Prometheus, Vol. 20, No. 1, 2002

Are We Eating our Seed Corn?: Basic Research in the US Corporate Sector[1]

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ABSTRACT *Since the mid-1980s, industrial research in the United States has gone through major organizational changes. Funding for centralized corporate research laboratories in the high technology industry, which leads in research, has shifted from corporate sources to business divisions. Research has been either transferred into individual business units or organized along product lines for well-known markets. As a result, support has shifted to low-risk, mission-oriented, and short-term research, and an extensive involvement of business elements in research activities. Basic research projects seem to be completely gone from centralized corporate research laboratories. In the long run, the shift away from the untargeted inquiry can be problematic to the company, as well as to the country.*

Keywords: autonomy, basic research, business-driven research, outsourcing research, restructuring of centralized corporate R&D laboratories.

Introduction

There is a general belief among economists, business leaders, and government that invention and technical changes are the major driving forces of economic growth. Karl Marx stressed this fact over a century ago and Joseph Schumpeter emphasized it in the middle of the twentieth century. Robert Solow,[2] a Nobel Laureate, established that the increase in output per capita is due primarily to technological change. In the last 100 years, many technological changes have been a product of deliberate economic investment activity, that is, research and development (R&D).[3] R&D activities serve as an incubator for new ideas that can lead to new products, processes, and industries. How R&D funds are spent, by which organizations, and in what areas of science and technology determine how technological changes will manifest.

In the United States, industry is the largest performer of R&D, conducting 75% of the total R&D. Industry is also the nation's largest source of total R&D funds, providing 65% of the total national R&D efforts. Industry employs more than 70% of the nation's scientists and engineers with bachelor's degrees, 60% of those hold master's degrees, and 28% of those hold doctorate degrees.[4]

Prometheus ISSN 0810-9028 print/ISSN 1470-1030 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/08109020110110277

Historically, the United States' technological leadership and main source of innovation have come from research conducted by centralized corporate R&D laboratories. These laboratories were created at the beginning of the twentieth century to provide an internal mechanism for a company's growth and for technological changes.[5] Most companies have functional R&D laboratories that are associated with business divisions to improve current products or processes. In contrast, centralized corporate R&D laboratories aimed at developing new product lines and process technology beyond the scope of present business. They were built away from manufacturing plants to isolate research from business concerns. Centralized corporate R&D laboratories' primary mission was demonstrating in-house creativity in scientific research. They were organized along the lines of scientific disciplines and managed by scientists and engineers who chose a managerial path. These managers attracted top academic researchers and created a university-like environment. Scientists were viewed as experts in knowing what research activities to undertake, and were provided with a large degree of autonomy in selecting their research priorities, directions, and programs. They carried out fundamental, long-term research without much concern about the cost or application. Corporate managers viewed research as an intrinsically valuable investment and provided unlimited funding for it.[6]

However, the challenge to US global dominance in the 1980s, both economically and technologically, caused US industries to cut costs and take a shorter-term approach for the centralized corporate research. As Lewis S. Edelheit,[7] senior vice president for General Electric's Corporate R&D Center, noted: 'All companies today face a complex, changing, competitive world in which products and services must balance cost, speed, quality, and performance'.

Some centralized corporate R&D laboratories have either transferred research into operating divisions (e.g. Eastman Kodak), or completely eliminated corporate support for central research (e.g. Allied Signal, Armstrong World Industries and W.R. Grace). Most centralized corporate R&D laboratories have gone through reorganization to link research capability with the business intent of the company. They have restructured their operations to accelerate customer needs and maximize return on investment in research. They are teaming up with business divisions, customers, suppliers, universities, and other industrial laboratories for shorter-term research for existing markets, focusing on low cost, desired product quality and speedy innovation. As Mark Myers, a senior vice president of Corporate Research and Technology at Xerox, and Richard Rosebloom, a professor at Harvard Business School,[8] declared: 'research must see its role in the context of the whole corporation—its markets, its customers' needs, and its core competencies'.

This new generation of R&D has been called 'strategic' or 'linkage model', with an emphasis on the partnership between R&D and business. Earlier R&D was said to be 'intuitive' or 'autonomous', with little strategic framework or connection to business.[9] The shift from untargeted to mission-oriented research that focuses on customer needs is viewed favorably, since American high technology industry has regained much of the world market share lost during the 1980s.[10] By the mid-1990s, the US industry had enhanced its position in several critical technologies in the global market.

In this article, I discuss the issues involved with the decline of what has been called 'pure', 'exploratory', 'fundamental', 'basic', 'curiosity-driven', 'unfettered', 'untargeted', 'blue sky' or 'long-term' research in centralized corporate R&D

laboratories in the high technology industry. Investigation into this decline indicates that this trend is likely to continue much further. Without investing money into research in leading-edge technologies, the United States might risk its global competitiveness in the long run. However, I find that centralized corporate R&D laboratories cannot meet the new challenge with increasing global competition and shorter product cycle by solely relying on old historical patterns. Instead research in these laboratories should be guided by a vision of technology.

The article is based on a 1997 study conducted with 72 scientists and 18 managers in six corporate R&D laboratories in the following high technology industries: computers–office machinery, electronics–communications, and chemicals–pharmaceuticals. Yet, the article integrates empirical findings with the literature to support the perceptions of scientists and managers.

Selection criteria for corporate R&D laboratories was based on total R&D funds as a percentage of net sales and the number of R&D scientists per 1,000 employees. R&D in these industries is concentrated in a relatively small number of companies, and most have experienced some form of restructuring. These industries are more-closely associated with innovation, success in global markets, and spillover effects than other manufacturing industries. I selected approximately 12 scientists and three managers from each laboratory who had been in the company for at least five years before reorganization began. I conducted taped interviews regarding the following issues: recent changes in the laboratory; the criteria being used to generate and evaluate research; the link between research and business; the new partnership between scientists and business managers; communication patterns between research laboratory and business; availability of research funds from business divisions; types of research being carried out; termination of research projects; changes in management philosophy; and the working relationship between scientists and managers.

Withering of Untargeted Research

From 1979 to 1984, US industrial R&D expenditures increased annually at an average of 7.4%, but between 1985 and 1995, R&D expenditures slowed down, in inflation-adjusted dollars. During 1984–89, the growth rate of expenditures was reduced to 3.0% per year, and by 1989, constant dollar expenditures actually declined to 1.3%. However, this downward trend reversed in the mid-1990s, when American industry increased spending on R&D to a greater level than ever before, even when the amounts are adjusted for inflation. From 1994 to 1998, industrial support for R&D grew at a real annual rate of 8.9%, compared with a 3.4% growth rate for the economy overall.[11] It is mostly due to more intense global competition, record high corporate profits for an extended period, and enhanced cash flows.[12] Most importantly, there has been a dramatic increase in R&D activities by companies in the non-manufacturing sector. This sector increased its share of R&D performance from less than 5% of total industrial R&D in 1983 to over 24% in 1997.[13] In the 1990s, computer software and biotechnology companies such as Microsoft, Sun Microsystems, Amgen, Seagate Technology, and Genentech became increasingly prominent R&D performers. Consequently, R&D expenditures have remained up and are likely to remain so in the near future.

It should be noted that other Group-of-Seven (G-7) countries—Canada, France, Germany, Italy, Japan, and the United Kingdom—have experienced similar aggregate R&D trends. These countries account for 85% of the R&D expenditures of the 28 Organization for Economic Co-operation and Development (OECD) countries.[14] The US accounts for almost 45% of the OECD countries combined R&D investments and spends as much by itself as the rest of the G-7 countries combined. Each of the G-7 countries experienced substantial inflation-adjusted R&D growth in the early 1980s, leveling-off or declining real R&D expenditures in the late 1980s and early 1990s, and a turnaround in R&D spending in the mid-1990s. However, Japan is the only country which has experienced a resurgence in R&D spending like the United States.[15]

An increase in the US industrial R&D expenditures is necessary to remain globally competitive, but alone is not sufficient cause for celebration; because despite the increase, most R&D dollars are spent on 'D' rather than on 'R'—potentially undermining long-term commercial success and national competitiveness. For example, development spending accounts for almost 75% of industry's performance, whereas basic research accounts for a falling 5%. To illustrate, in 1998 industry spent $9.625 billion on basic research, $32.701 billion on applied research, and $104.380 billion on development.[16] This is in contrast to the early 1990s when US industry funded 61% of development and 18% of basic research.[17] It should be noted that US basic research spending is less than some G-7 countries such as Germany, France, and Italy, but somewhat higher than Japan.

Although basic research has not been a large part of the total industrial R&D budget in the past, it has been the most visible research. The justification for basic research in Charles Stine's, the head of research at DuPont in 1926, words was: 'pure science or fundamental research work . . . is undertaken with the objective of establishing or discovering new scientific facts'.[18] By supporting costly basic research, centralized corporate R&D laboratories have made many key breakthroughs such as cellular technology, central electricity generation, incandescent electric lamps, nylon, personal computer, plastics, radio, satellite, transistor, and X rays. In 1932, the first Nobel Prize was awarded to an industrial researcher, Irving Langmuir, for his pioneering work at General Electric Corporate R&D Laboratory. Since then centralized corporate R&D laboratories have produced many Nobel Laureates. It is, therefore, no surprise that they have attracted policy maker and public support as the pioneering research organizations.

Now most research in centralized corporate R&D laboratories has become mission-oriented toward development. Instead of supporting research that would lead to new scientific discoveries to be capitalized by the sponsoring company, scientists are engaged in solving specific problems for business divisions. Even the chemical industry, which is often called first science-based, has cut back on 'risky' research.[19] If support for long-term strategic research exists, it is goal-oriented rather than curiosity driven. US industry has taken such a path mostly because of escalating international competition and shortening product life cycles. An increase in R&D expenditures toward the production of products, processes, and services, however, has occurred at the expense of basic research.

Industrial support for basic research remains important to generate knowledge about what companies do *not* know. It is basic research in that one cannot predict the definite outcome. In order to improve existing products and processes, industry requires a broad knowledge base. Untargeted research provides the fundamental concepts and theories for missing pieces of information. Corporate support for research guarantees a deep reservoir of knowledge and provides choices for addressing future needs of the industry. Most advances are products of years of intensive research that contribute a little bit toward the answer to a general problem. A company is unlikely to gain a competitive advantage if it does not carry out its own research or relies on others for it. Untargeted research is somewhat difficult to turn into profits in the short run, but it is an investment for future industrial growth. Support for such research creates value for the company and ultimately for the marketplace. Scholars have shown that successful firms are those in which corporate strategies are shaped by technology opportunities.[20]

As one scientist remarked, 'Research should not be viewed as generating short-term profits. It is not the purpose of research . . . Research is similar to education. We spend a very long time in education because it offers a bright future . . . Similarly, research offers unimaginable payoffs in five to ten years. [Company] needs to have patience to appreciate research'. Another scientist said, 'If we do not support basic research, we will reduce the chance for something interesting to emerge'. One manager added, 'By shifting research monies to development, we are limiting our chances to fundamental breakthroughs. That is the bottom line'. Another manager noted, 'Unfortunately, the Wall Street gives little reward to basic research. Stocks don't go up; they go down if we do not bring out the products soon'.

Seeking Decentralized Configuration for Research

Traditionally, centralized corporate R&D laboratories were funded directly by corporate sources to ensure long-term growth of the company. It was believed that unconditional financial support to scientists working in areas of general relevance would inevitably result in new acquisitions in technology-based businesses. Centralization offered synergistic interactions between researchers of different disciplines and cost-effective access to expensive cutting edge equipment such as supercomputers. Further, centralization facilitated building of broad science platforms from cross-cutting science fields to impact multiple technology sectors.[21] However, centralization also led to a support for those projects that were not vitally connected to the company's business needs.[22] As a result, the way research is supported within a company has changed significantly.

First, centralized corporate R&D laboratories are decentralizing R&D funding and control. The balance of laboratory funding has shifted from corporate sources to business divisions of the company, which are more closely determined by customer–contractor relationships. Most research funds are currently generated and dictated according to contracts arranged in a company's business divisions.[23] The funding structure has changed from less than one-third being contracted by business divisions to more than one-half. A survey of leading firms found that central corporate funding accounted for about 50% of central laboratories' budgets in 1988, but had fallen to about 40% in 1993; the percentage of corporate funding in the budgets of business unit laboratories decreased from almost 40% to less than 10% during the same period.[24] Corporate R&D laboratories in the computers/office machinery and electronics/communications industries have experienced greater decentralization than those in chemicals/pharmaceuticals. This difference is primarily due to the fact that drug-related research tends to be long term, thus demanding funding stability.

Second, there has been a tremendous growth in industry contracting out research to other companies, universities, and not-for-profit organizations. Companies increasingly are looking outside their centralized corporate R&D laboratories for meeting research needs. For example, in 1995, industry spent more than $5 billion on R&D conducted outside their company, or 4.7% of total industry funds. In the mid-1980s, R&D spending outside the company was under 2% of the industry total.[25]

Though decentralization of the funding offers a direct link between invention and commercial applications, and outsourcing brings flexibility and lower costs, both substantially limit opportunities for significant advances for future prosperity. In a decentralized funding system, R&D expenditures become a cost, and research a risky investment for company growth. Such a funding structure is biased toward mission-oriented, short-term research and has incremental improvement bias. Further, skills and facilities are duplicated as different business divisions fund similar technological improvements in their desire to be technologically self-sufficient.[26] Outsourcing research results in the loss of in-house scientific expertise, technical leadership, and control over technology, as well as knowledge.[27]

As one manager said, 'We have moved away from research being the source of cutting edge technologies to a source of funds for the business needs'. Another manager reflected, 'It is unfortunate that research has become dependent on contracts from business divisions'. Another manager noted, 'Unfortunately, we will see more research done under outside contracts'. One scientist reported, 'Business is deciding the direction of research by controlling funds. It is the worse thing that can happen to a corporate lab'. Another scientist noted, 'Business does not appreciate research. They have reduced funds for research. They only fund those projects which provide immediate payoffs'. Another scientist said, 'This constricting financial climate is not conducive for quality research'.

Increasing Business Elements in Research

The traditional model of research was science-driven, that is, first performing basic research to generate new facts and theories, then performing applied research to test the new findings, and finally developing research results into products and processes.[28] One of the main justifications for science-driven research was that scientific discoveries could not be predicted. Scientists basically selected a field of interest in which to probe and increase scientific understanding. Once they were able to interpret potential technical and/or business implications, scientists and R&D managers solicited business support to apply research to commercial products or processes.[29]

The current model of research is based on the belief that the research process should be customer-driven, not science or technology-driven. As Stanley Jaskolski,[30] vice president of technical management for Eaton Corporation, said: 'It's time for R&D to stretch into the role of a business partner for growth'. Similarly, Lewis Edelheit,[31] senior vice president for General Electric's Corporate R&D Center, declared: 'Being vital means that every technical contributor at the corporate level R&D center is working on a program essential to current business plans, or to strategic growth initiatives'. As a result, an increasing amount of research is done in collaboration with business divisions. The equation 'from research to business' has been reversed to 'from business to research.' Scientists must elicit ideas for research from customers as well as access funds for their research through business divisions. They are not only required to work on projects that are aligned with the company's products and processes, but they are also required to conduct research activities in accordance with standard business processes, such as cost of research, potential benefits from the investment, manufacturing feasibility, commercial possibilities, competitive analysis, and a distribution plan. In this new research model, 'successful' scientists bring research resources to business divisions. Similarly, R&D managers build working relationships with customers, vendors, and business managers. They are involved in the strategies with business divisions so research can be utilized for development at low cost and high speed.

This business-driven research has helped American companies to restore their competitiveness in the global market. Consequently, there is little incentive for American companies to pursue science-based research, which only worked successfully when there was little international competition. However, the fusion of business and research tends to shift the scientists' focus from discovering matter with enormous commercial, cultural or humanitarian potential, to finding details about funding sources; identifying the needs of those who are funding the research; learning the language of business; building working relationships with several customers; and dealing with outside managers in addition to R&D managers. The involvement of business interests from the very start means research is conducted only when the interests of various business groups, such as personnel in business divisions and marketing operations, are met. Business people measure success with financial gain and cost effectiveness rather than technology to be produced. Most importantly, business divisions fund those projects, which address their immediate needs. They expect a return on their investment in a short time, and do not consider the long-range needs of their business.

As one scientist forecasted, 'This new marriage between research and business is bound to fail. It is only a matter of time . . . Research can not be prioritized around cost, benefit and market. This is not the purpose of research. This is not the way to do research'. Another scientist said, 'The business of business is to make profit. This is what keeps them moving . . . Now they are evaluating us, our work, with the same ideal. Did we produce revenue for them or not?' Scientists made several disparaging remarks, such as: 'overly dominated by business'; '[business managers] don't understand research'; 'the technical sophistication [of business managers] is lacking'; and 'multi-layered review process with the new organization'. One R&D manager acknowledged, 'Folks in business divisions don't get excited by research or technology . . . They measure success by finance'.

Desiring to Outsource Research

Industry began investing in R&D as functional activities within the corporation in the early twentieth century, primarily because science-based products were becoming rather sophisticated and the possibility existed of losing markets to competitors with more advanced technologies. By funding centralized corporate laboratories, companies protected themselves from vulnerability caused by external technological change.[32] Industry, through centralized corporate laboratories, maintained independence in research from other companies, colleges and universities, and research centers. To use Chandler's metaphor, the visible hand of scientific research replaced the invisible hand of the problems of external technological change.[33]

As companies curtail in-house research, they increasingly rely on others for it. To leverage resources, reduce costs, and minimize risks, companies collaborate with other companies without joint equity investments as well as contract out to foreign companies or US-owned foreign subsidiaries. The frequency of international, multi-firm R&D alliances has increased from 175 in 1977 to more than 9,000 by 1998.[34] Most of these alliances involved US firms, and most were created to foster R&D partnerships in just a few high technology areas, notably information technology and biotechnology. For example, IBM forged 50 strategic partnerships with various business software specialists just in the last year.[35] Similarly, to capitalize the latest thinking regarding the fundamental aspects of science, US companies are forming new university–industry research relationships.[36] For instance, industry's share of academic research funds increased from less than 3% in 1970 to about 4% in 1980, to more than 7% in 1998.[37] It is estimated that 63% of industry's external R&D funds go to other companies, 22% to universities, 11% to other organizations including foreign laboratories, and 4% to federal laboratories.[38] From 1985 to 1996, US firms' investment in overseas R&D increased almost three times faster than company-funded R&D performed domestically (9.7% versus 3.4% average annual constant-dollar growth). By 1997, US firms had established at least 186 R&D facilities in other countries.[39]

Industry's desire to outsource research is accelerated by the lower costs, shorter product cycles, faster development cycle time, and existence of many willing suppliers of R&D. However, outsourcing is more likely to work in the development area than in the research area primarily due to the uncertainty associated with research. Further, when outsourcing R&D, a company is likely to lose control over science and technology research, and diminish in-house expertise.[40] In addition, the American public may begin questioning the continuing leadership of American industry in the global market. The place where research results are generated has an initial advantage in exploiting such advances for technical innovations.

As one scientist remarked, 'The bottom line is that R&D abroad is displacing our own R&D. The sad thing is that we won't see the impact at least for a decade'. Another scientist agreed, 'Collaborations between the [company] center and other labs have increased tremendously . . . There was a time all of us were excited about it. Now, the initial excitement is gone . . . The bottom line is that we are lacking badly needed expertise. [Company] must realize this'. One manager said, 'It is understood that if we do not provide the needed expertise, the company will go elsewhere . . . In fact, the company has a right to give contracts to others instead of giving them to us'. Another manager acknowledged, 'Some of our best people have moved to [those places] which are moving back to support in-house basic research'.

Declining Autonomy of Scientists

Traditionally, centralized corporate R&D laboratories created a university-like atmosphere to provide scientists with the freedom to select problems for investigation and the means to solve them.[41] It is mostly because of the belief that scientific progress results from the free play of free intellects, working on subjects of their own choice, in a manner dictated by their curiosity.[42] Scientists exercised varying degrees of autonomy on a routine, daily basis in the course of performing their research; managers mostly exercised indirect control.

As the theme of 'researcher as businessman' has become a key principle in creating a high-performance R&D group,[43] scientists have experienced some decline in their freedom. Corporate R&D laboratories in computers, office machinery, and electronics and communications are increasingly receiving contracts from corporate sponsors. Similarly, pharmaceutical companies are shifting from prescription drugs to over-the-counter business. As more weight is placed on innovation and commercialization than on technical or scientific merits, scientists generate projects that are closely aligned to the company's products and processes and for which funds are available from business divisions. Even when scientists work on less-defined projects, they must justify their projects to R&D as well as business managers by submitting research plans that designate a time line and specify how research results will be utilized in manufacturing. Moreover, scientists who do not find a sponsor end up working for scientists who are better supported. They are also driven to work on several different short-term projects to raise required funds.

Scientists and managers need to be involved in projects which are central to the success of their company. Nonetheless, every limitation on autonomy is likely to repress research initiative to some degree, take the joy out of research, reduce incentives to creative effort, and thus hinder the scientific progress.[44] Research is done best if scientists have the freedom to follow promising leads and are able to shift the direction of research. With too many constraints, there is less chance to bring interesting results. Moreover, scientists idealized to build their professional reputation by publishing papers in respected journals, presenting findings in prestigious conferences, and speaking in professional and public settings. They seldom idealize to work for bonuses and salaries or celebrate incremental improvements in commercial products. In addition, the quality of research is best valued if measured by peers on scientific or technical merits, and not by business people on non-technical factors such as commercialization, cost-effectiveness, efficiency, and profitability.

One manager reported, 'We have given a checklist to scientists to fill out each time [they propose] a project. The purpose of the checklist is to identify when research and business are partners and when they are not'. Another manager acknowledged, 'To be successful, scientists have to bring in an outside manager'. However, one scientist contended, 'I am not happy about switching my field of interest. My degree, specialization, training, and past experience do not appear relevant any more'. Another scientist questioned, 'What is going to happen to our reputation and career when we do not publish research results? [The company] has not thought about it'. Yet another scientist expressed disappointment, 'Under new organization, fundamental research has no future'. One scientist said, 'If business decides not to fund our research, we would have no other choice than to move to projects with more funds. . . . No one would like to be in such position. Only way to avoid is to work on those projects which have business backing'. Another scientist reported, 'We have to persuade operating divisions to support our research . . . Unfortunately, it is not easy to do'. And, as one manager acknowledged, 'It can be tough for some scientists who would like to decide research outside of business needs'.

What Can Be Done?

Since new inventions, once made, are likely to have an important impact on industry and society, it is important to support untargeted research. Industry appears to be dealing with technical problems only as they come up; instead of proceeding with a vision. The strategy of living off the advances made in the past or by other companies is unlikely to be successful in the long run. Even industrial leaders who demand immediate payback from research in their companies recognize the value of fundamental research.[45] There is a need for untargeted fundamental research in industry, but it must be recognized that the arguments for it are not as simple as they used to be.

The traditional model of research worked effectively until the 1970s, when American companies enjoyed economic and technological dominance in the world. That model facilitated industry's uncritical acceptance of the role of centralized corporate R&D laboratories. Now the United States operates in a global economy, which is highly competitive. There has been a shift from a situation in which high technology capabilities were uncommon to a situation where high technology capabilities are well distributed among many companies throughout the world. Presently, many G-7 countries, Japan, South Korea, and Taiwan successfully compete with the United States. Although American high technology industries have regained much of the world market share lost in the 1980s, they continue to face competitive pressures from several G-7 and Asian economies. In the existing competitive environment, it is difficult to support research if high returns on investment are not possible. If research in centralized corporate R&D laboratories functions outside the company's markets, customers' needs, and core competencies, the company is unlikely to succeed in highly competitive markets.

Research in new technology has become risky, not only in terms of achieving a technological advance but also in terms of acquiring the ability to market it first. Under the traditional model, many R&D projects have failed to produce an economic gain for the company that made the initial investment. Ideas and inventions, which came out of centralized corporate R&D laboratories, were not utilized for various reasons. The classic case is Xerox's Palo Alto Research Center, which invented many important technologies that shaped the information revolution; however, other companies developed the markets for those inventions.[46] When companies market technology invented by another company first, the company that supported the research seldom recovers its R&D costs.[47] In the case of computer research, the economic returns have been high for society, as well as for other companies (e.g. Canon, Hewlett Packard, Apple Computer, IBM, Adobe Systems, and Sun Microsystems)—but not for Xerox. Similarly, spillovers from technology, such as lower prices and new knowledge, bring many benefits to the economy as a whole, but not necessarily to the company that made the initial investment.

In the highly competitive market, R&D performance alone is not enough: increased competition requires high speed from centralized corporate R&D laboratory to the market place, lower costs, and higher quality. If research is not guided by a vision of technology that is well integrated with a company's strategic goals regarding the current and emerging realities of markets, the company will remain skeptical about expected gains from untargeted research. When Lucent Technologies decided to focus on research, and de-emphasize the development of a new generation of optical networking equipment known as OC-192 gear, their stock fell from $80 in 2000 to $11 in 2001. Now Lucent Technologies has announced the elimination of 10,000 jobs in an attempt to climb back to the top of the digital economy.[48]

Most importantly, steady growth in research has brought about significant internal changes in the R&D environment. For example, since World War II, the number and type of scientists employed in industry has grown tremendously. When centralized corporate R&D laboratories were established, a small group of scientists formed a loose coalition around a famous project leader; and the R&D director knew all of them individually.[49] Today, scientific research in centralized corporate R&D laboratories requires much more collaborative work from different disciplines. However, while the number of scientists engaging in research grew, the number of big fundamental discoveries did not. With increased competition, new scientific results do not stand out as much and the benefits of scientific superiority tend to be marginal. Instead of striking new results, incremental improvements are made. Further, the time between invention and a commercial product has shrunk dramatically in many areas.[50] With high returns from building products and processes, and low returns from research into basic knowledge, the latter tends to be de-emphasized. It is especially true since Japanese companies were able to compete successfully with the United States by adopting extremely goal-oriented research, taking an incremental improvement approach to technology, and dissolving the lines between R&D and manufacturing.[51] As a result, the prospects for a return to untargeted research in industry in the near future appear slim.

Perhaps American universities can maintain basic research, especially since they are the largest site of basic research and the second largest site of applied research. The academic sector accounts for about 50% of the national basic research expenditures and almost 15% of the total applied research.[52] However, they also face increasing pressure to change. When the United States lost its status as 'leading producer' of high technology products in the global economy in the 1980s, the needs of industry became paramount. Presently, government agencies support academic research that is geared to help industry. Industry is also involved in new university–industry research interactions, without any federal support.[53] With the increasing reliance on federal and industrial funding, academic scientists face pressure to engage in research that has value to society.[54] An analysis of more than 100,000 patent-to-science references conducted by CHI Research found that 73% of the references to scientific publications listed as 'prior art' on the front pages of US patents were authored at academic, governmental, and other public institutions.[55] In other words, industry has been making a good use of public science.

Government could increase its role as sponsor of basic research, especially since society benefits enormously from such scientific activities. As the chairman of the House Committee on Science, F. James Sensenbrenner,[56] noted: 'Federal R&D should focus on essential programs that are long-term, high-risk, non-commercial, cutting-edge, well-managed and have great potential for scientific discovery'. However, only 20% of 1998 Federal R&D budget is allocated for basic research. There is a need to increase Federal R&D of basic research because the benefits of such research are dispersed throughout the economy and the rate of return on research spending is high on a national scale.[57]

Federal funds to industry have fluctuated considerably. They fell from $34.6 billion in constant 1992 dollars in 1987 to $19.3 billion in 1994.[58] Since then, Federal support to industry has been relatively unchanged. In the light of market failures in a highly competitive environment, the government needs to consider cooperative research with industry. Public–private partnerships appear to be one of the valid policy instruments for basic research, competitive industry, and strong economy. The National Institute of Standards and Technology's Advanced Technology Program funds 'high-risk, generic' research projects in industry to support a more competitive, high technology economy. However, this program has been accused of being government supporting 'corporate welfare'.[59] Policy-makers need to reach a consensus by balancing public and private interests to secure US standing in the global marketplace.

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