

Industrial R&D in transition

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An American Institute of Physics study completed in 2008 documents the ways in which the corporate physicist's work has changed in the past 40 years. Here are its major findings.

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The halls of industry have always been peopled with physicists. For many years a bit more than a third of PhD physicists worked in industry, while almost half went into academic research and teaching. By the mid-1990s the numbers for new PhDs had reversed, with more than half going into industry and a little less than one-third going into academic institutions (see *PHYSICS TODAY*, April 2007, page 28). Notwithstanding the important relationship between physicists and industry, the kind of work that industrial physicists do and the way industrial R&D is organized have, until recently, been largely a matter of speculation. In 2003 the Center for History of Physics of the American Institute of Physics began a five-year study of the history of physicists in industry—the first systematic assessment of the work that physicists do in the corporate sector, how the organization and funding of industrial R&D have changed over the past several decades, and the extent to which the records of physicists in industry are being preserved for current and future researchers.¹

The study explores the extensive changes in the nature of the work that corporate physicists have experienced in careers that stretch over the past 40 years. Some of those changes, especially the development and use of computers, are ubiquitous in society as a whole, and computerization has both speeded up the work of corporate physicists and changed patterns of documentation. Other changes reflect the evolving business climate. A major force has been the volatility of corporate investment in R&D. Over the past 25 years, that investment has responded to market forces, new managers and management philosophies, and other factors. Another important issue is change in organizational structures and goals.

Principal findings include the following:

- ▶ Companies haven't achieved a consensus on how to conduct R&D and are struggling to find the best mix of longer-term research and short-term development. That is to say, they are trying to balance the need for a stream of innovative technologies with the ongoing need to report profits.
- ▶ The funding and organizational structures of corporate R&D have undergone radical changes since the 1980s. In particular, the traditional centralized R&D laboratory is an endangered species.
- ▶ Many companies rely on external sources—especially physicist entrepreneurs and physics startups—for innovative technology.
- ▶ No standards exist for preserving the records of corporate R&D. As a result, historically valuable records, including the

once ubiquitous laboratory notebook, are being lost.

In carrying out the study, we interviewed more than 130 people from 15 companies (see the box). At each locale, we interviewed a minimum of two R&D managers, at least one of whom was a senior executive, and three or more senior bench physicists. Nearly all interviewees had physics PhDs, and most had worked in industry for the majority of their careers. The median year for completing the physics doctorate was 1978. We also interviewed appropriate information professionals such as the head of the technical library, the person responsible for records management, and the archivist.

Balancing research and development

Interviewees at all the companies we visited said that during their careers they had observed an increasing emphasis on product development over research. However, managers at most of the companies also talked about the importance of balancing short-term work that directly benefits the company and longer exploratory research that might lead to “disruptive” breakthroughs that could change the nature of a technology. The corporations in our study use a variety of approaches in an effort to find a mix of R&D that they can sustain. In addition, interviewees frequently said that to give scope to creativity and the serendipitous aspects of invention, management allowed physicists and other scientists some personal time to pursue projects of their own choosing. Interviewees at four of the companies—3M Co, Agilent Technologies Inc, Corning Inc, and Eastman Kodak Co—mentioned that such relatively free exploration had been formalized as a 10% or 15% rule. Scientists were encouraged to use the allotted time on projects that were not reviewed or approved by the company but that might prove beneficial.

Overall, we found that corporate physicists seem to have a good deal of autonomy within company guidelines and can generally negotiate assignments. Long gone, however, are the reputed days of corporate funding of largely undirected research at centralized laboratories. After World War II, when many of the corporations we visited began to set up laboratories or restructured their existing research programs, a number of central laboratories were kept separate from the operating divisions of the corporations. Many were funded through a corporate “tax” on business divisions. Top R&D executives used the tax revenue to cover the expenses of their research centers and had the freedom to determine the labs' goals. By the 1980s, however, the utility of R&D—or at least research—increasingly came under attack as many leading companies faced growing competition



Figure 1. Charles Proteus Steinmetz, an industrial scientist and General Electric Co's chief consulting engineer, convinced the GE leadership to create the first industrial research laboratory in the US in 1900. (Courtesy of the AIP Emilio Segrè Visual Archives.)

and changing markets. Research, it seemed, did not provide an adequate return on investment. As a result, many labs began to struggle to develop a balance between maximum utilization of the creative talents of researchers and the economic interests of the company.

Three of the laboratories in the study—Bell Labs (part of Lucent Technologies at the time of our visit in 2003 and now part of Alcatel-Lucent); General Electric Co's central laboratory in Niskayuna, New York; and the IBM Thomas J. Watson Research Center—were described by interviewees as once being paradigms of “ivory tower” corporate research centers. Positions there had a prestige and autonomy similar to those of academic appointments but without the burden of a teaching load or academic politics. Beginning in the 1980s, all three labs saw changes that reflect some of the major directions of corporate research over the past couple of decades.

The nation's oldest central industrial lab was established at GE in 1900, at the urging of Charles Proteus Steinmetz (see figure 1 and the article by George Wise, *PHYSICS TODAY*, December 1984, page 52). Beginning in 1946 the company funded its research through an assessment levied on each GE business unit; the lab director and his staff thus obtained most of their budget with no strings attached. As a result, however, research typically was not oriented toward the needs of the operating divisions, and as often as not research output was irrelevant to the business units. One researcher who started at GE in the 1960s said that his first manager spent 30 years at GE without visiting a business division. He added, “People go twice a week now.”

Research funding at GE started to change in 1981, after John Francis “Jack” Welch Jr became CEO and began to make the company more competitive. GE became increasingly profitable under Welch, so research didn't face a reduction of funds. But it did go through a sharp change in funding source and direction. By 1986, when Walter Robb took over as head of GE Global Research, many of the business units were questioning the need for a central research lab. The laboratory, they argued, wasn't doing anything for them, but the corporate tax placed on them to pay for the central lab effectively reduced the business units' profits. Concerned that the business units

would pressure the corporation to eliminate the central laboratory, Robb changed the funding mechanism. The company would provide about 25% of the central laboratory's funding, but that would go to overhead—that is, to maintenance of the laboratory—rather than to research. Individual researchers would have to turn to the business units for 100% of their funding. Although the units were told that they had to contribute funds, they could determine where those funds went. As a result, research projects began to focus on smaller, shorter-term efforts central to the needs of the business divisions.

When we visited GE in 2003, however, research funding was beginning to go through another transformation, this one aimed at creating a balance between exploratory research and business-focused product development. One of our interviewees said, “Funding has changed in the last couple of years somewhat in that we are now again looking at or being funded on a longer-range concept.” An R&D manager told us that the funding formula was changing because new CEO Jeffrey Immelt, who succeeded Welch in 2001, felt GE was doing “too much short-term stuff. . . . We probably do about 50% to 60% business [unit] funding and the rest is either internal funding or government funding.” Another interviewee noted that the “businesses are being pushed to ask us to do longer-term things rather than product development.” From published reports, it appears that GE has significantly expanded its longer-term advanced technology projects since our visit and has globalized research with the opening of new central laboratories in

Sites and sounds

For an American Institute of Physics study on the history of industrial R&D, we conducted site visits and interviews at 15 US high-technology companies. The sample was selected based on size, industry sector, product mix, and other factors. All 15 companies were among the 27 largest employers of physicists in the US during the years 1996–2000, as identified by the American Institute of Physics's statistical research division. The sample included four of the five largest employers—Raytheon Co, Lockheed Martin Corp, IBM, and Lucent Technologies' Bell Laboratories—and a range of other companies: 3M Co, Agilent Technologies Inc, Corning Inc, Eastman Kodak Co, Exxon Mobil Corp, Ford Motor Co, General Atomics, General Electric Co, Honeywell International Inc, Texas Instruments Corp, and Xerox Corp.

Many scientists at those companies graciously agreed to be interviewed, some anonymously. Those we can name are David Arch, David Bishop, Dennis Buss, Praveen Chaudhari, Bijan Dorri, Edward Furlani, Gilbert Hawkins, Mark Ketchen, Taylor Lawrence, Robert Lorentz, Jeff Newmeyer, John Schenk, Linda Wagner, and Alice White.



Figure 2. Advanced research once characterized the more prestigious industrial laboratories. In this circa 1964 photo, Philip Anderson (left) and Paul Richards, both then at Bell Labs, inspect the equipment they used to confirm that superfluidity and superconductivity are related. (Bell Laboratories, courtesy of the AIP Emilio Segrè Visual Archives, *Physics Today* Collection.)

philosophy. The article noted that the “two imperatives for success” in a corporate lab are to balance product development and long-term exploratory research.

Prestige is not enough

AT&T Bell Labs long held pride of place as the most academic and prestigious corporate R&D facility. However, research there began to change after AT&T lost its monopoly in 1984 as a result of federal antitrust actions. Before then, one former Bell Labs scientist asserted, “Bell Labs was this wonderful place where they hired all these people and said, ‘Do what you want to do, and we won’t bother you.’” An R&D manager told us that the laboratory “had a tremendous reputation, even though the impact of that research on the business of AT&T was relatively minor.” Bell Labs scientists were free to explore fundamental issues in physics, as illustrated in figure 2. In the increasingly competitive environment of the 1990s, though, the central laboratory needed to provide more than corporate prestige and technological leadership. It needed to contribute to the company’s short-term financial returns. That created a great difficulty for “physical sciences, because we really didn’t impact the larger company.” The manager recalled that AT&T’s spinoff of Bell Labs as the newly independent Lucent Technologies’ Bell Labs in 1996 was “a very exciting time . . . because all of a sudden our company, Lucent Technologies, manufactured devices, and everything that we did was relevant to the new company.” But problems quickly arose. “We didn’t realize at the time that we were funded as a percentage of revenue, and . . . as the company shrinks, that number is shrinking on a yearly basis.”

Another manager noted that staff had been cut by about a third since Lucent was spun off. He said that to avoid the stasis that plagued IBM after its reductions, Lucent’s lab management was trying to make R&D relevant. He added, “If we’re still here five years from now, . . . then I guess it’s succeeded, but it’s still kind of a work in progress.” Six years after that testimony, the lab functions under the new Alcatel-Lucent label. However, in January of this year, we learned that five of the eight Lucent physicists we interviewed in 2003 had moved to other jobs and one had retired. That is a much higher attrition than at most of the other labs we’ve checked.

A manager at Kodak’s central laboratory described a transition away from fundamental research similar to that experienced at Bell Labs. He said that research and the rest of the business had been strongly separated when he arrived in 1982: “When I came, the research labs and the commercialization activities were completely disconnected. There was absolutely no linkage between them. Things [for example, inventions] were thrown over the wall. . . . So there was very little connection.” In the mid-1980s Kodak began to reorganize, and by 1992 all research reported directly to business units. When we visited in 2003, the corporation funded 10%

Munich; Shanghai, China; and Bangalore, India.²

Unlike at GE, major changes at IBM’s central laboratory, the Watson Research Center, were a response to the company’s near financial collapse in the late 1980s and early 1990s. A physicist who had spent more than 30 years at IBM said that the 1980s are “generally referred to here as the golden age of science.” Since then the “number of scientists in the physical sciences shrank to about a third.” He added that most of the science IBM does now is “with an eye on technology,” although exceptions exist. Like several other interviewees, he cited the work of IBM physicist Charles Bennett on quantum computing as one example of the pure science that the laboratory continues to support. An R&D manager told us how IBM began to balance technology with long-term research in the 1990s. No longer could one conclude, “Well, they let me do it, so it must be okay.” Instead, researchers had to be able to create a “story” defending the utility of their research. The practical value could be “way out there somewhere,” but researchers had to come up with something that justified how their work had the “potential of being important at some point to the success and profitability of IBM. That could be Charlie Bennett worrying about quantum computing. That was okay. But everybody had to think about it and have a story.” Those who couldn’t come up with an adequate story were forced out. Milestones also became increasingly important; if researchers didn’t reach a particular milestone, the manager said, they needed a “story why it didn’t happen.” He added that the company also changed hiring practices. Instead of focusing solely on hiring the best and the brightest, IBM began looking at how new scientists could benefit the company. A 2003 article (*PHYSICS TODAY*, July 2003, page 44) by Thomas Theis and Paul Horn, two of the Watson Research Center’s senior executives, reflects IBM’s post-1980s



Figure 3. Infotonics Technology Center Inc is a collaborative effort involving academia, industry, and the New York State government. The company's research center is located in Canandaigua, New York. (Courtesy of Infotonics.)

of the research at the laboratories; that research might be longer term, but it remained under “pressure to be quite relevant to the business unit.” The remainder was funded directly by the business units. Many of the researchers questioned whether research was done at Kodak. Certainly, they argued, new researchers would not come to Kodak seeking a robust research program.

The autonomy and intellectual freedom that researchers experienced at Bell Labs, GE, IBM, and Kodak through the 1980s is not typical of the other laboratories in the study. However, interviewees at all the laboratories we visited described a sharp transition over the past two decades toward shorter-term projects and more control by the business side of operations. The changes they described shared similarities with events at the academic-style facilities but in many cases went beyond those at the elite labs.

Decentralizing research

Forcing the central laboratory to contract research with the business units is only one way of focusing on product development and getting the maximum profit for R&D expenditures—at least in the short term. Another is to eliminate the central research laboratory altogether.³ Texas Instruments Inc closed its central laboratory when it sold off its defense division to Raytheon Co in 1997. Honeywell International Inc placed its laboratories under various divisions in the late 1990s. Raytheon moved its central laboratory to Hughes Electronics Corp in 1997 when it acquired Hughes's aerospace and defense units from General Motors Corp, and it shared with GM an interest in Hughes Labs. In 2007, shortly before we visited, Raytheon divested itself of its interest in Hughes Labs, which left all its research operations in its business units. When we visited, the company was still questioning whether there might be a role for a central laboratory, but to date it has not established one. As one interviewee told us, “Over time, central research organizations kind of disappeared . . . [as they] got absorbed into the organizations who actually used their research. What happened as a result of that is that they became more applications oriented.”

A different approach to research is to form industrial associations to fund “precompetitive research” that is unlikely to give any one company a competitive advantage. That approach is favored particularly by the electronics and chip industries but has also been adopted elsewhere. When we visited Texas Instruments in 2003, they were spending about \$40 million a year on “external research.” Such expenditures appear to have increased as the company subsequently reduced its internal research programs. As one manager told us, “There are research consortia . . . and we try to influence the kind of things they do and fund the things that we want to

do, and get the results for long-range research that way. I would stop short of saying that that's fundamental research. It's not. It's very directed.” Members form the consortia to fund directed research at selected universities, sometimes but not always in collaboration with various government agencies. Two such consortia are MARCO (Microelectronics Advanced Research Corporation), formed in 1998, and NERC (Nanoelectronics Research Corporation), formed in 2004. The universities own the resulting intellectual property, but consortia members receive a royalty-free license. The trend in companies using this approach is to eliminate research within the corporation as, for example, Texas Instruments has been doing, as of our last interviews with its employees in 2008. Exxon Mobil Corp is another company that funds research through a variety of consortia. It collaborates with Toyota Motor Corp and GM in a consortium doing work on combustion and hydrogen fuel cells. Other collaborations have extended beyond the immediate industry. For example, in 2002 Exxon Mobil, GE, Schlumberger Ltd, and Toyota funded Stanford University's global climate and energy project.

Another approach is to form collaborative R&D projects with government and universities. Sociologist of business Henry Etzkowitz argues, in “The Triple Helix and the Rise of the Entrepreneurial University,” that universities ought to play a crucial role with government and industry in “improving the conditions of innovation in a knowledge-based society.”⁴ Closest, perhaps, to Etzkowitz's triple-helix model are the efforts initiated in the late 1980s by Kodak, Xerox Corp, and others to outsource R&D.⁵ In 2001 Kodak and Xerox, with funding from the New York State Office of Science, Technology, and Academic Research, formed Infotonics Technology Center Inc. The idea was to bring small-scale microelectromechanical systems (MEMS) manufacturing to commercial viability. The center (pictured in figure 3) was formally opened in 2004. By 2006, however, Infotonics was losing \$200 000 per month. An Infotonics press release from August 2007 suggests an economic turnaround, but the ultimate success of the program remains unclear.

New York State also joined forces with IBM and Rensselaer Polytechnic Institute to create the Computational Center for Nanotechnology Innovations, established in 2007 to develop an industry-wide collaboration with academic researchers in the development and manufacturing of nanoscale materials, devices, and systems. Again, it's too early to determine the success of a program that seeks to contribute to the manufacture of semiconductors with sizes on the order of 20 nm by 2015.⁶

Some of the physicists we interviewed strongly supported government-university-industry coalitions, but we also found widespread criticism. An R&D manager at GE

specifically noted the problems with government-funded university collaborations. "The company has the objective to try to make money, and the university is trying to make publications." The two form an alliance to get funding from the government, but they continue to pursue their disparate objectives. "Both use [the alliance] to get money from the government, but it doesn't really work." What did work, he said, were one-on-one, personal collaborations between a research scientist in a company and a researcher in a university, "where we're trying to make a business out of it, and someone in the university wanted to work on some of this stuff."

Although corporations are encouraged by government funding sources and the downsizing of their own research departments to collaborate with universities, academia's increasing focus on intellectual-property issues and patents creates an awkward competition between nominal partners. And when universities continue to focus on publications, working with academe creates another set of problems—related to free versus proprietary information—for creating and protecting corporate intellectual property.

Some of those we spoke to sought to limit collaborations with universities to the "upstream" laboratories—those least focused on product development. "The closer you get to a product, the stickier it becomes working with universities," an R&D manager at 3M said. Just giving money to the university and hoping for results is not satisfactory either. A physicist at Lockheed Martin Corp said, "We need to have a shadow program inside. . . . There has to be somebody inside doing it, and we have to make sure that we specify some kind of deliverable."

Knowledge acquisition

Another important trend, and one that's growing stronger, is the outsourcing of knowledge creation to the marketplace, especially to new startups. Corporations recognize that knowledge can be created anywhere and that using in-house central research labs to develop innovative, breakthrough technologies has often been inefficient. Several corporations in our study use a portion of their internal R&D to assess knowledge created elsewhere for possible acquisition rather than to create knowledge itself. As a result, they can identify and acquire more basic-level research.⁷ As one corporate R&D manager told us: "The fundamental research will get done, the applied research will get done, the development will get done. . . . It's just that it may get done from different quarters. . . . It does change the question of what's done inside a corporation and how the corporation tries to position itself. Instead of doing some of that research now, many of us have to be aware of the existence of the research out in the rest of the community."

Agilent, General Atomics, Lockheed, Xerox, and others have researchers whose job it is to keep tabs on the small startups, many of which are affiliated with university research programs, and to identify those whose technologies fit their company's portfolio. If it anticipates a profit, the company will acquire the startups and utilize its larger R&D program to incorporate the startups' technologies into its product lines. Several individuals have established companies whose core business is intellectual property. For example, Nathan Myhrvold, Microsoft Corp's former chief technology officer, has formed Intellectual Ventures Management LLC, a specialized business that serves as an upstream intellectual-property resource. By July 2006 the company employed some 700 researchers. H. Ross Perot has also gotten involved, establishing a \$200 million private equity fund to purchase companies with "undervalued" patent portfolios.⁸ In many respects, the

use of corporate labs to evaluate external knowledge creation appears to be a free-market counterpoint to the inherently constrained triple-helix model of collaborative R&D.

Many commentators point to foreign governments' investment in industry and suggest that the US would benefit from increased government involvement in research. Our survey, however, indicates that the industry-government relationship is a complex one and that the benefits of federal funding vary from company to company. Most of the laboratories we visited, including those at 3M and GE, limit their government-funded research to less than 15% of research revenues because of intellectual-property issues, accounting requirements, and other factors.

Nonetheless, managers from 3M and GE asserted that they were quite willing to turn to the government to fund longer-term "high-risk" R&D. One GE researcher said, "We've had some support from government resources, . . . where we are involved in more academic or longer-range projects which are funded through government contracts, but that's quite a small fraction of the total." Another suggested that most government research contracts were related to products for which the government was the customer. Executives at 3M had reduced government-funded research to focus on programs within the company's core business that had potential commercial application. Admitting that 3M once had a much larger government research program, one manager told us, "Right now, very judicious use of government funding is applied to our projects where it's something that's directly in line with what we want to do."

At one time Corning had limited its government research, primarily because of intellectual-property concerns. But when we visited, the company was going through a major downturn because of the dot-com bust. One manager told us, "Things are changing. We're trying to get funding from the government to sustain some of our research." A researcher there told us he had changed his longer-term research emphasis in order to increase government contracts.

Ford Motor Co's government contracts are focused on longer-term projects. As one researcher said, "In the case of these long-term development projects . . . there's less risk and a lot of upside to engaging to contract research with the government." Agilent limited its government-funded research to 10% of R&D revenues and insisted that the research support the company's lines of business. On the other hand, two of the four aerospace and defense contractors in the study—General Atomics and Lockheed—developed research labs as profit centers for the purpose of contracting government research. A third, Raytheon Integrated Defense Systems, focuses its R&D on programs that support potential manufacturing and service contracts to the government. Honeywell Aerospace seeks government contracts for higher-risk, longer-term R&D projects. "You know, we think this is going to be ready for Honeywell in three years, so that's probably where Honeywell is going to put its money," said a manager. "But if . . . it will require a lot of risk, those are the types of ideas that we'll pitch to places like DARPA [Defense Advanced Research Projects Agency] because they're willing to go after the high-risk projects."

Preserving the records of research

The condition of research records in corporate R&D is as varied as the research itself. The extent to which future researchers—scientists, historians of science, and others—can understand the work that physicists currently do in industry depends on the ways that today's researchers record their work and the extent to which companies are able to identify

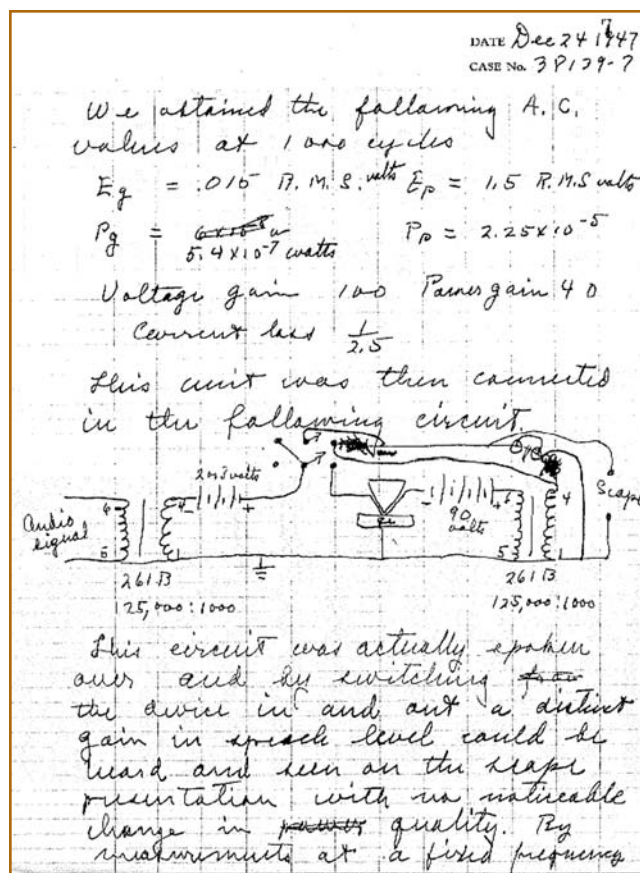


Figure 4. Lab notebooks were once ubiquitous but are now disappearing at many industrial laboratories. This page, from Walter Brattain's Bell Labs notebook, shows the scientist's notes regarding the Christmas Eve 1947 breakthrough in developing the first transistor. (Courtesy of AT&T Archives and History Center.)

and preserve records of value. Because of changes in how the information is recorded and the lack of standards for identifying and preserving corporate R&D records, much potentially valuable information is being lost. Most of the records that corporate physicists create today are born digital. About half the interviewees have altogether abandoned traditional laboratory notebooks such as that depicted in figure 4, and only one reported using an electronic notebook instead. Companies have invested heavily in a wide variety of electronic document systems, including commercial products like GlobalShare and DocuShare. Those and other similar systems allow project teams to work interactively online and to share their data, but the records that the teams generate are meant to survive only for the life of the project. None of the companies had developed long-term storage for those or other digital media.

Computerization has contributed to a general lack of documentary trails in corporate R&D. Another important factor is the lack of national standards. One corporate librarian told us that federal rules govern the preservation of personnel and business records, but no regulations govern intellectual-capital records. As a result, research records beyond those found in publications survived only at the discretion and immediate needs of the laboratory. A few companies, mainly those that combined a strong records-management

program with an active technical library, did a good job of identifying and preserving records. At other companies, the only permanent intellectual-capital records typically took the form of patent applications and high-level reports. The work on which this article is based (see the full report¹) includes best practices and recommendations for preserving corporate R&D records.

Struggle but no consensus

Throughout the course of our study, we found companies grappling with the role of research in a competitive environment. Corporations remained uncertain as to how to weigh the benefits of longer-range research against the immediate costs of that research. Several that had shortened their research time frames in the 1990s have since reversed that trend to a limited extent. Corporations that focused on commercial products saw increased competition driving research to shorter time frames and pushing it toward development. On the other hand, government contractors felt that government policies limited the return on their investment in research. Some, particularly in the electronics industry, saw the decline of research as part of a long-term cycle that would again swing to longer-term research as current chip technologies matured. We found no consensus on the role of research or the primacy of research in driving corporate innovation.

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The online version of this article includes links to cartoons from *An Introduction to Patents* (Bell Telephone Laboratories Inc, 1956), a primer on the importance of patents for scientists and engineers.