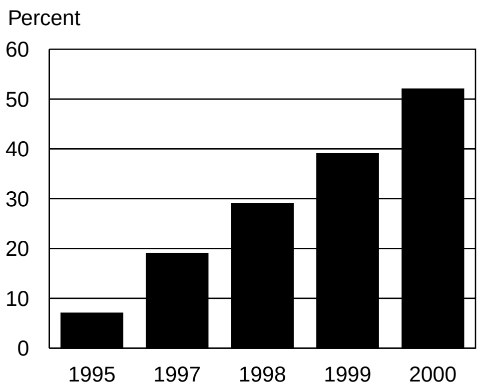
The information revolution found its market slowly. Some industries transformed fairly quickly—financial services, retail inventory control, and airline reservations—and white-collar information processing speeded up, but the economy as a whole needed another nudge. The second major step forward was the takeoff of the Internet in the early 1990s. The Internet transferred the power of the computer from individual applications or closed systems to easily shared networks. It created the possibility of forming new communications patterns, a wider sharing of information resources, and new markets. The Internet created the possibility of integrating consumer choice with business decisions, bringing on real-time inventory control. It also permitted suppliers and manufacturers to share a common database, and allowed transactions to move into real time.

The number of people who have gone online in the past five years is an indication of the widespread access the Internet affords and the range of applications it has opened up to the world (see Figure 2–1).

Applications and Markets

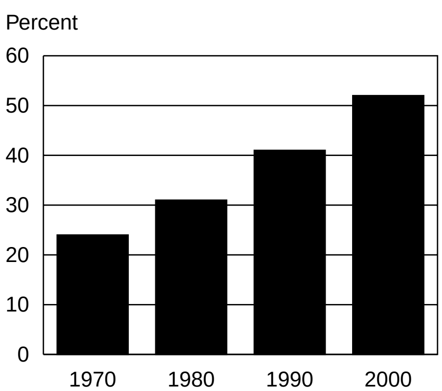
The information revolution had a gradual impact on how R&D was conducted. Businesses have responded to the opportunities of the information revolution by increasing their share of investment that goes into information technology (see Figure 2–2). During the 1980s, new information technologies penetrated the business world, paid for primarily out of the budgets of large and medium-size corporations. During the 1990s, spending spread to smaller firms and households. Spending was particularly heavy among firms moving some of their business onto the Internet.

Figure 2–1
Online Users Take Off
(Percent of U.S. population that go online)



Source: CommerceNet/Nielsen; IntelliQuest; NielsenNetRatings.

Figure 2–2
Spending on Information Technology Finally Took Off
(Information processing equipment and software as a share of all business equipment investment)

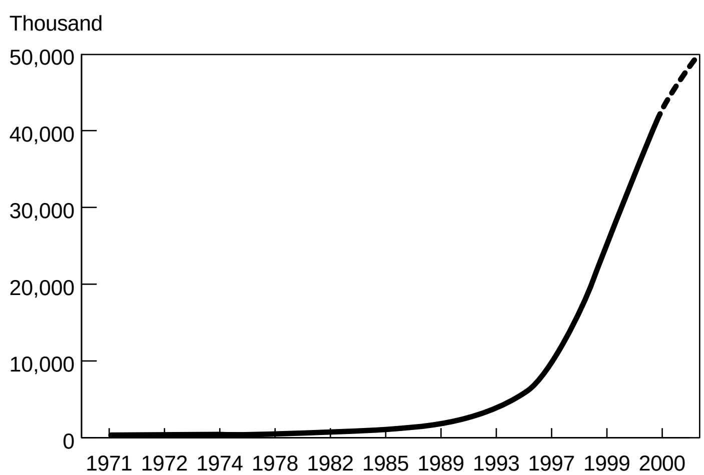


Source: U.S. Department of Commerce, Bureau of Economic Analysis, *National Accounts*.

MOORE'S LAW IN THE MARKETPLACE

The processing chip directly affects the amount of data that can be stored in easily accessible formats, and the speed and cost of processing and sharing that data. In 1966, Intel co-founder Gordon Moore realized that the number of transistors that could be stored on a chip was doubling every 12 months or so, and would continue to do so for the foreseeable future. While the doubling time is closer to 18 months now, Moore's Law is still operating. This incredible increase in computing power—at a constant price—has created a virtually limitless resource for information use and sharing (see Figure 2–3). The rapid growth in this power has revolutionized the marketplace, dramatically lowering the cost of and increasing the ease of access to information for consumers.

Figure 2–3
The Unprecedented Increase in Processing Power
(Thousands of transistors on a chip)



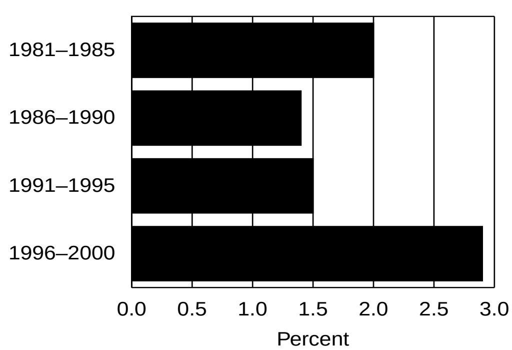
Source: Intel

From the mid-1960s until the early 1990s, as more money shifted to information and communications technologies, there was a gradual growth of venture capital markets. But these changes did not change the overall look or feel of the R&D market.

One of the reasons for the relatively slow response was the fact that it took this new technology a long time to work its way through all parts of a business organization and to really affect the operating efficiencies of companies. But as companies began to work more effectively internally and as they learned about using the new technologies to improve market performance, there was a decided jump in productivity, or output, per worker. Productivity almost doubled in the late 1990s (see Figure 2–4).

In addition to the large productivity gains, the development of the Internet helped transform thinking about technology. The Internet not only improved internal efficiencies but also promised the evolution of new markets that could displace the old, build new relationships with consumers, or create demand for new types of goods or services.

Figure 2–4
Productivity Took a Big Jump in Late 1990s
(Average annual percent change in output per hour of all persons working)



Source: U.S. Bureau of Labor Statistics

These two factors—the penetration of new technologies into American business and the opening of a world of new market applications through the Internet—were at the core of the recent surge in R&D. Over the last few years, 80% of new venture capital investments, for example, were in Internet-related businesses.

CONCLUSION

When the information revolution reached maturity inside of business organizations, and businesses proved that the Internet could improve relationships with consumers and along the supply chain, the possibility of transforming markets caught on with the wider investing public. Thus, the substantial net increase in R&D investment and the opening up of the venture capital market could come only with the arrival of the information revolution.

Chapter 3

The American Public Supports R&D

From Benjamin Franklin and his famous experiments with electricity to the ongoing Human Genome Project, the American public has firmly believed in the value of science and research. This widespread belief is one of the key reasons the United States has been so productive in its R&D efforts throughout the years.

This attitude works its way into the economy in a number of important ways—Americans are more accepting of new technologies, they are more willing to experiment with new products, and they are more willing to invest in equity shares in science or technology companies. Perhaps the most far-reaching consequence of this belief, however, is that, as a society, Americans set up institutions that support innovation—a patent system, regulatory agencies, and laws on licensing and contracts, to name the most important. And it doesn't stop there. The American confidence in R&D translates directly into behavior—Americans tend to adopt new technologies much more rapidly than the citizens of other countries.

A Century of Progress

The 20th century saw vast advances in science and technology, including Einstein's general theory of relativity, telephones, radio, antibiotics, television, moon landings, mainframe and personal computers, and the Internet (see Figure 3–1). These achievements have not been relegated to the pages of scholarly journals or the basements of research laboratories—most have produced, directly or indirectly, technologies and products that Americans use today.

Popular Support

The contribution of science and technology is widely appreciated by the American public, as confirmed in a variety of attitudinal studies by the Pew Research Center, the National Science Foundation, and the National Opinion Research Center, among other organizations.

Greatest Achievements

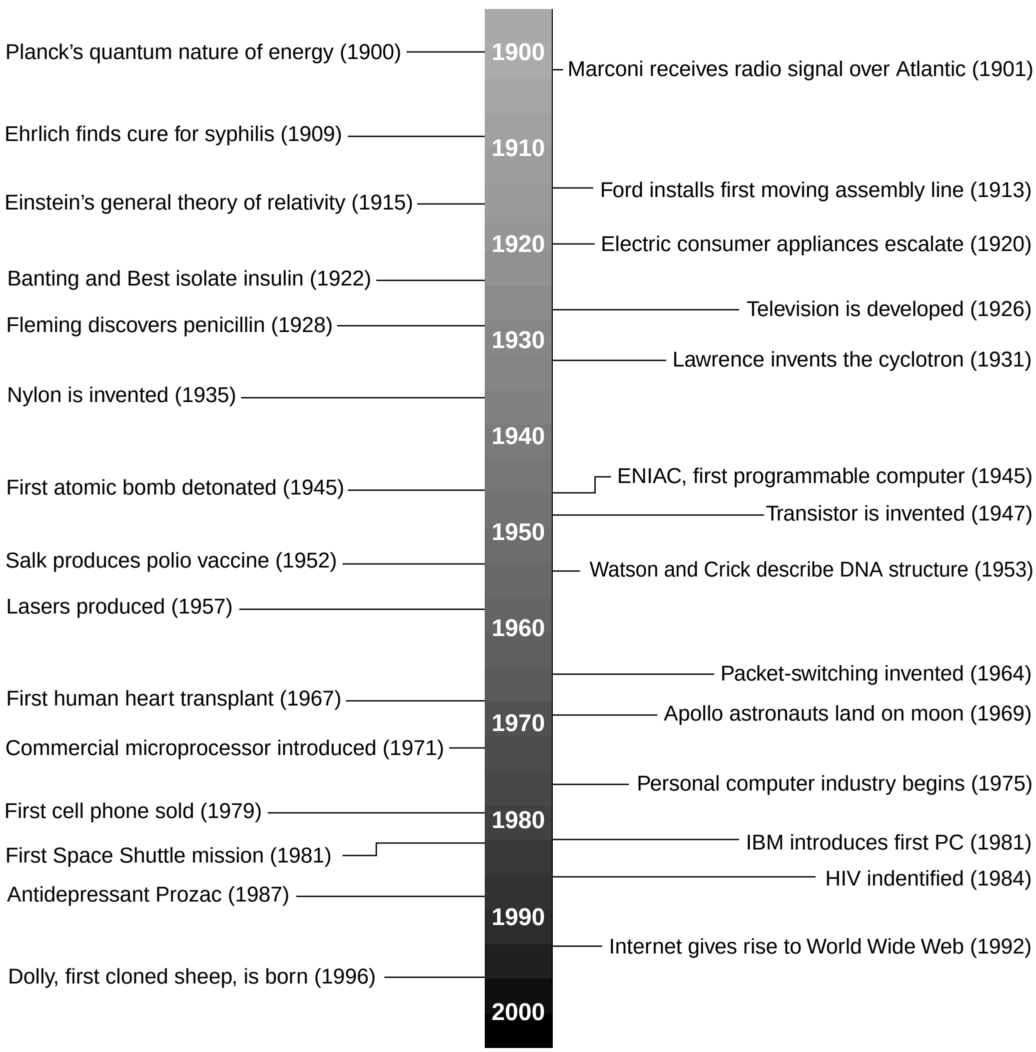
A recent survey conducted by the Pew Research Center asked people to name America's greatest achievements in the 20th century. More than 40% of those surveyed named an event or a concept from the world of science and technology (see Figure 3–2 on page 26).

The Future: A Better Place

Americans also place great confidence in science and technology for making a better future. The Pew Millennium Survey asked people to describe the role they thought several key institutions or domains would play in the future—major, minor, or none. Nearly 90% of respondents said science and technology would play a major role—making it the highest ranked institution or domain (see Figure 3–3 on page 26). Medical advances (largely based in science and technology) placed second at 85%. Schools and universities were third with 79%.

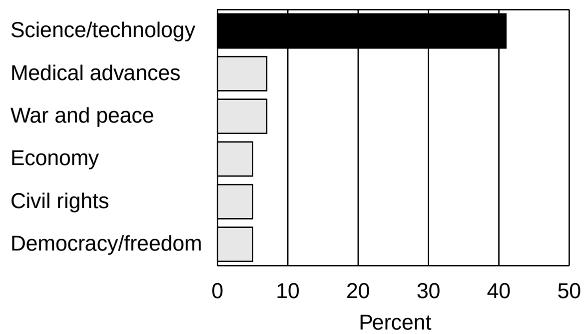
It is interesting to note that schools and universities scored so high at a time when our school systems are coming under widespread criticism. Perhaps the explanation is that it is human nature to pin great hopes on both education and children to make the world better. But perhaps an-

Figure 3–1
Science and Technology Milestones of the 20th Century



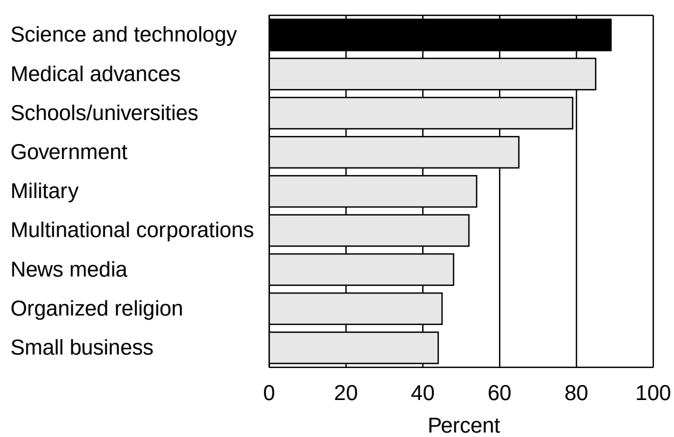
Source: www.pbs.org/wgbh/aso/databank/eventindex.html

Figure 3–2
America's Greatest Achievements Spawned by Science
(Percent who listed achievement in … area among America's greatest achievements during the 20th century)



Source: Pew Research Center, Millennium Survey, 1999.

Figure 3–3
The Keys to Making the Future Better
(Percent who said … would have a major role in making life in America better in the future)



Source: Pew Research Center, Millennium Survey, 1999.

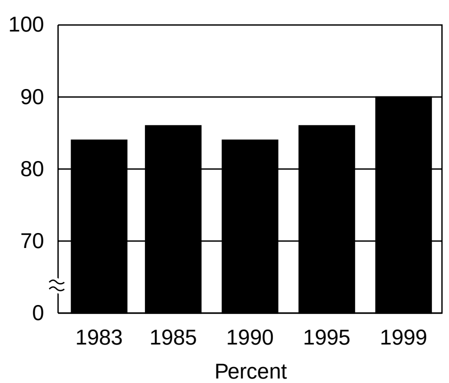
other reason is that schools and universities, for all their imperfections, also produce the very scientists and engineers who conduct vital research and help move it into the marketplace in the form of popular products.

The notion that science and technology can improve our lives is not only strong today, but it has been growing stronger for some time. The National Science Foundation surveys over the years have found that an overwhelming (and increasing) majority of Americans have consistently agreed that "science and technology are making our lives healthier, easier, and more comfortable" (see Figure 3–4).

High Marks for the Scientific Community

Since the days of the Vietnam War and Watergate, Americans have demonstrated increasing skepticism about the leaders of many of our major societal institutions. For example, confidence in the leaders of education, the federal government, and the mass media has declined significantly

Figure 3–4
Science and Technology Are Improving Our Lives
(Percent who agree that "science and technology are making our lives healthier, easier, and more comfortable")



Source: National Science Foundation, *Science and Engineering Indicators*, 2000.

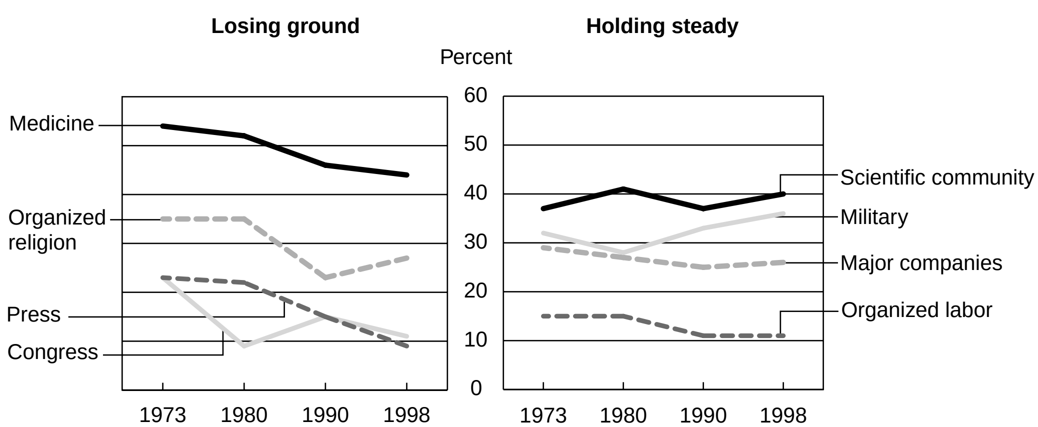
(see Figure 3–5). Even the once venerated medical institution has seen a dramatic drop in confidence in its leaders in the past few decades. However, the scientific community has not suffered a similar decrease in confidence. It has remained in second place for more than two decades. About 40% of the public has consistently responded that they have a "great deal of confidence" in the leaders of the scientific community.

Scientific Understanding Is High

We often hear how poorly American students perform in science and math compared to students in other countries. The most recent international study shows that American eighth-graders fall slightly above the average for 38 countries, but significantly behind several countries in Europe and in Asia (see Table 3–1).

At first glance, this survey looks like bad news for science knowledge in the United States. This isn't actually the case, however. Although Ameri-

Figure 3–5
Confidence in Scientific Community Is High and Steady
(Percent who say they have "a great deal of confidence" in the people running … institution)



Source: National Opinion Research Center, General Social Survey, various years.

Table 3–1
American Eighth-Graders Fall in the Middle
(Average score relative to the U.S. score on Third Annual Mathematics and Science Study-Repeat [TIMSS-R] science assessment, 1999)

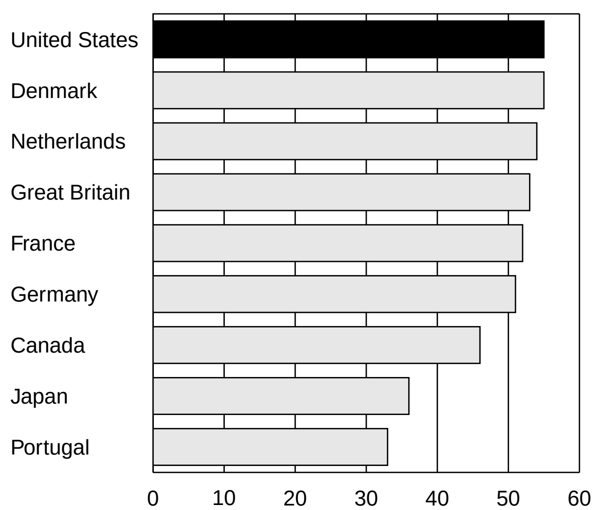
Score significantly higher than U.S.	*Score not significantly different than U.S.*	*Score significantly lower than U.S.*
Chinese Taipei	Hong Kong SAR	Italy
Singapore	Russian Federation	Malaysia
Hungary	Bulgaria	Lithuania
Japan	***United States***	Thailand
Republic of Korea	New Zealand	Romania
Netherlands	Latvia	Cyprus
Australia		Moldova
Czech Republic		Macedonia
England		Jordan
Finland		Iran
Slovak Republic		Indonesia
Belgium-Flemish		Turkey
Slovenia		Tunisia
Canada		Chile
		Philippines
		Morocco
		South Africa

Source: TIMSS 1999 International Science Report: Findings from IEA's Repeat of the Third International Mathematics and Science Study at the Eighth Grade, 2000.

can students lag behind some of their peers in middle school, by adulthood Americans score very well, coming out at the top of the list in scientific understanding (see Figure 3–6).

Several factors could be at work here. First, overall educational achievement is higher in the United States than in the rest of the world and a much higher percentage of the population attends at least some college. Second, U.S. universities are far more likely to impose general education requirements on their students than universities in Europe or Japan. This means that regardless of degree objectives, most U.S. college students are required to take at least one or more years of college-level science. Third, it could be that formal scientific training is enhanced in the United States by the informal opportunities for learning about science afforded by the prominent place that scientific and technology issues receive on

Figure 3–6
U.S. Adults Lead in Scientific Understanding
(Mean score on Index of Scientific Construct Understanding)



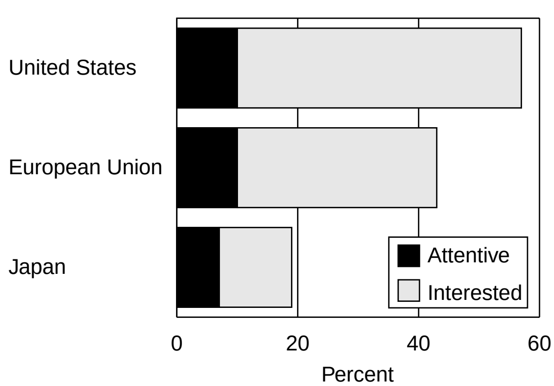
Source: National Science Foundation, *Science and Engineering Indicators*, 1998.

TV and in the press, as well as the wide range of opportunities for learning about science through zoos, aquariums, museums, magazines, public libraries, and the World Wide Web.

Interest in Science Is Higher

Adults in the United States not only score higher in scientific understanding than adults in Europe and Japan, but they also are more interested in science and technology issues. The National Science Foundation and other groups have conducted surveys to measure the public's attentiveness toward science issues (expressing a high level of interest about a scientific issue and feeling well informed about it) and interest in them (expressing a high level of interest in an issue but feeling not so well informed about it). International comparisons show that about 10% of adults in the United States can be considered "attentive" to science issues, a share similar to Europe and Japan, but that a much higher percentage of U.S. adults can be considered "interested" (see Figure 3–7). Attentiveness and interest both

Figure 3–7
Americans Most Interested in Science Issues
(Percent of adults in each region who are members of the "attentive public" and "interested public")



Source: J.D. Miller, R. Pardo, and F. Niwa. *Public Perceptions of Science and Technology*. Chicago: Chicago Academy of Sciences, 1997.

increase with education in all three regions, reaching 74% of college graduates in the United States compared to 58% and 29% in the European Union and Japan, respectively.

Benefits of Science Outweigh the Harm

Most scientific advances bring both benefits and negative effects—or at least the prospect of negative effects. For example, vaccines protect millions of people from disease, but a few people get ill or die from them. And the Internet has brought information, community, and convenience to much of the wired population, but some people have experienced fraud, theft, and a loss of live social connections.

When asked to weigh the benefits of science against its possible harmful effects, Americans come down overwhelmingly on the side of the benefits. In 1999, the National Science Foundation survey found that 74% of all adults agree that the benefits of science outweigh any harmful effects—up from 68% in 1985 (see Table 3–2). This belief is even stronger for people with more education—90% of college graduates agree, compared to 50% of people with less than a high school diploma.

Table 3–2
Benefits of Science Outweigh the Harm
(Percent who agree that “the benefits of science are greater than any harmful effects”)

	1985	*1990*	*1995*	*1999*
All adults	**68**	**72**	**72**	**74**
< High school	41	49	48	50
High school	73	76	74	78
College	90	90	90	90

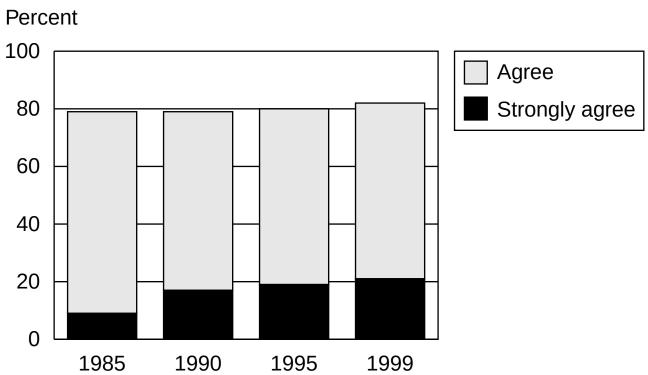
Source: National Science Foundation, *Science and Engineering Indicators,* 2000.

Americans Support Research

As suggested by these surveys, Americans think that science has produced our greatest achievements and will make the future better. Americans' interest in and understanding of science are both high, and they believe that the benefits of science outweigh possible harm. But are Americans willing to put their money where their mouths are in support of R&D? As it turns out, they are.

Indeed, basic research, the key to innovation, enjoys wide support from the American public. When asked if the federal government should support basic research, about 80% agree it should (see Figure 3–8). Even more remarkable is that the percentage that strongly agrees has increased sharply in the past 15 years.

Figure 3–8
Wide Support for Federally Sponsored Research …
(Percent who agree that "even if it brings no immediate benefits, scientific research which advances the frontiers of knowledge is necessary and should be supported by the federal government")



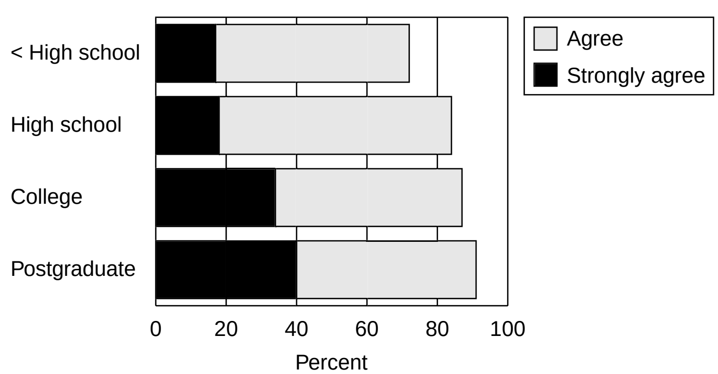
Source: National Science Foundation, *Science and Engineering Indicators*, 2000.

As we have seen with most other measures of public attitudes toward science, support for federally sponsored research increases with education—90% of people with a college degree support such federally sponsored research (see Figure 3–9).

Americans Use the Fruits of Research

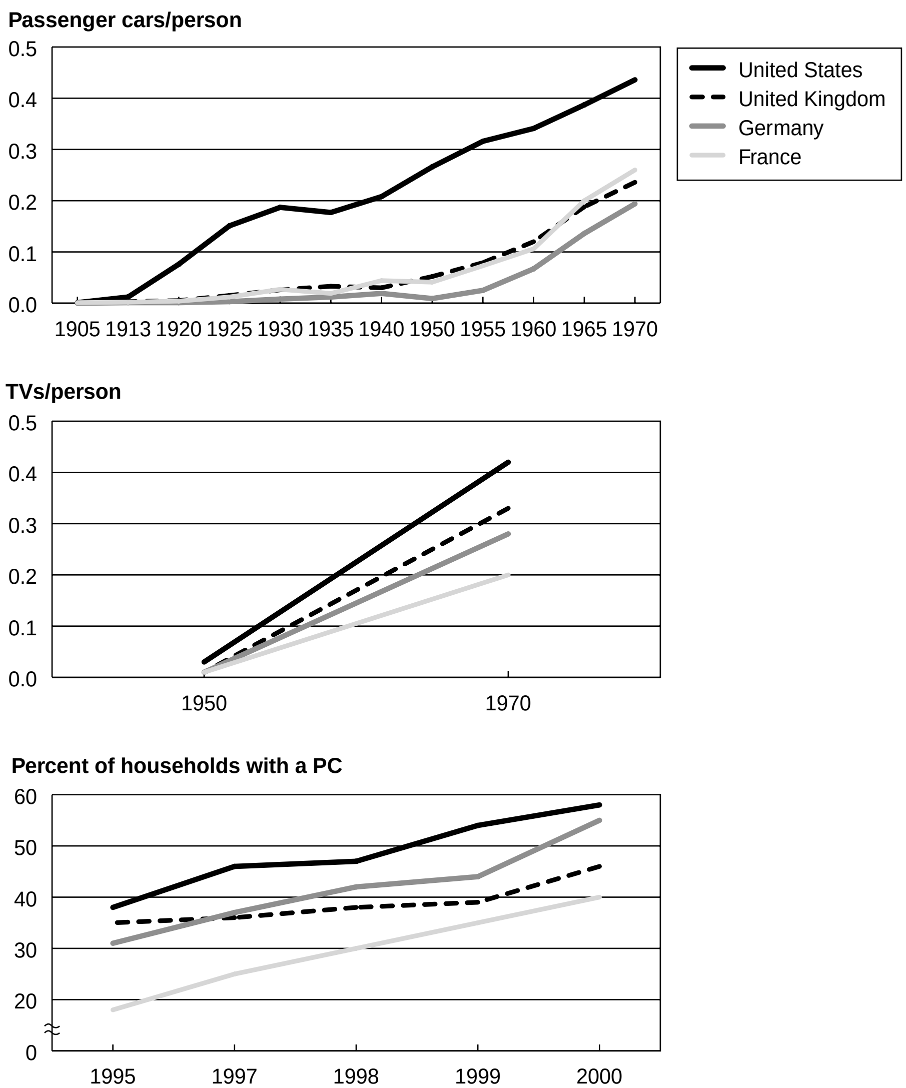
Americans express their attitudes by means of their behavior. And Americans' behavior suggests that in the last century Americans have clearly adapted to new technologies faster than the citizens of other countries. As evidence we cite the penetration rates of three technologies over the course of the 20th century: automobiles early in the century, televisions at mid-century, and PCs late in the century. In each case, penetration rates in the United States were markedly quicker per capita or household than in other countries (see Figure 3–10).

Figure 3–9
… And Support Increases with Education
(Percent who agree that "even if it brings no immediate benefits, scientific research which advances the frontiers of knowledge is necessary and should be supported by the federal government")



Source: National Science Foundation, *Science and Engineering Indicators*, 2000.

Figure 3–10
Technology Penetration Rates Higher in the United States



Source: U.S. Census Bureau; B.R. Mitchell. *European Historical Statistics*. New York: Columbia University Press, 1978.

The penetration rates for many other consumer technologies, such as radios, refrigerators, washing machines, dishwashers, and microwave ovens, would look the same, as they would for new medical devices and pharmaceutical products as well. The exceptions to the rule—such as mobile telephones and high-speed trains—usually indicate the success of a relatively sophisticated installed base of existing products. In general, American consumers tend to experiment with and adapt to new products faster than consumers in other countries.

Conclusion: U.S. Public Support Means More and Better R&D

Since public attitudes and opinions play an important role in R&D, it's no wonder the United States has been so successful. The American public's support of the federal government's efforts in basic research is extremely strong. Especially important is the broad public support for a federal role in sponsoring research in the universities. Indeed, it is just this government support that makes most large U.S. universities the huge, world-renowned independent research centers they've become.

American consumers also support R&D more directly, by experimenting with new products and adopting them quickly when they fill a need. This potential for large, quickly responding markets supports both large research-intensive companies and small entrepreneurial firms. It also means that, based on the future promise of innovative products likely to find a receptive market in America, investment banks and venture capital firms are willing to invest in such technologies long before they make it to the marketplace. As a result, the American public itself helps reduce the risk profile of new and innovative products, and contributes directly to the strength of the United States' R&D-driven economy.

Chapter 4

NEW MECHANISMS FUND R&D

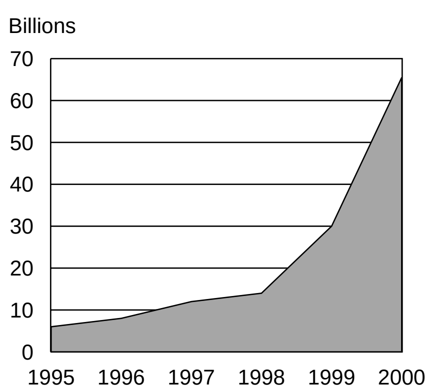
One of the main drivers of the rapid growth in R&D spending in the United States in general, and of the R&D sector's shift to more industry-sponsored research, more research in smaller firms, and more basic research in particular, has been the rapid adaptation of the financial markets to emerging opportunities in the R&D sector. In other words, new funding sources and mechanisms arise in the R&D sector as needed, and then become a permanent part of the system.

The Venture Capital Market Emerges

The best example of financing that arose at just the right time is the venture capital market, which exploded in size and impact in the late 1990s. Venture capital firms raise money to fund promising start-ups in the early phases of development, usually before they're ready for the marketplace. Most firms that receive venture capital funding are trying to package a clearly defined idea for the application of a technology to a concrete business problem or a market need. These start-ups offer the promise that, with a substantial dose of funding, they can bring the idea successfully to market.

Venture capital funding grew from about $10 billion in the mid-1990s to more than $65 billion in 2000 (see Figure 4–1). A large portion of this funding went into tech-based start-ups—small entrepreneurial firms pushing a single idea based on an innovation in science or technology. About 60% of the funds went into one of two areas: information and communications technologies or biotech.

Figure 4–1
The Explosion of the Venture Capital Market
(Billions of dollars)



Source: PricewaterhouseCoopers Money Tree

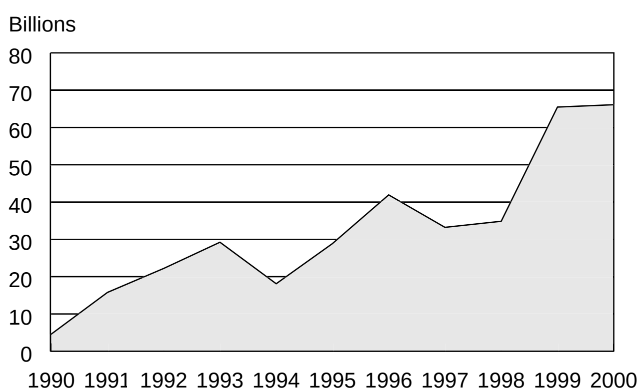
IPOs Support the Venture Market

A venture capital firm provides funding to entrepreneurial start-ups in exchange for an equity position in the company. But the venture group—which specializes in assessing high-risk opportunities—has little interest in keeping its capital tied up for any length of time, so it is always on the lookout for a means of "cashing out." One of the most popular means is taking the company public—selling equity shares in the stock market. Thus arose the importance of the initial public offering (IPO).

The rise of the Nasdaq market, which accepted smaller companies with somewhat less rigorous standards than the New York Stock Exchange, made it easier for smaller venture firms to take their start-ups to a wider public market, and thus enabled them to cash out. The welcome acceptance of the new start-up firms by science and tech-oriented mutual funds—and thus the general investing public—completed the circle.

As a result, the IPO market grew strongly throughout the 1990s and remained substantially higher than the venture capital market throughout that period (see Figure 4–2).

Figure 4–2
Solid Growth in IPOs
(Billions of dollars)



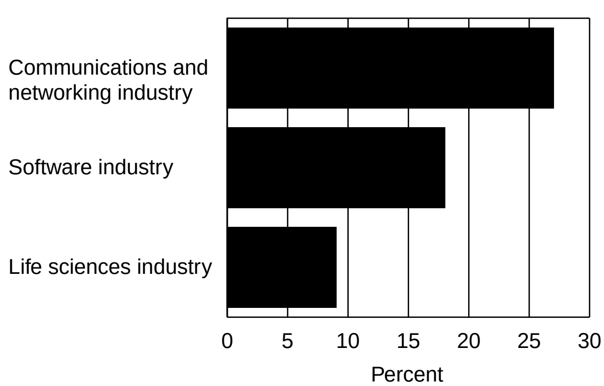
Source: Jay Ritter, University of Florida; Securities Data Corporation.

The phenomenal enthusiasm about Internet-related companies spurred the venture capital and IPO booms in the late 1990s. Approximately 80% of all venture capital distributed in 2000 was invested in firms that were active participants in the Internet. The communications and networking sector, for example, experienced a fourfold increase in venture capital investments between 1998 and 2000. Funding for the software industry jumped fivefold and doubled for life sciences (see Figure 4–3).

Other Supporting Market Players Emerge

The venture capital and IPO markets were only the most publicized manifestations of a much larger market sector growing during the 1990s—the channeling of private investment funds into R&D-based firms. This larger market sector had many smaller components. Many venture capitalists, for example, came to specialize either in firms in a particular region or those selling a particular type of technology. Others wanted to be initial investors at the earliest stages of innovation, while still others only worked with consortia of other venture firms as they began to develop products and bring them to market. Some wanted to

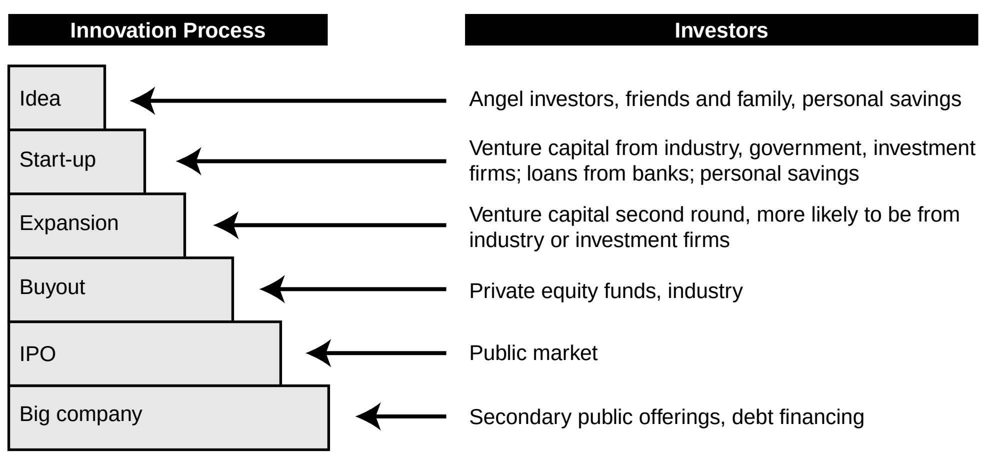
Figure 4–3
Market Focused on a Couple of Areas
(Percent of total venture capital investments, 2000)



Source: PricewaterhouseCoopers Money Tree provide just the funding, while others had a cadre of managers and marketers who could actively help a start-up move toward the market.

Even before the more formally organized venture capitalists came on the scene, individual investors, so-called "angel investors," often provided seed money at the very earliest stages of an idea's development. Other pools of investment funds—private equity firms—cropped up to play a more prominent role. These funders contribute to equity participations only with other investors; they do not attempt to play a role in starting or managing a venture as venture capital firms do, but rather leverage the capital of a venture firm as silent partners. Also, traditional investment banks began to set up venture funds within their operations and were able to bring much larger resources to bear on the start-up market than the smaller venture capitalists. And once the mania for mergers and acquisitions took hold, larger firms looking for high-tech plays were able to gobble up start-ups at almost any stage of their operations. Usually, however, they waited until after there was some public equity holding that placed a market value on the company (see Figure 4–4).

Figure 4–4
Emerging Financial Players All Along the High-Tech Start-Up Spectrum



Source: Institute for the Future

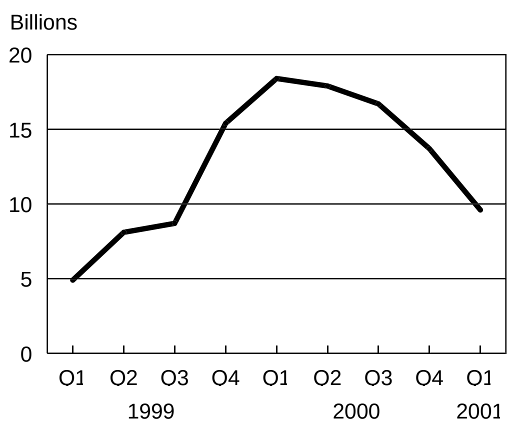
Facing the End of the Boom

The venture capital market proved susceptible to boom-and-bust cycles, however. As many of the high-flying dot-coms failed to generate a profit or build a credible business plan that would get them to profit in a short time, their value on the market dropped sharply. Without the real or potential support of stock shares, venture capitalists became less eager to fund untested technology-oriented firms.

As a result, by the beginning of 2001 the venture capital market was operating at an annual rate of less than $50 billion (see Figure 4–5).

IPOs also dropped off significantly at the end of 2000. In the fourth quarter of 2000, only $15 billion was raised in a total of 56 IPOs, compared to $23 billion and 133 IPOs in the previous quarter. And only one year earlier, in the fourth quarter of 1999, IPOs had raised more than $47 billion.

Figure 4–5
The Big Market Shift
(Venture capital investment per quarter, in billions of dollars)



Source: PricewaterhouseCoopers Money Tree; Institute for the Future estimate.

Venture Capital and Innovation

How important is venture capital in supporting a healthy R&D and innovation environment? The National Bureau of Economic Research conducted a study to examine just that relationship. The study determined that there is a strong correlation between the amount of venture capital in an industry and its rate of patents (patents being a good proxy for innovation). The study estimates that venture capital-backed R&D is responsible for about 15% of all industrial innovations, while it accounts for only 3% of total R&D funding. While there is much more research to be done on this subject, it is clear that venture capital has come to play an important role in spurring the innovative R&D that propels the U.S. economy.

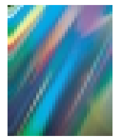
Conclusion: New R&D Financing Mechanisms Are Here to Stay

Market mechanisms that support new technological solutions surged during the 1990s, and more and more money became available to fund the 30-year-old wave of the information revolution. The manifestation that caught the public's imagination was the Internet, which literally brought the information and communications revolution home to the public. Financial and business productivity applications came of age during the 1990s as well, in the form of electronic payment systems, consumer databases, inventory control systems, just-in-time logistics, and customer relationship systems.

The excitement of entrepreneurial growth brought venture capitalists into high-risk R&D funding. As the rewards for funding these innovations grew, a number of other players entered—angels, a greater variety of venture funds, private equity funds, and investment banks. Although the recent stock market downturn will discourage many of these funders, the diversity of formats and the wide dispersion of risk-based opportunities will provide a permanent means of funding R&D. Once the market and economy settle down, look for this market to continue to operate effectively in the longer term to channel funds to entrepreneurs with marketable new ideas.

Chapter 5

The United States Protects Innovation



R&D doesn't succeed in a vacuum. As we've seen in previous chapters, certain drivers have been responsible for creating an excellent environment for R&D in the United States. Research has shown that R&D works best in countries, like the United States, that reward innovation by protecting intellectual property rights, primarily by means of patents. Patent and copyright protections grant the inventor of a technology or an idea the monopoly use of the invention as long as it can be shown to be distinctly different from others in the public domain. Such protection is granted for a given period of time; for patents it is usually 20 years after the application is filed.

International studies have shown that countries with the highest economic growth rates also have the highest standards of intellectual property protection—that is, the longest periods of protection, the broadest ranges of products covered, and treaties that ensure equal treatment for companies and individuals from other countries.

Countries with the highest economic growth rates also have the highest standards of intellectual property protection.

But protection alone is not the end-all and be-all of an effective intellectual property system. There is a critical dilemma in the question of how much protection to provide—too little protection reduces the incentives for investing time and money in discovering new ideas; too much discourages effective competition and can slow the spread of useful ideas to the rest of society. The goal of an effective patent system, then, is twofold: to reward the developer of an idea to the point where more people are willing to spend time developing such ideas; and to encourage an orderly dissemination of ideas others might use in their own inventions.

Balancing the protective monopoly against the open sharing of ideas is especially problematic in high-tech R&D, where small-scale improvements can make a big difference in market applications. In recent history, this has been the case in the computer, software, database, and biotech industries, which involve what we call the "fast-evolving technologies."

These fast-evolving technologies have achieved tremendous growth in the past couple of decades, as well as huge commercial success. Because of their growing role in R&D and their importance in the economy as a whole, it is particularly instructive to examine the intellectual property issues concerning them. The three most important are:

- A myriad of different parties, all with different interests and claims on intellectual property, are involved in taking infotech discoveries from concept to market.
- The U.S. intellectual property system both protects ideas and eases their diffusion to other potential users.
- A wide range of cooperative practices has grown up in the infotech industries to deal with potential areas of conflict and to disseminate intellectual property even more effectively to those who need it most.

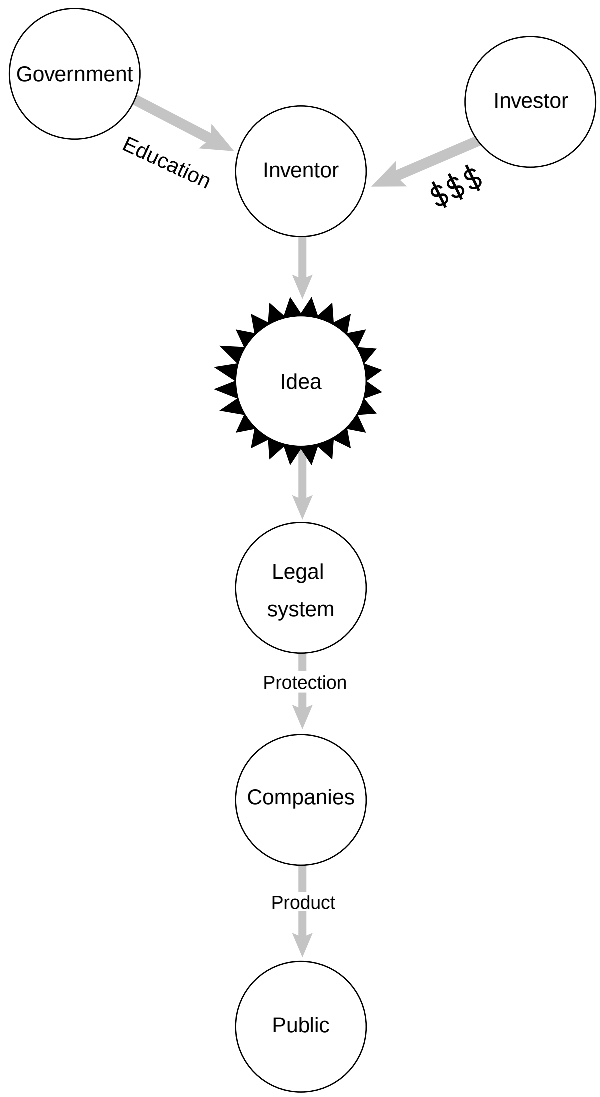
Many People, One Innovation

The fast-evolving technologies sector has been growing more quickly than any other part of the economy in recent years. And because the technologies are so complex, they involve a much wider range of participants at any given stage of development than most—participants all interested in holding some rights to the intellectual property.

One reason for this desire to retain rights is that the results of each innovation are truly uncertain—much more so than for R&D investment in more mature economic areas, like the auto industry, where the pace of innovation is more incremental and the potential impacts can be more clearly understood. In the auto industry, for example, where R&D on engine efficiency has been going on for a hundred years, innovations can be more clearly anticipated in both the likelihood of a given technology coming on-stream and the size and scale of its impacts on marketable products. But in the newer fast-evolving technology industries, the impacts of each round of innovation spawned by a new breakthrough—the PC, the Internet, mobile communications, the Human Genome Project—chart new ground into an uncertain market. Businesses simply cannot assess with certainty the full range of applications, new products, services, and markets that might emerge from a given innovation. Indeed, it took decades before businesses could adapt their organizational structures to take advantage of some of the enterprise and supply chain adaptations of the networked PC; and it took years for businesses to begin building applications that were able to make harnessing the home PC and the Internet a good business proposition. Because innovation in many of these fast-evolving technology areas is much more complex, a wider range of players can take credit for at least some part of the process. And, naturally, all of them want to participate in the rewards, which can be very significant for the most successful products. As a result, the relationships among these players can be complex and difficult to manage (see Figure 5–1 on page 48).

Balancing the protective monopoly against the open sharing of ideas is especially problematic in high-tech R&D.

Figure 5–1
The Key Players Along the Innovation Spectrum



Source: Institute for the Future

If innovations are ever to reach the marketplace, however, let alone succeed there, these players along the spectrum must know their roles and be able to work with the others up and down the line.

The Inventors

In the world of the fast-evolving technologies, there are many inventors, and for good reason. As scientific research becomes more complex, collaboration is essential, but ownership of ideas becomes increasingly fuzzy. Let's look at some examples when:

- *Individuals are part owners.* Ideas are no longer singular, even in academia. In biomedical research, for example, rarely does one person know enough to advance the science. Each researcher can lay claim to part of the invention. And, as monetary rewards for ideas go up, more academics are interested in getting credit for that idea.
- *Universities want to own their interest.* Universities have an interest in generating *core* patents for academic scientific research. Because the federal funding of science programs at universities has not kept pace with their size, more universities are encouraging researchers to take out patents, sometimes in the name of the individual but often in the name of the university. In this way, the universities can earn money from their discoveries and become more self-supporting. Since most scientific papers have multiple authors, a growing number of patents have complex ties with universities, individual academics, and even private industry.
- *Companies must draw on a wider purview.* Most of the marketable inventions in fast-evolving technologies are made by combining more than one innovation—a hardware device, a chip, a software program, or an applications process, for example. The marketable product may draw on work from many disciplines, each with its own technologies, and each protected by its own patents. This situation creates spirals of overlapping "inventors," each of whom can justifiably claim some rights to the market innovation.

The goal of each of the inventors is not only to keep title to his or her own innovation and gain financial compensation and prestige from that achievement, but also to participate in the success of the larger project. Under the law, each can potentially play a role in any commercial applications of the project as a whole.

As a result, we increasingly see disputes among academics over ownership of a critical idea, as in the recent bitter battle between Robert Gallo of the National Cancer Institute and Luc Montagnier of the Pasteur Institute over the AIDS virus. Although both shared a sample of infected virus developed at the Pasteur Institute, they conducted their work independently. This made the dispute over rights terribly complex. The final resolution involved governments, the research institutes, the sequence of reporting in scientific journals, and, of course, ultimate credit in prizes, prestige, and patents.

The Investors

Since it is uncertain how any given innovation will be accepted in the marketplace, investors in fast-evolving technologies take on high risks. These investors are rightly concerned about the ownership and control of the innovation they are asked to fund. Investors include venture capitalists giving seed money, investment banks helping a company go public, and the investing public purchasing shares in mutual funds. The investors' goal is to receive compensation equivalent to the risk they have underwritten.

The cost of developing, marketing, and distributing a product can be very high. At the extreme, the cost of launching a new pharmaceutical product (including the clinical testing and government approval process) can be more than $100 million. With costs like these, all of the investors expect clear rights to the benefits of commercialization.

The Companies

The companies are at the center of the action. They see the commercial possibilities of an innovation and have the vision to transform the idea into a product or service people want. The companies' goal is to make money by spending the necessary resources and time to create the market conditions that enable them to distribute the innovative product as widely as possible. To ensure a return on their market-building investment, the companies need to get control of the innovation; to this end, they either buy the patent from the inventor or license it.

To do so, they put together an organization that can take that idea and turn it into a product, produce it in scale, advertise it, build and maintain a market for it, and distribute it to the public, all while keeping costs low enough to make a profit.

The Public

The public has an interest in innovation as investors, but also as consumers and workers. The public understands the value of innovation—it leads to better products, better jobs, and a better quality of life. As we saw in Chapter 3, nearly 90% of the public supports science and feel that science and technology will improve the quality of life in the future. As consumers, the public wants a continual influx of new products. The public's goal is to make sure that innovation will continue at a high rate.

The Government

The government in the United States plays several roles in R&D. First, it shares the public's view that innovation is good, and thus it attempts to balance the interest of all the parties in fostering ideas and ensuring the dissemination of innovation. To this end, the U.S. government provides patent and copyright protections that are particularly strong in intellectual property, compared to those of other developed countries. For example, patent protection in the United States is extended beyond products to include living organisms (such as plants) and software. The United States does not force patent holders to license their ideas, and it gives patent holders an extended period to use their inventions. To achieve the best atmosphere for innovation, the government is constantly revising patent and copyright laws and its own role in the patenting process. The U.S. government also is working through the World Trade Organization to increase patent and copyright rights around the world. Courts also play a key role in constantly reinterpreting the extent and degree of intellectual property protection.

It is in the cooperation among the various parties that the best environment for innovation is created.

Second, the U.S. government acts to maintain a healthy infrastructure for innovation. It funds much of the training of scientific researchers and still provides direct funding for much of the basic research done in the country (though the private sector is taking on more of this funding, as discussed in Chapter 1). In the 1980s, the executive branch and Congress made an explicit endorsement that universities and other public research agencies should act to protect their own patentable ideas but also to keep them in the public domain so they could be used as widely as possible. Congress ruled that publicly funded research programs could hold patents on their ideas but that they had to be licensed on a nondiscriminatory basis. Congress also mandated that federally funded research labs enter into cooperative agreements with private businesses to conduct joint research.

The government's goal is to foster the highest-quality science and technology in the world, to protect the rights of the inventors, and to ensure the widest dissemination of ideas possible.

The Intellectual Property System: Tool of Cooperation, Not Exclusion

The intellectual property laws drive the relationships among the various players who bring a product from idea to market. But the laws themselves are limited in what they can do. It is in the cooperation among the various parties that the best environment for innovation is created.

To work, intellectual property rules must be firm enough to protect the rights of each player and flexible enough to encourage a continual flow of ideas to a variety of people who work to build innovative products. In the United States—at least in the fast-evolving technology areas—players have developed unique ways of spreading innovative ideas by leveraging the U.S. system of patent and copyright protection.

Patents and copyrights do different things. Patents provide an exclusive right of ownership to the commercial use of an idea. Any novel idea that has commercial potential is eligible for a patent, which can be enforced against any other use of that idea. Article 1, Paragraph 8, of the U.S. Constitution states that Congress shall have the power "to promote the progress of science and useful arts by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." As one of its very first acts, then, Congress set up a strong patent system with a 20-year period of exclusive use protection.

In contrast to patents, copyrights are based on the originality of an idea (if someone comes up with the same idea through his own creative process, he has the right to use that idea). Copyrights are usually protected for a shorter period of time, and the holder must bear the burden of proving misuse. Damages are limited.

Balance of Powers

The goal of intellectual property protections is not to restrict use—rather, the goal is to allow the author/inventor to benefit from innovation's use. In fact, it is only with the widest possible use of the innovation that the author/inventor gains either prestige or financial reward.

The intellectual property system does pose some threats to dissemination, since each use must be approved separately. The administrative burden of monitoring use in this way seems to pose particular problems in the fast-evolving technology areas. In these areas, there are many cases where collaborative research has produced the innovation and many basic inventions must be used all together to develop a commercial idea. Take an example like biotech. According to a recent article in the journal *Science*, there are no effective substitutes for some biomedical discoveries such as patented genes or receptors. Patents for such things may exclude rivals from building on earlier inventions because they "may not be able to invent around patents in research aimed at understanding the genetic bases of diseases as they occur in nature."

But there are many forces that help to encourage the full use of patents. As the market comes to buy more innovative products, the potential value of a marketable patent rises. As patents take on higher economic value, inventors in the United States have found a growing number of ways to share their innovations with others for the benefit of all: by developing those ideas into marketable products; by forming ventures with partners; by selling their patent to others who can market them; by col-

The goal of intellectual property protections is not to restrict use—rather, the goal is to allow the author/inventor to benefit from innovation's use.

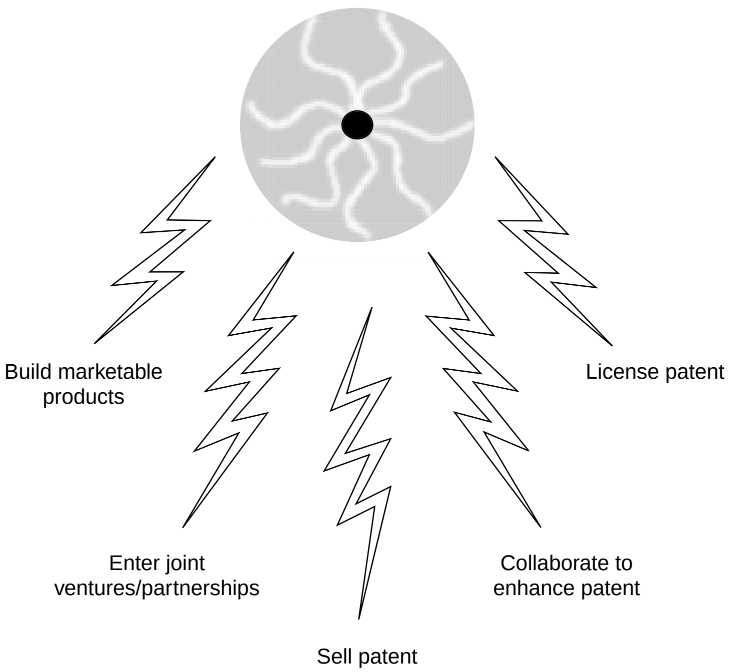
laborating with other patent holders who can enhance the value of the invention; or by licensing the patent to third parties (see Figure 5–2).

Order in the Courts

The constitutional basis of the patent law focuses on the economic precepts of progress rather than strictly on the notion of protecting property. In many continental European countries, however, courts follow civil laws, leaving judges only the leeway to interpret what the legislature has written. In the United States, however, where the courts are based on common law, judges have more freedom to treat each case as a unique application and to apply the body of accepted rulings, which allows judges to use a wider range of information for each case. This freedom lets judges utilize economic arguments to foster dissemination in the light of the general goal of promoting the progress of science. The U.S. system thus encourages the use of royalties and licenses as a means of dissemination that benefits both the author/inventor and the rest of society.

Tracking recent legislative and legal action shows the continual interplay between strengthening protection and fostering competition and dissemination. Congress, the Patent Office, and the courts have extended basic patent and copyright protections in two areas that directly affect the new information economy—software and the Internet. As software has become a key component of new business application areas, it has become more valuable. Traditionally, software has been protected under the more lenient copyright laws rather than patent laws because programs evolve so fast that the patents would be useless before the 18-month to two-year approval process was completed. But as the economic value of software rose, the Patent Office began to treat software as a separate category and hired staff to assess innovations and contributions to business applications. The greater valuation of software and the friendlier atmosphere at the Patent Office increased the flow of software applications. The number of software patents jumped sixfold during the 1980s and fourteenfold during the 1990s, rising from around 250 in 1980 to 24,000 in 2000.

Figure 5–2
Dispersing Knowledge Among Interested Parties



Source: Institute for the Future

Firms that demonstrate an ability to successfully build and maintain cooperative relationships, or that can learn how to collaborate well, have a distinct market advantage.

In the meantime, the courts have been seeing more intellectual property–related cases and ruling in favor of intellectual property protection online. Recent court cases involving Amazon and Napster captured the courts' attempts to set strong protective rules for intellectual property. The Amazon case (1999) reinforced Amazon's control over a software application that reserved purchases in a shopping cart. The Napster case (2000) ruled that the song-swapping service had to protect access to copyrighted material made available on its site.

Congress has also shown some limits on how far it would push for increased protection. Following a Supreme Court decision that limited the copyright protection of factual databases (*Feist v. Rural Telephone Service*, 1991), a bill was introduced to protect such rights. But there was a coalition of interested parties, such as libraries and news services, that opposed restrictions on such databases, and Congress ultimately shied away from passing the bill.

Beyond Patents: Maximum Collaboration

Patent laws and market opportunities seem to work to disseminate innovation throughout the system. But it isn't easy. Older companies and organizations have had to adapt to new ways of building collaborative partnerships, and a number of new organizational forms have been designed to make the system work.

When large firms dominated R&D, those firms relied on a traditional, vertically integrated model with in-house R&D feeding directly into departments adept at testing, meeting regulatory approvals, and marketing the end product. With more innovative ideas coming from smaller firms today, however, increased collaboration and strategic alliances are emerging to help get new products and services to the market. Even large firms are looking to external partnerships to foster productive R&D.

For example, the biotechnology and pharmaceutical industries have realized the potential for cooperative relationships between start-up biotech firms, large pharmaceutical companies, and university researchers. Large pharmaceuticals seek start-ups with innovative technology and research; small biotechnology firms rely on the large pharmaceutical companies for marketing and clinical trial skills; and universities frequently license patents to corporations for commercial development. Recognizing the value of collaboration with external partners is crucial to many of the innovations in this industry.

As Robert Merges, a law professor at the University of California at Berkeley, has pointed out, there is now "a dizzying array of organization forms" to help companies bring ideas to market. These include joint ventures, R&D partnerships, corporate venture capital arrangements, spin-offs, start-ups, licensing, cooperative efforts with government agencies, and outsourcing. Most large research-intensive firms are accepting the principle that they can no longer do it alone and that they have to cooperate with companies that may be competitors in other markets. In this way, intellectual property rights in the fast-evolving technology industries are redefining the very boundaries of firms themselves. Firms are being forced to work together as never before. The ones that demonstrate an ability to successfully build and maintain cooperative relationships, or that can learn how to collaborate well, have a distinct market advantage.

Several clear trends are emerging. For one, lawyers are becoming key facilitators—they are helping companies, both big and small, sort through the variety of opportunities and mechanisms to get maximum value out of collaboration. Indeed, according to the latest occupational employment reports from Silicon Valley, lawyers rank as one of the fastest-growing occupations in tech-intensive industries.

Perhaps the best way to build a collaborative model, however, is to have a wide variety of organizations in close proximity that have had positive experiences with collaboration. In this regard, Silicon Valley bears special attention (see text box on page 58).

Lawyers are becoming key facilitators—helping companies sort through the variety of opportunities and mechanisms to get maximum value out of collaboration.

The Silicon Valley Story

Large numbers of fast-evolving high-tech enterprises exist side by side in Silicon Valley, but there are no giant, dominant players able to set the tone or establish preeminent rules. As a result, no single company has exclusive claims on many ideas, or even people. In fact, one of the keys to disseminating intellectual property in the Valley is the mobility of people among firms. For instance, the processor revolution really got under way in the Valley when the "Traitorous Eight" walked away from William Shockley's eponymous company, Shockley Semiconductor Laboratory, in 1957 and founded Fairchild Semiconductor. The group of eight (Rob Noyce, Gordon Moore, Jean Hoerni, Gene Kleiner, Jay Last, Sheldon Roberts, Victor Grinich, and Julius Blank) included the future founders of Intel and a range of other electronic component firms that formed the basis of the first great Silicon Valley revolution. The movement of people fosters the interchange of ideas. It has also made it easier for a later generation of Valley firms to establish licenses and agreements for sharing those ideas in new innovative products.

Silicon Valley has also developed its own form of financing for the fast-evolving high-tech industries—the venture capitalists mentioned in Chapter 4. Small, local venture capital firms found that they could assess the risk of small start-up firms as long as the intellectual property rights were clear and the legal route to using those ideas for collaborative agreements with larger firms were clearly demarcated in the thicket of IPOs, mergers, buyouts, and collaborative joint ventures.

It is this rich and varied experience—very personal and a part of the Silicon Valley legend—that has helped create a culture of collaboration in which even failures do not inhibit attempts to try again. Thus, licensing is facilitated by the general ethos of the Valley—where academics, entrepreneurs, large firms, lawyers, and venture investors all understand the rules of the collaboration game. Often, collaboration starts even before the formal licensing agreement is completed. Repeat players make the process of licensing work, since in the long run, if not in each particular case, everyone does well.

Conclusion: Cooperation Means Growth

In the last decade or so, the United States has put together an exemplary intellectual property system that works well to bring products to market. The U.S. system provides strong protection for new ideas, but it also enables the development of collaborative institutions that help disseminate those ideas to the enterprises that can use them most effectively. The collaborative system works because of many formal and informal cross-cutting arrangements from colleague to colleague, company to company, industry to industry, sector to sector, and so forth. This type of collaboration works best within innovation clusters such as Silicon Valley, where a wide range of experience with collaboration is shared across academic, entrepreneurial, and large research-based enterprises with a network of experienced lawyers, managers, and investors.

The institutional forms of R&D collaboration that have grown up in the United States, and particularly those in the areas of intense research activity, will be essential for future growth, since such R&D collaboration not only fosters innovation but also draws long-term investments into R&D. These long-term investments will ensure that these new forms of collaboration will continue to find markets for the next wave of innovative products. As these types of cooperative arrangements become increasingly international, the U.S. model for an intellectual property system that is firm but flexible will become more and more useful worldwide.

Chapter 6

U.S. R&D Spending Leads the World

The United States stands apart from its international peers in R&D spending for a number of reasons. It spends more on R&D; it has invested more of what it spends on high-tech equipment; and it puts more money into new research-oriented companies. In addition, at least for the past decade, U.S. spending on R&D has grown faster than that of the other developed countries of the world. This strategic use of funds is an important driver behind the R&D success story in the United States. Given the history of the U.S. economy of the past decade, many other countries are beginning to pay closer attention to their R&D strategies as well.

U.S. Spending Is Higher

The United States plays a dominant role in worldwide R&D funding, accounting for about 43% of the R&D spending by all Organisation for Economic Co-operation and Development (OECD) countries. In fact, the United States typically spends more than the rest of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined (see Table 6–1).

In the early 1990s, R&D spending slowed or declined almost universally, due to economic recessions and subsequent budgetary constraints. The severity and length of the decline, however, varied significantly by country and region. While the United States, Germany, and Japan recovered from the slump in the mid-1990s, R&D spending in the United Kingdom and France has remained flat.

The total spending on R&D in the United States grew rapidly in the last five years, and U.S. R&D expenditures as a share of GDP jumped from 2.5% to 2.7% (see Figure 6–1). The only reason it didn't move up even more sharply as a percentage of GDP was that GDP growth in the

Table 6–1
United States Spends More than Other G-7 Countries Combined
(R&D expenditures in 1998, in billions of constant 1996 dollars)

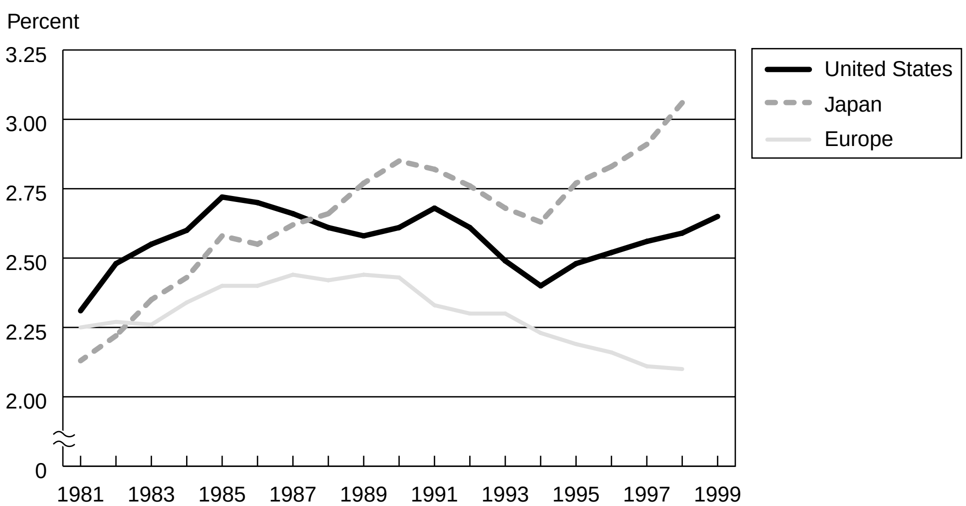
United States	220
Japan	90
Germany	42
France	27
United Kingdom	23
Italy	12
Canada	12

Source: Organisation for Economic Co-operation and Development, Main Science and Technology Indicators database, 2000; National Science Foundation.

United States was also high, at well over 4% per year during that period. Japan's ratio was also high, rising above 3%, but its GDP growth rate was very low. At the same time, R&D as a share of GDP fell across most of Europe.

In 1990, the distribution of funding in the European Union (EU) looked very similar to that of the United States, with government, universities, and other organizations accounting for about half of R&D funding and industry accounting for the other half. By the end of the decade, however, the distribution in the United States had changed dramatically, with the private sector accounting for more than two-thirds of R&D funding. In Japan, by way of comparison, where industry has historically played a

Figure 6–1
Japan and the United States Lead Europe
(R&D spending as a percent of GDP)



Source: Organisation for Economic Co-operation and Development, Main Science and Technology Indicators database, 2000; National Science Foundation.

very large role in R&D funding, the government's share of R&D actually increased in the 1990s, though it remained relatively low (see Table 6–2).

More Investment in High-Tech Equipment

The United States is notable not just for spending more on R&D than other countries but also for investing more in the use of the technologies spawned by R&D. The contribution of information and communications technology growth to overall GDP growth, to name one important example, expanded rapidly in the last few decades.

In 1997, the latest year for which we have such data, the United States invested more in R&D in the information and communications technology sector than the EU and Japan combined. In fact, the United States accounted for more than half of all worldwide R&D funding in this sector. The EU accounted for only 17% of information and communications R&D investments, and Japan, 22% (see Table 6–3).

The United States Leads in Knowledge Investment

The European Commission, unlike the United States and Japan, takes a broader look at what it calls "knowledge investment" by adding investments in education and software to those in R&D. While Japan leads the world in R&D spending as a percentage of GDP, the trend for knowledge investment as defined this way favors the United States. As a percentage of GDP, the United States' knowledge investment is much higher than that of either the EU or Japan (see Figure 6–2 on page 66).

This broader concept of knowledge investment may be a better indicator of the importance a country places on R&D, because it takes into account education (always an important driver of innovation) and software development (a relatively new sector of the economy that goes hand in hand with scientific development but falls outside the traditional definition of R&D). The United States has increased its investments in knowledge as a percentage of GDP throughout the 1990s, while the EU's knowledge investment has actually declined as a percentage of GDP.

Table 6–2
No Shift in R&D Funding in Europe or Japan
(Percent of R&D spending, by source of funds)

	1990	*1998*
European Union		
Industry	52	54
Government	41	37
Other	7	9
Japan		
Industry	78	73
Government	16	20
Other	6	7
United States		
Industry	55	68
Government	41	27
Other	4	5

Source: European Commission Research, *Towards a European Research Area, Key Figures,* 2000; National Science Foundation.

Table 6–3
R&D Investments in Information and Communications Technology
(Billions of purchasing-power parity dollars, 1997)

United States	60
European Union	20
Japan	26
Total for all OECD countries	**116**

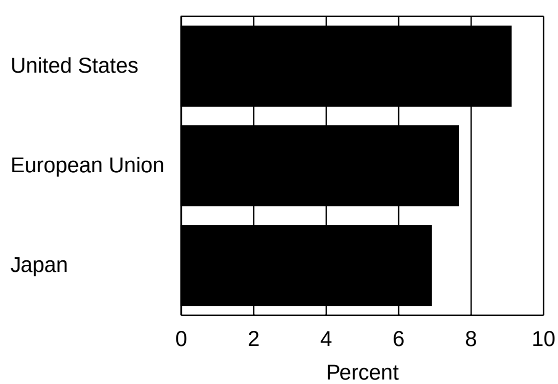
Source: Organisation for Economic Co-operation and Development, *Measuring the ICT Sector*, 2000.

Research Cooperation

It is slightly misleading, however, to focus on the R&D spending of single countries or groups of countries in isolation. Increasingly, research is a cooperative venture that involves many people and many institutions around the world. Both the United States and the EU have encouraged public–private ventures and international cooperation. According to the National Science Foundation, for example, many governments now allocate more than 10% of their R&D funding to projects participating in some form of international cooperation. In a report by the National Science Foundation on R&D, the foundation quotes the findings of a study on international cooperation: "Seven agencies of the U.S. government participated in 575 international science and technology agreements in FY 1997 with 57 countries, eight international organizations, and ten groups of organizations or countries."

The trend toward cooperative agreements is not limited to government research. Many corporations are also relying on international partnerships to leverage their R&D expenditures. The Maastricht Economic Research Institute in the Netherlands tracked more than 5,100 strategic

Figure 6–2
Investment in Knowledge Is Higher in the United States
(Total investment in R&D, education, and software as a percent of GDP)



Source: Eurostat

technology alliances between 1990 and 1998. This number represents a 34% increase from the decade before. U.S. companies seem to be much more adept at these technology alliances, since U.S. firms are participating in over 80% of them (see Table 6–4).

About half of these deals were international, yet more than 2,000 alliances were formed within the United States alone (see Table 6–5).

U.S. firms have aggressively pursued strategic technology alliances, both within the United States and abroad. As companies and governments come to rely on partnerships and cooperation for conducting and funding R&D, the importance of clear intellectual property laws intensifies (see Chapter 5, "The United States Protects Innovation," for more on intellectual property protection). With global partnerships becoming more prevalent, consistent and enforceable international laws become more imperative as well.

More Money in Private Equity and Venture Capital

Not only does the United States dominate the market for R&D in the strictly defined sense, it also dominates the market for funding new venture start-ups, which are often driven by R&D. Globally, $136 billion of private equity and venture capital was invested in 1999—up 65% from 1998. North America accounted for almost 75% of total private equity and venture capital investments. Western Europe accounted for 20%, and Asia, 4%.

Table 6–4
U.S. Companies Involved in Most Strategic Technology Alliances
(Percent of all alliances, by home country of firms involved, 1990–1998)

United States	80
Europe	32
Japan	13
Others	9

Source: National Science Foundation, *Science and Engineering Indicators*, 2000.

Table 6–5
Domestic and International Alliances Are Important for U.S. R&D
(Percent of all alliances involving U.S. firms, by home country of allies, 1990–1998)

Domestic	52
U.S.-Europe	31
U.S.-Japan	11
U.S.-Others	6

Source: National Science Foundation, *Science and Engineering Indicators*, 2000.

Although the United States has the biggest venture capital and private equity market in the world, it doesn't have the fastest-growing market. In fact, the venture capital markets of eight countries, including Germany, Sweden, Switzerland, and Taiwan, are growing faster than that of the United States—but from a much smaller base. Overall, venture capital investment grew substantially in the EU over the 1990s, when it averaged 14% annual real growth in total venture capital investment. Countries with particularly high growth include Austria (44%), Finland (37%), Greece (37%), and Sweden (24%). In the same time frame, Japan's venture capital market grew 15% a year on average and the U.S. market grew at 26%. The Japanese venture capital market is very small, however, at just 0.2% of GDP, and in 1998 the amount of funds actually declined by almost 20% from 1997.

While U.S. venture capital firms are particularly interested in using funding early in the innovation process, European private equity firms focus primarily on investing in the later stages, favoring instruments such as buyouts, mergers, and acquisitions. European firms are increasingly interested in the technology sector, once the particular domain of U.S. investors. In fact, many companies in Europe and the United States are developing internal venture funds and other incubator activities to support such innovation.

International R&D

The EU recognizes the strategic importance of a strong R&D community, and the fact that its own is lagging behind that of the United States. The EU acknowledges that the emphasis placed on R&D in the United States is increasing, and that without a strong research community within the EU, its economy will suffer in the coming decade. As a result, the community has developed a framework for a European Research Area—an attempt to build a shared research base. Three elements are at the heart of the EU's proposal:

- *Integrated research.* The EU will fund a number of joint projects, provide a legal framework for joint cooperative research, and help build shared research facilities for cross-border work.

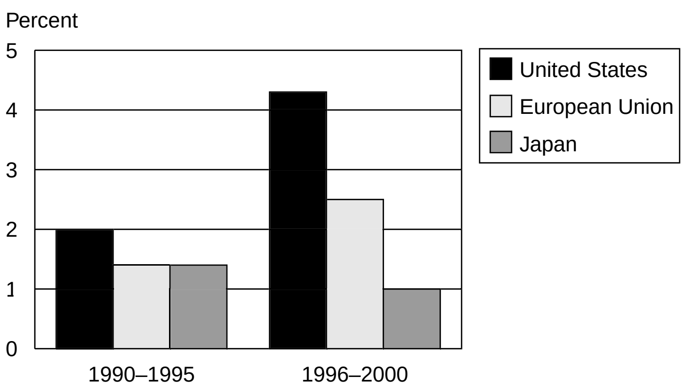
- *Support*. The EU will encourage national spending on education and on training scientists and engineers, and will move to make the work environment more friendly to third-country researchers.
- *Links.* The EU will work to build cooperative research links by means of forums and joint research centers (such as CERN—the European Organization for Nuclear Research—and the European Space Agency).

Still, base funding for European efforts will have to come from the national governments and private businesses.

Sustained Higher Growth Rates in the United States

Helped by its higher investment rates, its higher investment in new information technologies, and its more entrepreneurial bent, the United States has shown higher sustained GDP growth rates than those of other developed countries throughout most of the 1990s (see Figure 6–3).

Figure 6–3
Long-Term GDP Growth Rate: United States Leads the Way
(Average annual percent growth)



Source: Eurostat

Conclusion: U.S. R&D Spending Will Continue to Lead the World

The United States spends more than other countries on R&D and R&D-related activities, and it invests more in R&D-intensive industries. It has also aggressively pursued technology alliances and cooperative agreements with both domestic and foreign companies. These trends suggest that the United States is likely to continue to lead the world in future spending on R&D, and thus continue to expand one of the strongest economies in the world. Other countries, namely those in the EU, are recognizing the importance of R&D to long-term economic health and are beginning to emphasize R&D in their long-range planning. After the phenomenal performance of the U.S. economy in the late 1990s, it's not surprising that many countries are trying to follow a similar path.

Part 3: Forecast and Implications

Chapter 7

FORECAST: R&D SPENDING WILL CONTINUE TO GROW

The big question that launched this exploration of the state of R&D in the United States was this: Does the increase in R&D spending in the 1990s reflect a fundamental shift in the United States' willingness to invest in R&D, or merely a temporary exuberance brought on by the incredibly strong economy of the 1990s?

To us, the answer is clear: The recent increases in spending and changes in the way R&D is conducted and financed indicate a fundamental change rather than the vagaries of a temporary investment boom. As a result, R&D spending will continue to grow in the next decade as a share of GDP, spurred on by the following drivers:

- The private sector will continue to play a bigger role conducting R&D.
- There will be a greater commercial interest in basic research.
- Smaller, entrepreneurial firms will conduct more R&D.
- Nonmanufacturing players will conduct more R&D.

The key developments driving these trends are the unique evolution of strong but flexible intellectual property laws, the maturing of the new capital market structures, the speed with which markets adapt to innovation, and the ability of players throughout the innovation cycle to work together to bring products from concept to market.

Four More Questions

Although we've tackled the big question, we need to answer at least four other questions before we can forecast the direction and size of future R&D spending.

Have We Reached Technology Saturation?

The biggest impetus for the rising investment and structural changes in the R&D market was the tremendous growth of the information and communications sector in the second half of the last century. Indeed, advances in information technology drove the R&D investment boom of the late 1990s. The innovations began as early as the 1950s, but finally worked their way into core business processes and commercial applications just this past decade.

The information and communications sector is now reaching a degree of maturity. Many firms have internal and supplier networks in place and are gathering and utilizing consumer links and databases effectively. As a result, for the first time in a decade, many companies' information technology budgets are leveling off, as they stop to reassess what they have and what they need. Telecommunications firms are slowing the implementation of next-generation mobile devices, for example. And firms that specialize in software development or implementation are seeing a slowdown in sales.

Still, the opportunity for new applications remains sizable. Business-to-business e-commerce continues to grow rapidly, consumer direct purchasing is on a steady growth path, opportunities in the logistics area for quick and reasonably priced delivery abound, and the next wave of innovation from new generations of wireless devices, sensors, and microelectromechanical systems, better known as MEMS, is gathering force.

Moreover, another new wave of innovations is about to hit—the biotech revolution. The information revolution got its start with the invention of the transistor in the 1940s and came of age with the advent of the Internet in the 1990s. The biotech revolution got its start with the discovery of the structure of DNA in the 1950s and is only beginning to come of age with the mapping of the human genome in 2001. In the coming years, 50 years of work in biosciences will come to fruition. (For a fuller description of the potential for future technology changes, see "Transformative Technologies: On the Cusp of a Bioscience Revolution" in the *2000 Ten-Year Forecast*.)

The well-publicized mapping of the human genome will open the door to myriad developments: a better understanding of disease states and predispositions for disease, new ways of targeting and developing pharmaceuticals, a better understanding of the connections between food and nutrition, and improved means of developing and utilizing crops and animals for food. Since providing adequate health care and enough food to go around is important to just about everyone on the planet, the biotech industry is ripe for a levels-of-magnitude jump in productive innovation.

Given the potential for further innovation, we see plenty of opportunities for the continuing growth of information and communications technologies and the possibilities of genuine breakthroughs into new areas of biotech R&D. There will be no shortage of commercial opportunities driven by new R&D.

Will Investors Have Flexible Options for Allaying Risk?

The changes in the investment market that took place in the 1990s are permanent. The key to opening the market to help fund innovation was the rise of venture capital. Venture capitalists were able to move investment funds into small high-tech start-ups and break the barriers that had channeled innovation into just two major places—large firms and universities.

The venture capital market existed for more than 50 years, and accounted for many early successes—Hewlett-Packard, Varian, and Fairchild Semiconductor are a few notable examples. But it wasn't until the information revolution of the 1990s that the size and scale of the venture market took off. The venture market invested roughly $1 billion in 1980, about $2 billion in 1990, and close to $65 billion in 2000.

Not only did the size of the venture market change, but its shape and structure changed as well. Funds flowed in from a much wider range of sources—wealthy individuals, large companies, investment banks, pension plans, mutual funds, universities, and foreign governments among them. Investment options have broadened. Venture capital can now be directed in many ways in support of many different types of organizations, including the high-risk initial funding of an idea, large-scale development funding, and funding designed to build particular markets. Other options include investments in geographically based funds, specific industries, and specific products.

The channels for smaller venture-funded companies to receive the deeper funding long available to larger firms expanded as well. The amount of funds raised by taking a small company public by means of an IPO jumped over the course of the decade from $4 billion in 1990 to $66 billion in 2000. In addition, many venture-sponsored firms were bought out directly by large firms that integrated the start-ups' products into their own lines. Cisco, Nortel Networks, and 3Com all bought dozens of young start-ups in the last decade. In fact, only a very small minority of start-up firms like Amazon or eBay have been able to go it alone and succeed in building a grand enterprise from their start-up origins. Ironically, such companies often did so by acting like the big players and buying or partnering with a host of other firms.

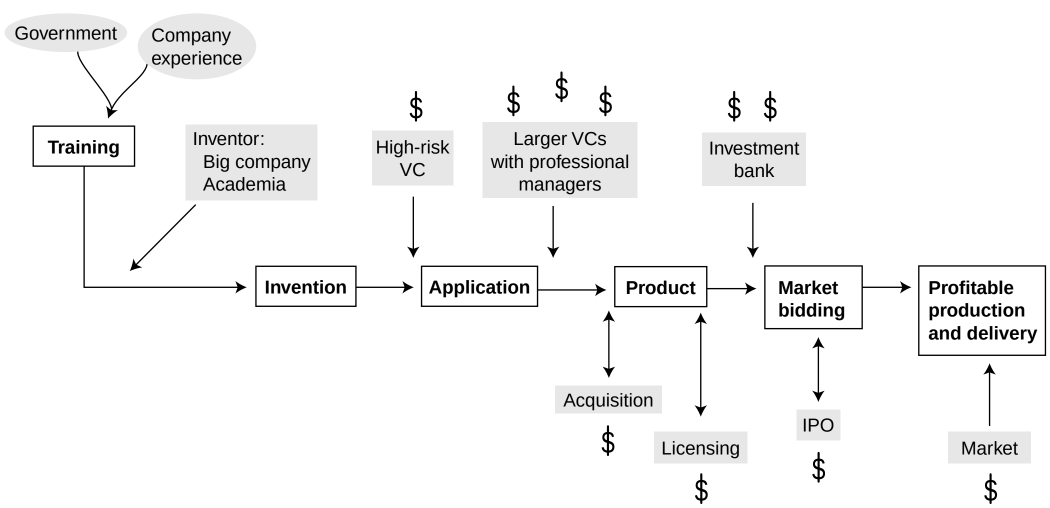
These alternative routes to funding allow the venture start-up to realize the value of its innovations relatively quickly, by getting enough funds to move from idea to product, and then to prepare it for market. One result has been a shorter product life cycle from innovation to market shelf. Another has been a shorter funding cycle—today, certain types of high-risk funds are needed for shorter periods of time, thus creating natural points where those funds can be rewarded, cashed out, and reinvested (see Figure 7–1).

The new mechanisms for financing high-risk investment have opened the market in two ways. First, they have created a much larger pool of funds to support the R&D of venture-supported firms inventing the next wave of innovative products. Second, they have developed an easy way for millions of individuals to invest in the high-risk sector, by means of institutions such as pension plans and mutual funds. These two institutional changes have enabled investors in the United States to make high-risk investments in innovations that can be potentially rewarding as part of a well-balanced portfolio. The increasing number of these investment options will ensure a permanent flow of funds into high-risk, innovative R&D.

Does the Intellectual Property System Work?

The United States has developed a system that provides very strong protection for the inventors and authors of intellectual property, as well as incentives and institutional mechanisms that foster the rapid diffusion of innovation. Because the protection of intellectual property is embodied in the U.S. Constitution, few challenges to intellectual property rights arise in the United States.

Figure 7–1
Risk and Reward in the Innovation Business



Source: Institute for the Future

Working in tandem with the strong intellectual property protections, sectors of the U.S. economy have shown great facility in spreading innovative ideas quickly. The high-tech sector is especially adept at these efforts. Ideas that have commercial opportunities and that are protected by patents can usually find an active market. Whether by takeover, merger, license, or outright purchase, ideas tend to get a market price quickly and find eager buyers.

In general, the greater the capital invested, the higher is the pressure for innovative firms to facilitate a quick dispersion of ideas. What makes these markets so successful in the United States is a collection of players that can make the transfer smoothly and efficiently. These players include investment banks that can quickly put a value on intellectual property assets, the Securities and Exchange Commission with its rules forcing public companies to disclose the licenses they hold and their relative value, and lawyers who are experienced in valuing intellectual property and making deals that leverage that value (see Figure 7–2). All of these elements make the transfer of ideas to the marketplace smooth, especially in innovation clusters like Silicon Valley in California and the Research Triangle in North Carolina, where the networks of key players are well developed.

The combination of strong, formal intellectual property protections and the informal networks that have developed in the United States makes it easier for U.S. companies to leverage the fruits of R&D. This combination will be crucial for the continued growth of R&D in the United States in the next decade.

Who Will Reward Basic Research?

There is substantial evidence that basic research is being converted to commercial products much more quickly today. A recent study of patents in the United States finds that, while venture funds are equivalent to about 3% of total R&D spending, they have accounted for about 15% of industrial innovations, as measured by patent data. Another study points out that an increasing portion of patent citations are from academic sources, not other products or patents—further evidence that basic research is having a more direct impact on commercial-oriented patents than ever before.

As a result, companies are doing more of what they consider basic research—that is, research that does not have an immediate commercial application (but may contribute to one down the line). Research shows that more commercial applications—particularly in information technology and biotech—are derived from basic research, and not by combining existing patents or simply creating a new market application for existing products. Small entrepreneurial firms in the fast-evolving high-tech areas are prime examples of how basic research can be sponsored and funded in private industry, and how such research can be channeled into product markets much more rapidly than ever before.

Figure 7–2
Setting a Market Price Takes Many Experienced Players

Source: Institute for the Future

Basic research will continue to play a crucial—and growing—role in innovation. Many players in R&D are already enjoying the benefits of basic research—including academics who earn monetary rewards, small firms that get high-risk funding, and large corporations that buy ideas already tested in the marketplace. This type of market focus on basic research speeds up the evolution of innovations. Such widespread investment in basic research will keep the U.S. economy at the forefront of world innovation.

Putting It All Together: R&D Inspires Cooperation

Perhaps the most important reason the United States will continue to lead the world in R&D-inspired products is the cooperation among the different players required to take an idea to market. Such cooperation facilitates inventions and eases their rapid dissemination in the marketplace. Patents are citing more findings in basic science research—a reflection of the ability of the system to build more effective collaborative ventures between science and industry. As the 2001 *Economic Report of the President* says: “Patents applications increasingly cite scientific research, and not just existing patents; this suggests that basic science is becoming more important for technological change.”

The collaboration between academics, federal research labs, small entrepreneurial firms, and large research-intensive industries is stronger and more effective than ever before. For example, plans are in the works for a new research campus on the site of the NASA Ames Research Center in Mountain View, California. Ames is in talks with Lockheed Martin and three universities—Carnegie Mellon, San Jose State, and University of California Santa Cruz—to redevelop the aging aircraft research laboratory. If efforts are successful, Ames could become a major player in information technologies, astrobiology, and nanotechnology, and the corporate and academic partners would benefit from being located in a research-intensive environment in the heart of Silicon Valley.

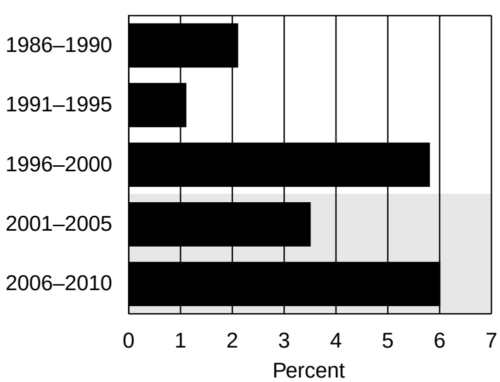
With initiatives like these in the works, the United States has taken a clear leadership role in building collaborative structures. The elements are clear—bringing together diverse parties that allow an idea to flow from the inventor to the final product.

R&D IN 2010

All of these indicators translate into a fundamentally positive outlook for U.S. R&D spending for the next decade. While a market correction to the speculative exuberance of the late 1990s is undoubtedly taking place, R&D is still attracting a steady stream of funds from well-heeled investors, large investment banks, and "everyday" investors through pension plans and mutual funds. Reflecting the slowdown in the economy in the early part of the 2000s, the rate of growth in real R&D spending will fall somewhat during the next few years. But in the longer term, R&D spending will continue to grow faster than GDP (see Figure 7–3). By 2010, R&D as a share of GDP will rise above 3% for the first time ever in the United States.

Our forecast for R&D spending overall is based on the trends we have already identified as important indicators of the robust R&D sector—private sector R&D spending, the role of basic research, the growing importance of small firms, and the increasing share of R&D performed by nonmanufacturing firms.

Figure 7–3
R&D Will Continue to Grow Faster than GDP
(Annual average percent change, in constant dollars)



Source: Institute for the Future; National Science Foundation.

Private Sector R&D: Forecast

At the moment, the private sector is drawing increasing benefits from innovations in small entrepreneurial high-tech firms, which is attracting additional funds into the R&D efforts of these companies. Look for the private sector's share of R&D to grow from two-thirds today to around three-quarters in 2010 (see Table 7–1).

Basic Research: Forecast

As ideas move from invention to product to market, the market is becoming more sophisticated in valuing basic research. Look for basic research to continue to grow at a healthy clip, slightly above the rate of growth for overall R&D (see Figure 7–4). At the same time, more basic research will be done in settings where investors will push for quick development.

Small Company R&D: Forecast

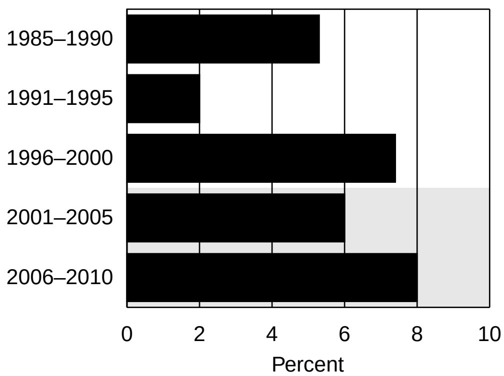
One of the notable shifts in recent years has been the growing influence of very small firms as R&D players. The way the venture capital market helps sort out and move new ideas quickly through small entrepreneurial firms ensures that small firms will only become more important. As a result, look for the share of spending in small firms to continue to grow rapidly (see Table 7–2).

Table 7–1
Private Sector R&D Continues to Grow
(Percent of total R&D expenditures)

	Federal	*Industry*	*Other*
1980	48	49	4
1990	41	55	4
2000	27	68	5
2005	23	72	5
2010	19	75	6

Source: Institute for the Future; National Science Foundation.

Figure 7–4
Basic Research to Grow at a Healthy Clip
(Average annual growth rate, in constant dollars)



Source: Institute for the Future; National Science Foundation.

Table 7–2
Very Small Companies Will Be Increasingly Prominent in R&D
(Percent of R&D spending, by number of employees)

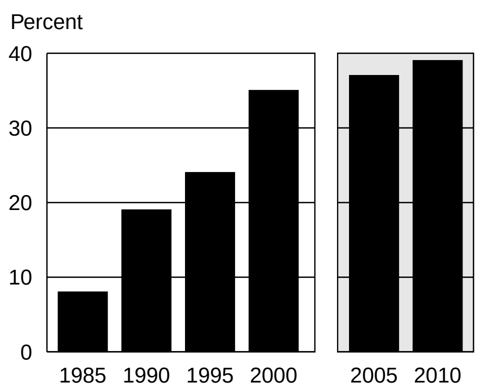
	2000	*2010*
< 100	11	18
100–999	13	15
1,000–9,999	24	23
10,000–24,999	15	14
25,000+	37	30

Source: Institute for the Future; National Science Foundation, *Research and Development in Industry,* 1999 (early release).

Nonmanufacturing R&D: Forecast

Finally, the amount of R&D being done outside manufacturing firms will continue to grow (see Figure 7–5). This growth reflects the importance of the software industry in developing commercial applications, and the fact that software is not treated as a manufactured product but as a service. In addition, this trend captures the rise of small entrepreneurial firms that specialize in forming and developing a product innovation, and that ultimately want to patent and sell such an idea rather than engage in the production and distribution of that product. It captures that firms in the trade sector will be spending more time and money on developing consumer and supply chain applications that involve R&D. Finally, it acknowledges the emergence of R&D firms that will conduct a variety of research for larger firms and sell them the findings and the results.

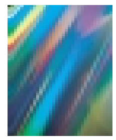
Figure 7–5
Nonmanufacturing R&D Will Expand in the Future
(R&D expenditures by nonmanufacturers as a percent of all industry R&D spending)



Source: Institute for the Future; National Science Foundation, *Research and Development in Industry,* 1998.

Chapter 8

The Great Transformation of R&D



In the past five years, there have been important structural shifts in who funds and conducts R&D. With an increase in the number of participants, the market has spread the risk among a much larger group, and as a result, more money has been generated for conducting R&D. This shift was due, on the one hand, to the public's growing interest in the market opportunities engendered by the information revolution, and, on the other hand, to the opening of new channels for funneling money into R&D-based firms, through investment banks, pension and insurance plans, and mutual funds. Although this maturing institutional support for R&D—built on venture capital, the growing popularity of IPOs, and the public's attraction to high-tech share markets like the Nasdaq—will undergo wide swings of the business cycle, it will continue to provide a growing portion of R&D funding in the years ahead.

But spreading risk in these ways creates a new dilemma for the future. R&D funding increased partially because small entrepreneurial firms offered a means of channeling money directly into R&D and then receiving clear and quick benefits from successful market innovations. But the enormous financial success of some R&D-based firms, and the rapid payouts to those who invested early, meant a sharp rise in the interest of everyone, especially the inventors themselves, in participating in the gains attributed to intellectual property. More inventors took out patents for themselves, and more of the participants in the funding and innovation chain bought into the patent rights as well.

With a greater number of inventors and investors, and more R&D taking place in decentralized locations, the dissemination of ideas is becoming more complicated. For many future innovations, more people will have a say at each stage of the process as to which ideas will be used, and when. The old method of R&D often meant that a single large research-intensive corporation could generate an idea for innovation in-house or combine its own research with ideas gathered from the publicly available academic or government-funded literature. The company would then spend large sums developing those ideas into products and paying for the testing, marketing, and distribution of those products—products it controlled the rights to. When everything worked out, the company got to keep the profits to itself as well.

In the new world of R&D, we will see a much more complicated process whereby ideas for product innovation are gathered from many sources. Each of these sources must be partners in the process or provide licenses to those who are partners. This wider distribution of idea ownership—and thus of profits from ideas that successfully make it to market—makes it more difficult for a single large corporation to justify spending the huge sums required for testing, developing, and marketing a product. Paradoxically, while there are more ideas available, there may be fewer companies willing to gamble on long-term market success. This added complexity in distribution is the cost of moving more innovative ideas into the development stage more quickly.

Business Implications

What do the transformations taking place in R&D mean for businesses in the next ten years? We close this report by highlighting the key points of the transformation itself, as well as those of its drivers.

The Transformation

- R&D spending will continue to grow in the coming decade, as will the importance of R&D to the global economy. These investments will bring many innovations into the marketplace, and many of these innovations will come from sources other than the usual "big R&D" players (i.e., universities, government-supported labs, and huge, research-intensive corporations). Small entrepreneurial start-ups will conduct more and more of the important R&D. Companies that want to remain competitive in a changing marketplace must be ready to take advantage of the opportunities presented by these newer, smaller players.
- Companies must keep a constant lookout for intellectual property—they must protect what they have and keep alert for other ideas they can leverage now and in the future. They should learn to make the strict regulations protecting intellectual property work for them—by making acquisitions, purchasing licenses, and forming new types of partnerships based on intellectual property.
- Because purchasing other firms will be a critical R&D strategy, it will be important for companies to develop effective metrics for valuing the intellectual property of those companies. Effective metrics will give them the ability to strike while the iron is hot; that is, to know the value of an idea before others discover it as well and push up the price.
- Mergers will also be an important element of R&D strategy. Businesses must have appropriate management and organizational structures to quickly and effectively incorporate new firms into their operations and leverage their innovations.

- R&D is a long-term investment. In a world where innovative ideas are of increasing importance, companies need to think for the long term and figure out ways to spread their R&D risks over a variety of ventures, sometimes with a variety of parties.

Public Support

- The public rewards innovative companies by trying new products, and by investing in public shares, either directly or through mutual funds, pension plans, or both. The increase in public investing has put a premium on share values, though the market has been undergoing a correction for the last year or so. Companies (and the public) shouldn't worry so much if not all new products stay in the marketplace very long or if share values fluctuate—that's part of the new game.
- Companies making a strong R&D play ought to beware of the possibility of public backlash. New technologies and products can upset the public—consider the current outcry against genetically modified foods in Europe, for example, or the growing worry over large-scale, efficient farming that sometimes leads to the spread of virulent diseases. Other likely sources for negative public reaction will be products and services perceived as harming the environment and invading personal privacy.

Intellectual Property

- Companies should think about how they can best take advantage of licensing the fruits of their own R&D as sources of income. This is just one of several options for controlling and leveraging intellectual property—a key aspect of any R&D strategy.
- If companies don't develop their own intellectual property, they have several ways of building a strong base of intellectual capital through the market, including mergers, partnerships, and licensing.

- As companies become more adept at evaluating innovation in the coming years, they will find it easier to create new products by combining a number of outside ideas or products with their own. For example, a company could expand its offerings by licensing a hardware product, an operating system, and several software applications to provide better customer service for people with wireless phones. This new product may depend on up to four or five licenses, in addition to internally developed new ideas.
- Businesses must build a strong network of facilitators to help them manage their intellectual property. These can be internal or external resources, or some combination of the two. Lawyers, accountants, and investment bankers experienced with handling intellectual property are perhaps the most important source of market savvy and facilitation expertise.

Investments

- Now that the venture capital market has come of age, companies should consider several options for high-risk R&D projects they can fund themselves, invest in with innovative partners, or jointly invest in with a portfolio of outside efforts.
- Companies that depend exclusively on their own stock to fund pension or employee incentive programs should think about expanding their investments to include at least some outside, riskier investments in innovative companies.
- While a huge share of start-up investment in the last few years has been channeled into the Internet, innovations will be coming from a much wider spectrum of industries in the future. More investments will be made in, and more developments will come from, the bioscience, energy, retail, and service sectors, for example, as well as non-Internet–related information technologies such as sensors and microtechnologies like MEMs.

Small Companies

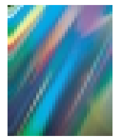
- Small companies will conduct more of the R&D in the future. Big traditional companies must be aware of the flexibility and focus of small innovative players in experimenting with, developing, and bringing products to market readiness. They should let these small companies do what they do best, but realize that the earlier the investment in the innovator, the bigger the reward.
- As small players become more important, larger firms should look for ways to work with them—usually by partnering with the smaller firms or by purchasing them outright.
- Service and retail firms are especially well positioned to take advantage of the R&D outputs of others, by adopting software and process applications rapidly, for example, to meet the needs of the eager consumer looking for better service.

International Scene

- Overall, the United States leads the world in most strategic measures related to R&D, including investing in education, spending on R&D, and achieving return on investment. While the unique characteristics of the flexible and experimental market in the United States can't be easily duplicated, companies in other countries can still learn from the Americans. Companies around the world ought to focus on taking advantage of intellectual property by building support networks for their R&D efforts and spreading the cost (and rewards) of risk over a much wider investing public.
- In this respect, everyone ought to keep an eye on Japan. Japan spends more on R&D as a percentage of GDP than any other country. While Japan has been in an economic slump for several years, all that R&D spending may be sowing the seeds for a burst of innovation in the next decade.
- There are also clear signs that an increasing portion of R&D will be conducted in innovating centers (or clusters) outside of the United States.

Appendix

RESOURCES ON THE TOPIC OF R&D



Dreyfuss, Rochelle C. Collaborative research: Conflicts on authorship, ownership, and accountability. *Vanderbilt Law Review* 2000; 53,4:1161–1232.

European Commission. *Towards a European Research Area: Science, technology, and innovation. Key figures 2000*. Brussels: European Commission, 2000.

Heller, Michael A., and Eisenberg, Rebecca S. Can patents deter innovation? The anticommons in biomedical research. *Science* 1998; 280:698–701.

Kortum, Samuel, and Lerner, Josh. Does venture capital spur innovation? Division of Research Working Papers, Harvard Business School, 1999. www.hbs.edu/dor/papers2/9899/99078.pdf.

Lerner, Josh. 150 years of patent protection. Division of Research Working Papers, Harvard Business School, 1999. www.hbs.edu/dor/papers2/9900/00-39.pdf.

Merges, Robert P. Intellectual property rights and the new institutional economics. *Vanderbilt Law Review* 2000; 53,6:1727–2254.

National Science Board. *Science and engineering indicators.* Vols. 1 and 2. Washington, DC: National Science Foundation, 2000.

Economic report of the president. Washington, DC: U.S. Government Printing Office, 2001.