Restructuring Corporate R&D: From an Autonomous to a Linkage Model

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ABSTRACT *Since the mid-1980s, industrial R&D in the US has been going through major changes, i.e. a decline in industrial R&D expenditures and restructuring of centralized corporate R&D laboratories. The autonomous model of research, which has existed since World War II, is being replaced by the linkage model in many leading corporate R&D laboratories. This paper presents the main features of both models, the reasons behind the restructuring, and the future implications of the linkage model. The findings of the paper are primarily based on 53 interviews with industrial scientists and managers; most of the changes are new and have not been examined in the literature. This paper draws the attention of scholars to recent changes in the management of innovation and suggests further study. The linkage model links scientists' research to the immediate needs of business. However, it also decreases the likelihood of major breakthroughs occurring in technological innovation.*

Introduction

In an increasingly technological world, a country's well-being is significantly determined by the quality of its investment in human and capital resources dedicated to science and technology. As the major economic segment of the US economy, industrial R&D plays the dominant role in the national effort to maintain a high standard of living and to keep the country competitive in the global market. In industrial R&D, inventions in science and technology are converted into innovations, and high-quality products and processes are produced in a cost-effective manner. However, industrial R&D has experienced two major changes since the mid-1980s: (1) the growth of US industrial R&D expenditures in constant dollars has slowed; (2) centralized corporate R&D laboratories are being restructured to link research directly with the business divisions of the company.

Industrial R&D expenditures have significantly declined in inflation-adjusted dollars since the mid-1980s. From 1979 to 1984, industrial R&D expenditures in 1987 constant dollars grew from $58 271 million to $89 236 million—an average annual increase of 7.4%. However, the growth rate of industrial R&D expenditures was reduced to 3.0% per year during 1984–89. In 1989, constant dollar expenditures actually declined—this happened for the first time in 14 years. Since then, industrial R&D expenditures have continued to decline in constant dollars, from $93 875 million in 1989 to $90 711 million in 1993.[1] During the entire 1985–93 period, industrial R&D expenditures have been virtually flat.

The decline in industrial R&D expenditures has coincided with the restructuring of the centralized corporate R&D laboratories, which are an internal mechanism for a

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company's growth and for technological change. Centralized corporate R&D differs from R&D laboratories associated with business divisions. Corporate R&D aims at developing new product lines and process technology beyond the scope of present businesses. It plays a role when the business divisions are confronted by a problem for which they do not possess the required technical capabilities. R&D laboratories associated with business divisions aim at improving current products or processes.

In this paper, a study is made of the restructuring of centralized corporate R&D laboratories, which began in the mid-1980s. It is found that the old autonomous model, which viewed economic gains as a by-product of research, has been declining in many leading corporate R&D laboratories. A new linkage model of corporate R&D, which directly links research to the needs of business divisions of the company, has been put into practice since the mid-1980s. The main features of both models are outlined here and their implications for research are described, primarily on the basis of 53 interviews with scientists and managers of high technology manufacturing industries. Since changes in corporate R&D are new, scientists who actually conduct research and managers who actually supervise research are best suited to identify these changes and their impacts on research activities. The interviews with scientists and managers provide primary data on the subject for further investigation. The methodology is given in the appendix.

First, a description is given of the history of corporate R&D, to show its contributions. Then, some problems in US industrial performance in the global market are addressed, to highlight the reasons behind corporate R&D restructuring. Finally, analysis of the autonomous and linkage models is considered. A concluding suggestion is then made for the future role of corporate R&D laboratories in the company.

Role of Corporate R&D

Organized research as a major corporate activity began in the 20th century. Prior to the creation of corporate R&D laboratories, companies purchased patents to produce technological change, instead of investing in science and technology as functional activities within the corporation. Many companies did designate a small area in the manufacturing sector, where a few scientists and engineers tested the accuracy of raw materials and specifications of products, and made patentable improvements in existing processes and equipment.[2] At that time, technologies were relatively stable, subject only to minor changes.

Starting with General Electric (GE) in 1900, many US companies established corporate R&D laboratories, such as DuPont in 1902, Corning in 1908, American Telephone and Telegraph (AT&T) in 1909, Dow Chemical in 1909, Eastman Kodak in 1912 and General Motors (GM) in 1920. Corporate R&D laboratories were separate from manufacturing units, and they employed scientists and engineers who were engaged in industry-related research. These corporate laboratories were created for a number of reasons. On the demand side, the science-based products were becoming rather sophisticated and there was a possibility of losing markets to competitors with more advanced technologies. For instance, by 1900, GE faced serious competition to its electric lighting business. New developments in incandescent lighting technologies in Europe threatened to make GE's carbon filament lamp obsolete.[3] Kodak was threatened by the vigorous international competition of the German fine chemical and optical cartels. Also, there was an opportunity to develop a color film for the rapidly growing amateur photography market.[4] AT&T needed scientists and engineers to develop an electronic repeater for telephone service and control radio technology.[5] By funding corporate R&D laboratories, these and other companies protected themselves from the problem of external technological change. Any company that hoped to compete with such companies had to invest in corporate R&D laboratories.

On the supply side, only a handful of companies possessed the capital to invest, so few were able to start and sustain corporate R&D laboratories. Also, the number of scientists and engineers graduating from universities was increasing, and they were capable of addressing problems relevant to industry.[6] In addition, there were prominent scientists, such as Charles P. Steinmetz at GE and Frank B. Jewett at AT&T, who proposed and advocated the centralized industrial research laboratory for discovering scientific principles for industry.

By supporting corporate R&D, companies transformed themselves for the better. General Electric succeeded in inventing new technologies, such as central electricity generation and distribution systems, motion picture systems and phonographs, practical telephone transducers, incandescent electric lamps, and radio and X-rays. DuPont converted itself from an explosives manufacturer into a large chemical company, by inventing nylon and the complex technology to manufacture synthetic fibers, synthetic rubbers, fluorocarbons, safety glass and many others. IBM transformed itself from a typewriter company into the world's most important provider of powerful office technology.

Social scientists have examined the relationship between R&D and industrial company's productivity. Griliches and Mairesse studied 133 firms for the period 1966–77 and found a strong relationship between a firm's productivity and the level of its R&D investment.[7] Morbey and Reithner studied 727 companies for the period 1983–87 and found that there is a strong relationship between R&D expenditure per employee and subsequent company productivity, measured as sales per employee.[8] A statistical analysis that *Business Week* commissioned of historical data from its R&D scoreboards suggests that the companies with the strongest performance in their markets are also those which spend the most on R&D. A comparison was made of 897 companies' performance (measured in terms of profit margins, return on assets and sales per employee) in 1987, with average R&D spending (measured by per dollars of sales and per employee) from 1983 to 1986. The correlation between the two sets of measures was beyond a 99.9% statistical significance.[9] In other words, the more that the companies invest in R&D, the better they perform.

International Competitiveness

Since the early-1970s, the US has been facing many economic problems. Growth in productivity—a crucial indicator of economic performance—has been slower in the past 15 years than it was for two decades before. From 1949 to 1973, the annual growth rates in labor productivity (dollars of output per hour worked) and multi-factor productivity (dollars of output per unit of combined labor and capital input) averaged about 3% and 2% respectively. Between 1973 and 1979, labor productivity dropped to less than 1%, while multi-factor productivity reached almost zero.[10] Since then, there has been an improvement but the current growth rate still remains far below that of the years before 1973. Productivity is the mechanism by which economic resources expand. Unless there is an increase in growth, those living in the US will eventually suffer stagnant or falling living standards.

Furthermore, the US has been unable to compete with the major industrial countries in the manufacturing sector.[11] Transistors, radios, color televisions, video cassette recorders, steel, automobiles and numerically controlled machine tools are just a few examples of product areas now dominated by foreign manufacturers, even though the major technological advances in these products were first made in the US. Andrew Grove, President of Intel Inc., a world leader in computer chip manufacturing, says that "deep down, there is a defeatist attitude in this country [the US] about manufacturing".[12]

For a long time, the US produced and exported products with little concern for meaningful competition from other countries. Now, it operates in a global economy where over 70% of its goods compete with merchandise from abroad. As Western Europe and Japan rebuilt their war-affected industries, they were able to manufacture an increasing amount of the products needed for their domestic markets; thus, they started to depend less on the US. During the 1970s, foreign competition was a major factor that contributed to the decrease in the US manufacturing trade surplus. However, the US was able to maintain a trade surplus in high-tech products that was large enough to offset the trade deficit of non-high-tech products. By the early-1980s, Western Europe and Japan were able to compete with the US in the export of high-tech products, and the US was soon no longer the leading producer of high-tech products. For instance, in 1992, the US supplied 37% of the world's high-tech products, down from 40% in 1980. For the same period, Japan increased its share of the global high-tech market from about 18% percent to nearly 28%.[13]

The inability of the US to compete in an increasingly global market is also evident from the growing import penetration of its domestic market. A country's domestic market is usually seen as the natural destination for its manufactured goods, because of common language, currency, customs, laws and regulations. However, during the 1980s, demand for high-tech products in the US domestic market was increasingly met by foreign suppliers. For instance, by 1992, imports supply of US purchasers of high-tech products increased to 28% from 11% in 1981.[14]

It should be noted that the high-tech industries have become an important component of a country's gross economic output and, thus, of its standard of living. This is mostly because the high-tech industries invest more heavily in manufacturing technology than do other manufacturing industries, and support higher compensation to the production workers employed. Furthermore, the US, Japan and Western Europe have been moving resources toward the manufacture of high-tech products. The market for high-tech products is growing at a faster rate than is the market for other manufactured goods. In 1980 constant dollars, global production by the high-tech industries more than doubled from 1980 to 1992, while production in other manufacturing industries grew by just 29%. Output by the high-tech industries represented 22% of global production of all manufactured goods in 1992—up from 14% in 1981.[15]

The rapidity with which other countries are catching up with the US in the high-tech industries is evident from statistics in R&D activities, which shows a country's commitment to scientific and technological development. The US undertakes an extremely high level of R&D, spending more per year for R&D than the combined total R&D expenditures of the next three largest performer of R&D, i.e. Japan, Germany and France. However, these countries have been increasing their R&D efforts at faster rates than the US. An examination of R&D expenditures as a percentage of gross domestic product (GDP) shows that these countries are closer to the US R&D effort, in comparison with the size of their economies. These countries and the US had maintained an R&D/GDP ratio of between 2% and 3% throughout the 1980s. In 1991, the ratios for Japan, Germany, France and the US were 3.0%, 2.8%, 2.4% and 2.6% respectively.[16]

US companies are dealing with the problem of international competitiveness, with strategies which are designed to increase their earnings and generate cash.[17] The 1980s witnessed leveraged buy-outs (LBOs), mergers and acquisitions (M&A), hostile and friendly take-overs, and transactions aimed at delivering higher values to shareholders. US companies are involved in financial restructuring which substitutes debt for equity, so forcing management to allocate more funds to debt services rather than to other activities such as R&D.[18] For instance, John F. Welch, Jr, chairman of GE, authorized for GE to buy its own stock in 1989, because it was a better way to generate value for shareholders than taking a 'wild swing' on an acquisition or investing in new technology.[19] A company's stock price usually rises after a buy-back, because, with fewer shares in circulation, its earnings-per-share ratio is likely to improve. According to C. Gordon Bell, R&D vice-president of Ardent Computer Corporation: "American companies don't like to build things—they like to make deals. Our large organizations have become purchasing agents".[20] William J. Spencer, Xerox Corporation's executive vice-president for R&D, says: "We have moved from research and development as being a corporate asset to where it is what a corporate raider looks for first. They can make significant cuts and get cash flow".[21]

Autonomous and Linkage Models of Research

Since the mid-1980s, many leading US companies have developed a new R&D strategy for their corporate R&D laboratories, which I call the linkage model. Prior to this model, corporate R&D laboratories were organized under what I call the autonomous model.[22] Under the autonomous model, corporate R&D was assumed to be a valuable and cost-effective investment for the company's growth. Therefore, corporate management placed a premium on stability in funding. Corporate R&D expenditures were an outcome of a flat tax on the sales or profits of the various business divisions of the company. Corporate R&D enjoyed a large degree of autonomy in choosing research projects. Industrial scientists saw their primary objective as being one of discovering and inventing, albeit within a corporate context. Many technical managers supported basic and long-term research of scientists, without much regard to development. They believed that the cumulative benefits of research would automatically produce products and processes of great value to the company.

This autonomous model worked effectively until the 1970s, while the US enjoyed economic and technological dominance in the world. The dominance of the US facilitated for managers and scientists uncritical acceptance of the corporate R&D role. Many corporate R&D laboratories produced promising research results but they were often not converted into useful products and processes. Mansfield studied the R&D programmes of three companies and found that, while 60% of the R&D projects were technically successful, only 12% of them were economically successful.[23] A well-known example of the business failure of corporate R&D programmes is what happened at the Palo Alto Research Center (PARC) of Xerox. It succeeded in exploratory research on a computerized office system, which it called the 'architecture of information'. However, it could not translate the research results into money-making products.[24] In contrast, other US companies, such as Apple, were able to make use of the research results produced at PARC and marketed the technology.

Corporate management has come to believe that corporate R&D is not helping business divisions in developing relevant technology. It is questioning the very basic purpose of supporting corporate R&D in a company. For instance, Arno A. Penzias, vice-president of research at Bell Laboratories, declared: "the test is not going to be whether we do good science or not. The test is: is the company going to be healthy or not?".[25] Consequently, many leading corporate R&D laboratories have implemented the

Table 1. Main features of the autonomous and linkage models

Autonomous model	Linkage model
Existed since World War II	Implemented in the mid-1980s
Research funds generated as a result of a flat tax on the company's business divisions	Research funds generated as a result of direct contracts from the company's business divisions
Scientists generate projects on the basis of company's generic interests	Scientists and managers generate projects on the basis of customers' needs
Corporate R&D enjoys autonomy from the rest of the company	Corporate R&D depends on the rest of the company
Emphasis on long-term research	Emphasis on short-term research
Technical feasibility directs the research	Availability of money directs research
Strategies for R&D are clear	Strategies for R&D are vague
Indirect link between research and business divisions	Direct link between research and business divisions
Emphasis on research	Emphasis on development
Scientists work on a few and similar projects	Scientists work on many and different projects
More layers of management	Fewer layers of management

linkage model, which involves restructuring the laboratory to link research directly to business divisions. Now, managers and scientists have to work with one of the business divisions, to encourage joint projects between scientists and business divisions people. The cooperation between research and business divisions is enforced by changing the funding scheme. Scientists have to obtain contracts from business divisions for their research efforts. Under the linkage model, there is less emphasis on fundamental and long-term research, and more emphasis on solving specific problems of business divisions. The main features of both models are given in Table 1, and each row is elaborated below.

Centralized vs Contract-based Funding

Corporate R&D laboratories have mostly three types of research fund: money made available by the company; direct contracts from the company's business divisions; and government contracts. Under the autonomous model, corporate R&D laboratories received most of their funds from a flat tax on the sales or profits of business divisions; only a small portion of their funds were generated from direct contracts from the company's business divisions or from the government. Under the linkage model, most of the research funds are being generated by the company's business divisions. The proportion of funds generated by the company and by contracts from business divisions varies in different corporate R&D laboratories. Companies such as GE and Bell Labs have changed their funding structure from one-third being generated by business divisions to almost two-thirds and one-half respectively. Of two corporate R&D

laboratories studied, one had started obtained approximately two-thirds of its R&D funds from business divisions; earlier, only one-third was generated by contracts from business divisions. The other laboratory was obtaining its R&D funds from the profit that the company made; however, changes had taken place within a year of this study being completed. The 16 ex-industrial scientists interviewed represented six different corporate R&D laboratories; four of six laboratories had experienced major funding changes since the mid-1980s.

Company's General Interests vs Business Divisions' Needs

Project selection in corporate R&D laboratories is one of the most critical activities, as a result of the technical and economic uncertainty that surrounds the process of technological innovation. Under the autonomous model, scientists worked mostly on projects which they generated; on some which were jointly initiated by scientists and managers; and on a few which were assigned by managers. Scientists generated ideas, wrote proposals, recruited colleagues and got managers interested in supporting these projects. They made their choices on research topics which interested them the most from a technical standpoint. However, their interests also fell within the general goals of their company. Managers rarely assigned projects for scientists, unless they needed to single out some scientists to work on top-priority projects. Managers mostly generated projects for junior scientists when they joined the laboratory. However, as time went by, junior scientists developed their own projects. The most common process of management assignment of projects involved consultation with scientists, with managers taking the initiative. Managers believed that, if the scientists had significant input in proposed projects, they would be highly motivated. Scientists and managers selected projects on the basis of generic interest of the company, technical feasibility and scientific breakthroughs relevant to the company.

With the linkage model, projects are mostly being generated by managers of business divisions and R&D managers. There are two ways that this is happening. The first method is rather indirect, making use of the project selection process under the autonomous model. Managers convey to scientists that their research can no longer remain vaguely related to the company's business; instead, it has to be closely aligned to the company' products and processes. Consequently, scientists examine the business divisions to identify problems and propose projects accordingly. The second way of generating projects is direct. Projects emerge when the managers of business divisions and R&D managers reach some consensus on what scientists ought to be doing. Managers figure out how specific projects are linked with the needs of business divisions. They simply inform the scientists that there is a type of work which needs to be done. The scientists may not know in advance what sort of projects the managers will assign to them, so the scientists have to be flexible. This pattern is described in one scientist's words:

> Earlier some of my projects came from my managers while for others I got the idea myself and I talked to my manager for the support. This was in the past, about seven to eight years ago. Now my projects come mostly from [business divisions] ... [they] approach scientists directly for the work that is relevant to them. Now my projects are being dictated by the people who do hardware.

Autonomy vs Control

Autonomy operates within particular social contexts and, in the case of a corporate R&D laboratory, many of the controls are internalized beforehand by scientists and managers. None the less, under the autonomous model, corporate R&D had a lot of autonomy from the rest of the company. Once broad objectives of the company were conveyed to scientists, they figured out how their research interests coincided with the company's goals and interests. They emphasized the potential relevance of their ideas to their company's interests and objectives. They performed their research according to their own judgement, without any direct supervision from managers. Managers indirectly controlled the scientists' work, by reviewing the research. However, evaluation of projects was fairly informal. The scientists discussed their ideas with the managers on the phone, via electronic mail, in the hall or in the dining room. Once the immediate managers were persuaded, the scientists made a formal presentation to the upper management. The managers evaluated the proposals on the basis of their intuition about the fit with company's goals, cost, technical feasibility, time required, tract record of scientists, etc. They basically supported research if they believed that the proposed technical knowledge would be beneficial to the company.

With the implementation of the linkage model, corporate R&D has to depend on contracts from different business divisions of the company. This means that R&D managers and business division people are controlling research, by allocating the funds necessary for the research. Scientists have to find out whether or not a particular business division is interested in certain work and would fund the research. The work scientists do has to be closely relevant to the company, aligned to the company much more closely and viable in the market-place. Earlier, while scientists' research might be theoretically relevant to the company, in practice, they had autonomy to work on projects only vaguely related to the company's products. As long as the scientists were forceful and convincing in their proposals and presentations, they were able to make their work appear relevant to the company. Now, scientists propose their work to R&D managers and/or people in business divisions to seek financial support. Both sets of managers review the scientists' proposals and decide on the particular kind of research that should be supported by allocating funds. As one scientist explained:

> The most common situation is that let's say my expertise is in the area for which the business is not that excited. So, they are not going to fund my work any more. Now I have to find something else to do, in some cases, to switch to a completely new area which has funds. Within a month, I have to stop everything which I was doing for a number of years and start something new. I will still consider this a good situation. The bad situation is if we can not get any more funds, what are we going to do? We have to find some other job.

Long-term vs Short-term Research

Projects carried on within a company can be both long term and short term. Scientists engage in short-term research in response to well-defined problems encountered by the company. Long-term projects are generally undertaken because there is an opportunity, but not the technology, to achieve certain goals. Usually, long- and short-term projects are defined by the time-frame involved, from the conception to the completion of projects. Needless to say, different companies have different needs, and projects are classified accordingly as long and short term. Long-term projects may take 10 or more years for some companies and 1 year for others. 'Short term' in pharmaceutical research could mean 4 years, whereas it might mean 1 year or less in electronics.

Under the autonomous model, many managers supported projects which were exploratory. Many scientists were able to convince their managers to support projects which could easily be classified as long term. Such projects dealt with the new product or process that the company decided to explore. Emphasis was on fast-moving technologies of generic interest to the company, and promising ideas for which technical feasibility was in doubt and risk high. The scientists carried out long-term research in their fields of expertise and there was very little to show for a long time, but the management went along with the scientists.

Instead of aiming for growth through developing new products and processes, mostly short-term solutions are being sought by R&D managers under the linkage model. These short-term solutions have taken many forms, such as acquiring the technology outside the R&D department, cutting down on long-term and risky endeavors, etc. Furthermore, people in business divisions who fund most of the research projects have specific problems which they would like scientists to address. Business division people neither have the time nor the desire to consider the long-range needs of their business. They like to continue to do exactly what they have been doing, i.e. modifying equipment, and they hesitate to consider anything that is radically different, or which would involve considerable changes, training of employees or additional overhead costs. One scientist showed his concern as follows:

> With the new funding scheme, if you are trying to do something that is far reaching, it is very difficult to convince someone in business division that this far out idea of mine is likely to have impact on what you will do in a few years. Essentially, you are asking them to think about something that may happen in five to ten years. However, all they think about is how to get product out next week, how to make their profit look good, or how to look good at this quarter. You cannot convince them to look into this idea of mine, as it may change things down the road. If I go to business division people and propose that it is a very important area and we should work on this for a year or so, I would be almost laughed out the door.

Management is not excited about long-range scientific research, because of the risk involved. If some managers were to let long-term projects go on, profits might drop, because there would be nothing to show on paper for some years. Managers believe that "the pressure on [them] to maintain quarterly earnings is built into the system". According to managers, "investors in equity markets demand return on their investment in a short time". Therefore, intellectually, managers may believe in a long-term research policy but, in reality, they are not able to pursue it. Consequently, with the implementation of the linkage model, many long-term R&D projects were terminated in certain areas of research, despite a long history of research in those areas.

Technical Feasibility vs Availability of Money

Under the autonomous model, scientists and managers were mostly driven by scientific and technical reasons, to generate research ideas which were within the company's general goals and interests. Scientists dealt with scientific and technical questions, but the usefulness of their projects was business oriented. When generating research ideas, scientists considered various factors: what unfulfilled needs are in the area of interest; what the level of existing research is in that area; whether there is a rational scientific way to approach the research problem; what human and material resources are available to them; and what the time constraint is. Managers brought forward the cost and money issues rather than the scientific merits of a project during the selection process. However, they based their decisions on their intuition about the project, the production of good quality research, the professional reputation of scientists, their visions and commitment for research, and the leadership role of the project leader. These considerations exerted an important influence on decisions made by the managers.

However, with the implementation of the linkage model, projects are being generated mostly on the basis of business interests. People in business divisions need help with their current work, so they support research that they consider to be important to them. Since they pay the money for research, they fund what deals directly with the problems they face. Consequently, scientists generate projects which they think would be easily funded. They find out where the money is concentrated for research. The real focus of the scientists has become where the money is coming from and what the needs are of people who are funding the research. R&D managers' new responsibility is to obtain financial support for projects and consult scientists accordingly. In the last analysis, it is funding which is ultimately determining what projects are undertaken, how they can be achieved and what projects will be discontinued. Scientists can have all kinds of proposals but a proposal without funding by management is going to remain only as an intellectual exercise. As one scientist said: "Basically, it is the person who controls the money dictates the themes". Another scientist said: "You have to have money for your research. No money, no research. This is the bottom line".

Furthermore, under the linkage model, scientists are receiving recognition by managers, if they have generated financial support for their projects. Under the autonomous model, scientists were rewarded on the basis of the quality of their work. Now, scientific and technical contributions are appreciated only if they have financial backing. This further pushes scientists to generate research on the basis of the availability of research funds.

Clear vs Vague R&D Goals

Overall R&D goals define what the laboratory is to become in a given area. They provide criteria for determining and judging the activities of scientists and managers. The future of research, as well as that of the companies, depends on what is hoped to accomplish and how. Under the autonomous model, goals for R&D were well established. Management clearly stated what business the company was in; what business the company was going to be in; which particular area of the business was likely to undergo changes; how far the company wanted to develop and expand away from its present product lines; the amount of profit desired; the extent of risk and uncertainty accepted; and the type of public image sought. Managers also outlined R&D strategies, such as policies and plans to achieve the goals in light of the given resources. Therefore, scientists were able to link their research agendas to the broad goals and objectives of the company. They had a definite understanding of what the corporate R&D is seeking and how.

Since the mid-1980s, goals for corporate R&D have become rather vague. US manufacturing companies with corporate R&D have products and processes which involve technical problems. Therefore, it is necessary for these companies to have some research capability in science and technology within their organizations. This is then the broad basis for the continued support of corporate R&D laboratories. However, corporate leaders are supporting corporate R&D as a discretionary item rather than providing a steady support, as indicated by the decline in industrial R&D expenditures. Managers are cutting down on risky endeavors, such as basic long-term research, and directing research to solve specific problems. Both scientists and managers reported that their companies did not have plans for what their products would be in 3–4 years, or what businesses they would be in 5–10 years later. Scientists are rather ambiguous and unclear, because their work is going through frequent changes. In one scientist's words:

> I am not always clear on company goals and I do not think my manager is either. There is a problem within the company in terms of goals, because they are not well established from the top going down.

Indirect vs Direct Link between Research and Business

Under the autonomous model, the whole R&D process was comprised of a spectrum of related activities, such as project identification, basic scientific research, technical development, production and marketing. The model which linked research to the business was very much like an assembly line; research was on the one end and products on the other end. There were several intermediate stages between the first stage and the final stage, and each stage itself was divided into several steps. Different corporate R&D laboratories had different stages but the whole process was sequential, from one layer to the other. Scientists carried out the research and then turned it over to the people in a production division. The production division people worked and then turned the work to the marketing division to take the product to the market. This sequential organization of research had an inevitable problem of persuading each successive function to accept the results of its predecessor in the chain. Consequently, there was a large gap between research conducted in corporate R&D laboratories and technology which could be developed on the basis of such results, especially in highly diversified high-tech companies. Recently, management scholars have identified many barriers in the transfer of technology from the laboratory.[26]

With the linkage model, corporate management is seeking to link research directly to business divisions. Managers have conveyed to scientists that the research they do has to be closely relevant to the company. Scientists are to define a causal chain of events from the starting of a project, within at most one year, when their work will have an important impact on the company. Someone from the business divisions has to say that the scientists' research is crucial to the business needs. The cooperation between research and business divisions is enforced by changing the funding scheme, as explained earlier. Since projects are financed by business people and are carried out specifically for the division, it is assumed that the research will be utilized. The hidden assumption is that people in business divisions will have a strong commitment to receiving the developed technology, since they are paying for it. They no longer have an option to buy the developed technology, which was the case with the autonomous model. Under the linkage model, business divisions of a company are committed at the start of the project, and it is not difficult for managers to transfer the developed technology successfully to business divisions. One manager explained:

> In my division, scientists no longer work on abstract ideas. Their research has become useful to our customers ... Now it is easier for me to transfer the research to the [business divisions] because they see the same potential which scientists and I see.

Research vs Development

According to the National Science Foundation, 'research' is a systematic study directed towards a fuller knowledge or understanding of the subject under study. It is classified as 'basic' and 'applied' research. In industry, basic research is defined as research that advances scientific knowledge but does not have specific commercial objectives, although such investigations may be in fields of present or potential interest to the company. Applied research in an industrial context means investigations directed at the discovery of new scientific knowledge which has specific commercial objectives with respect to products, processes or services. 'Development', however, is the systematic use of the knowledge or understanding gained from research directed towards the production of useful materials, devices, systems or methods, including the design and development of prototypes and processes.[27]

Under the autonomous model, scientists were involved in research which was both basic and applied, because there was an opportunity but not the technology to achieve the company's goals. They worked on promising ideas, for which the technical feasibility was in doubt and the risk was high. Management believed that the company's innovative output is directly related to the percentage of its R&D expenditures devoted to fundamental long-term research. With the changes in the funding system, if scientists do not have a target application for their work activity, then it is difficult for them to obtain funding. Now, corporate management wants scientists to solve specific problems and develop specific things. There is less emphasis on fundamental research and it is quite difficult for scientists to obtain funding if their proposals are on such research. According to scientists:

> Most of research has become mission oriented towards development and money is not going for research as such.
>
> The current paradigm at [the company] is not to do research, which is unfortunate.
>
> When I came, it was really a research institute. We did really fundamental long term research. That is what exactly I dreamed about. We do not have such programs anymore. We do some fundamental research but not a whole lot more. If I had to apply for the job here right now, I would not find it to be as exciting and sexy. But this company is not different from others. U.S. companies aren't doing fundamental long term research. Where would I go?

Development has been the fastest growing R&D activity. In 1993, industry performed 86% of total development and funded 61% of it. Of the total applied research, industry performed 67% and funded 53% for the same time period; the performer and funder figures for basic research were 19% and 18% respectively.[28]

Specialized vs Diverse Projects

Scientists generally work on more than one project at any given time. This is considered to be a safer route to follow, because scientists may not technically succeed in all the projects that they are involved with; many may not achieve the stated objectives within the given time period. There are some scientists who are always successful but this is not the case with the majority of scientists. They work with all kinds of ideas and only some of those ideas are successful. This is the way that research is performed.

Under the autonomous model, scientists worked on projects which were in the area of their specialty. Projects were related, in the sense that there was an underlying common theme. Under the linkage model, scientists are driven to have a lot of projects which are very different. They have to diversify themselves to obtain the necessary funds. If they are unable to obtain funds for their projects, then managers move them to other projects. Scientists with less money go and work with scientists with more money. Often, scientists end up working on a project for which they have little experience. As one scientist said:

> Right now, I have four different projects. There is no way I can be an expert in four different areas. These projects are only moderately related to each others.

More vs Fewer Layers of Management

The number of layers of managers in any corporate R&D laboratory depends on its organizational structure. Under the autonomous model, corporate R&D laboratories were organized on a hierarchical basis—groups of scientists reported to managers, who then reported to still fewer managers, until all lines merged in a single person, i.e. the vice-president of R&D with ultimate responsibility. Under the autonomous model, some corporate R&D laboratories had more divisions than others. Typically, a corporate R&D laboratory was organized in a number of sectors; each sector consisted of a number of laboratories; each laboratory then had a number of branches; each branch had a number of groups. Usually, each division was headed by a manager. The immediate manager of scientists managed five to ten scientists. The second and third levels of managers supervised approximately 25 and 50 scientists respectively. As one kept going up the hierarchy, the number of scientists being managed by managers increased.

With the linkage model, an attempt is made to organize the laboratory in a fairly flat structure, mainly to improve the communication pattern and to reduce the overheads. The flat structure of the linkage model also has a hierarchy of managers, but there are fewer layers. However, an invisible layer of managers has been added; scientists have to deal with managers of business divisions to get their projects funded. These managers often do not have a background in scientific or engineering disciplines, unlike R&D managers. Business divisions' managers have expertise in finance, business, accounting, budgeting, marketing, etc. Such managers grasp financial concepts fairly easily but they are unable to hold their own on technical details when debating allocation of resources to projects. They support projects in output mode, because that is what they understand. As one scientist said:

> Our customers are not technical oriented people. It is very difficult to convince them. A technologist with management skill is easy to convince.

Conclusion

Since World War II, scientists have generated projects within the framework of company goals and interests. It was believed that, if scientists enjoy their research and their results are recognized by their peers in the scientific community, then some useful product or process would result. This autonomous model has come under attack by corporate management as being insufficiently successful in generating useful results for the company. A new linkage model has been sought in many leading corporate R&D laboratories since the mid-1980s. This new model has restructured the laboratory, by directly linking research to the needs of the business divisions of the company.

The linkage model successfully addresses the main issue of making corporate R&D more relevant to corporate business goals, which the autonomous model failed to do. With the implementation of the linkage model, the scientists and their managers have become aware of business needs, and the business division people have become familiar with the scientific expertise available to them. The need for scientists to acquire funds from business divisions by linking their research to the needs of those divisions has enhanced communication and improved the links between the corporate R&D laboratory and the company's business divisions—this is a highly desirable means for corporate R&D to have an impact on the rest of the company.

Under the linkage model, however, companies are seeking short-term solutions, such as acquiring technology outside the R&D laboratory instead of building their own; cutting down on fundamental long-term research; and directing research to incremental improvements. The linkage model decreases the likelihood of new products and processes being developed for which new markets can be created. By diverting the focus to the short term, the US is placing itself at a major disadvantage. Furthermore, how one is funding a particular research group has become a key factor for the direction of research. Scientists who are actual producers of research are having a difficult time adapting to the change. Therefore, while the linkage model for corporate R&D is good, because R&D cannot function productively in splendid isolation, it still faces significant challenges.

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Appendix Methodology

Empirical information was obtained by in-depth interviews with scientists and managers of high-tech manufacturing industries, because they lead in total R&D expenditures by US companies and employ the largest numbers of R&D scientists. There are five high-tech industries: aircraft and missiles; professional and scientific instruments; electrical equipment; machinery; and chemicals. Two centralized corporate R&D laboratories were chosen in the machinery and chemical industries. Both laboratories were in many ways typical of other corporate R&D laboratories, in terms of size, expenditures and research activities. They operated independently of any business division and employed over 1000 scientists and engineers from a broader range of scientific and technical disciplines.

Scientists were identified by PhD and MSc degrees in scientific and engineering disciplines, and employment as research scientists in corporate R&D laboratories. Managers were identified by their organizational status, irrespective of any similarities with scientists in training and credentials. Managers have the authority from their governing boards to implement the policies of the corporate R&D laboratory for which they are responsible. Since there are layers of managers in any corporate R&D laboratory, only the first two layers of management were concentrated on. Such managers are the link between scientists on technical possibilities and the upper management on business interests.

Some 31 scientists and six managers from two corporate R&D laboratories were interviewed. In addition, 16 scientists who had worked in corporate R&D laboratories in machinery, professional and scientific instruments, and electrical equipment industries and later joined two academic institutions were selected. They were considered useful for this study, because they were in a position to give outsider perspectives and comments about the reasons behind their moving to academic institutions.

The total sample of this study consisted of 53 subjects, who included 47 scientists and six managers. The pretesting of interviews carried out with six scientists and one manager is not included in the total sample. Interviews were conducted in three stages: from May 1991 to July 1991 with ex-industrial scientists; from September 1991 to January 1992 with industrial scientists; and from July 1992 to August 1992 with managers.

The interviews combined structured and unstructured formats. They were structured, in the sense that certain topics were covered; they were unstructured, in the sense that they resembled a private conversation with the participants. Such a combination provided a better picture of the issues involved in corporate R&D laboratories, by allowing the scientists and managers to express themselves in depth, while the interviewer could maintain a control over the topics and was able to probe interesting leads. The interviews were tape-recorded and lasted from 40 minutes to almost 2 hours.

The interviews were transcribed verbatim for data analysis. The material from each interview was used to develop themes concerning underlying patterns and processes. Once all the interviews were categorized under general themes, the original transcript materials were studied again to determine the reliability of the categorized information. Following this verification procedure, individual interview materials were integrated under general themes. Information under each theme was first separated by the source—ex-industrial scientists, scientists from the first company, scientists from the second company, managers from the first company, and managers from the second company. The main patterns and generalizations under each theme were identified from the five sets of subjects. A final report was then prepared. Great care was taken to minimize bias in inference and interpretation. Interview materials at various stages of analysis were reviewed by Professor Richard Worthington of Pomona College, who was my dissertation advisor at Rensselaer Polytechnic Institute.

Interviews served two purposes: firstly, they provided the information on what was happening in corporate R&D laboratories, so could be compared and contrasted with accounts in the literature; secondly, they presented the perceptions, values and concerns of the interviewees.

Sample Characteristics

Out of 31 industrial scientists interviewed, 27 were male and four were female. Twenty-five male scientists were white and two were Asian. Out of four female scientists, two were white, one was black and one was Asian. These scientists were employed as researchers. Most of them had joined industry after finishing their education, and they have stayed in the same company since then. Only two scientists came to industry after teaching in academe for a couple of years, and one had worked in another company for 4 years. All the scientists had been in the present company for a good number of years; two scientists had joined the company in the late 1960s, 17 in the 1970s and the rest in the early 1980s.

Most of industrial scientists had PhDs; only two had master degrees. One MSc scientist was working towards his PhD, after working in the company for 8 years. The other MSc scientist was regarded as a successful scientist, with over 50 publications and having received the highest technical achievement award given by the company. The scientists' degrees were in a wide range of disciplines, such as bacteriology, biology, computer science, electrical engineering, inorganic chemistry, materials science, mathematics, medicinal chemistry, microbiology, organic chemistry, physical chemistry and physics. These scientists had excellent publication records. Two had published over 100 articles, nine had published over 50, seven had published over 25 and the rest had published around 10 articles. Eight scientists had received the highest award given by their companies for sustained technical achievement.

The ex-industrial scientists were currently employed in various scientific and engineering disciplines as associate professors and professors in two academic institutions. All 16 ex-industrial scientists interviewed were male; 12 were white, one was black and three were Asian. They had PhDs in biochemistry, biology, chemistry, computer science, inorganic chemistry, mathematics, metallurgy, organic chemistry, physical chemistry and physics. They had published well and many held distinguished awards, including a Nobel Prize. Two were editors of prominent journals in their field. All had worked in industry for a minimum of 5 years prior to joining academe. Eight scientists had worked in industry for more than 10 years and two for over 20 years. Some had left industry for opportunities to teach and work with students and because of corporate R&D laboratories started being reorganized in the 1980s.

All six managers interviewed were white males. All had PhDs; their degrees were in disciplines of biology, chemistry, computer science, electrical engineering and material science. Three managers held the title of the first-level management and three of the second level. The first-level managers managed 4–7 PhDs, 3–5 MSc and 1–6 BSc scientists. The second-level managers managed 4–6 of the first-level managers' groups, consisting of about 60 people, including almost 30 PhD scientists. Two managers had joined the company in the early 1970s, two in the late 1970s and the rest in the early 1980s. Five managers initially joined the company as scientists and, within a few years, moved to managerial positions; one manager joined the company as a first-level manager.