Behavioral Rules in R&D Strategies: German and Dutch Electrical Equipment Enterprises between the Wars

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Both business history and the history of technology demonstrate that the decision processes of firms are not always reducible to rules defined by standard economic theory. Individuals and organizations must analyze problems and make choices in a context of unpredictably changing circumstances. In this paper, we will see how firms' decisions, both in periods characterized by technological discontinuities and in more stable phases of cumulative technological and scientific knowledge, can be explained on the basis of rational, but non-optimizing, behavioral principles.

We employ the concept of "Task Environment" to classify operating factors that decision-making agents (individuals and organizations) must consider. Next, we formulate principles of behavior that direct the construction of organizational patterns appropriate for dealing with the various technological dynamics. We then discuss the theoretical framework and in that context reconstruct the R&D activity of the German and Dutch electrical equipment industry during the interwar period.

Task Environment Decisions: Importance of Representational Models

An important principle of procedural rationality requires the use of representational models, which structure circumstances to make them amenable to problem-solving processes [14]. Decision making clearly is affected by the representational model devised, which in turn is not given definitively, but is continually modified on the basis of environmental information. Thus we can assert that the configuration of information flows is fundamental within the decision process.

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Our analysis assigns basic importance to environmental variables--i.e., to the constraints and possibilities created by contingencies and task environments. The starting point is a consistent definition of task environment in terms of complexity, assessed by means of two indicators: the range of technical variations, and the degree and intensity of connections among entities acting in a particular context. Let us take a familiar model of technological evolution: the "technology cycle" [19], characterized by four components: technological discontinuity, "eras of ferment," "dominant design," and "eras of incremental change." A slightly different, but similar, model describes sequences of "macroinventions" ("macro-mutations") followed by adaptive "microinventions" [15].

An element common to both views is the randomness of technological breakthroughs and selection processes. According to Tushman and Rosenkopf, technological discontinuities "are fundamentally different product forms that command a decisive cost, performance, or quality advantage over prior product forms" [19, p. 607]. Because technological discontinuities begin as discontinuities of production trajectories of knowledge, it is impossible to define a single set of parameters (technological, economic, or cultural) within which to assess firms' performance.

The "era of ferment" is characterized by increased "variation in a product class" [19, p. 318] resulting from strong competition among different technologies (old and new) or among different forms of a new technology. During this period, activity aimed at widening the range of technical variations prevails over selection activity, and retention mechanisms (i.e., learning by doing, learning by using) grow stronger. This process involves making choices among a multiplicity of rival technologies in situations of great uncertainty.

Finally a "dominant design" - "a set of core design concepts that corresponds to the major functions performed by the product" [10, p. 14] - emerges; it is embedded in a product and expresses a technological knowledge system: it defines the coordinates that model evolutionary shapes. The emergence of a dominant design opens an era of incremental change, within which problem- and puzzle-solving activities prevail within general and determined parameters. During such periods. the level of uncertainty gradually decreases.[2]

[2] During periods of discontinuity, the agents can neither define a complete list of possible states of the world nor assign probability distributions to them. These are situations with "strong substantive uncertainty" [4] or "imperfect structural knowledge," where an uncertain (unstable) task environment prevails [11]. In "eras of ferment," the agents (individuals and organizations) have a complete list of possible states of the world ("perfect structural knowledge"), but they do not know the specific parameters of their decision problem: the contexts are characterized by "imperfect parametric knowledge" where a stable task environment prevails [11].

Task Environment, Information Processing, and Organizational Architecture of the Firm

Determining the complexity of the task environment is a fundamental step in analyzing the requirements of information processing and making the corresponding choices about the structure of firms. The choice of the organizational architecture of firms is closely connected to the two types of task environments.

When environmental complexity is characterized by the existence of independent parts - that is, during phases of technological discontinuity - organizational behavior has to acquire flexibility in order to extract signals from environments in which the parameters remain unclear [12]. The need for flexible behavior implies that less integrated organizational models will prevail, because they can gather information more efficiently.

If environmental complexity is based on connections among the parts of environments, firms can order production sequences on the basis of technical and economic linkages. Consequently, limits to the adaptation processes between the subunits of firms arise, because these subunits must be arranged within sequences of adaptive behavior--that is, in contexts ruled by serial adaptation. The ordering of the adaptation process, by reducing the field of possible interactions for every subunit, leads to rigidity, as integrated and sequential organizational patterns emerge. Even as the organizational components become subject to greater information constraints, the validity of the bounded behavior is dependent on the existence of particular environmental knowledge flows.

Behavioral Rules in R&D Strategies

We reconstruct the strategies and behavior of the German and Dutch electrical equipment industries (Siemens, AEG, Telefunken, Osram, and Philips) from 1920 to 1936 to examine how firms characterized by specific technological paths and organizational capabilities and routines selected different strategies and decision procedures in order to confront the changes taking place. All of the firms examined faced the following fundamental problems: 1) the need to choose the best strategy in unstable and rapidly changing markets; 2) the need to use research to foster and control technological evolution and at the same time to reduce technological and economic uncertainty; 3) the need to select an organizational model able to promote interaction between research activity and production units.

The technical and scientific environment of the period was formed by the technological stimulus associated with World War I and the great expansion of industrial R&D, which significantly changed market and competitive factors. The 1920s and 1930s were a period of particular uncertainty and instability in the electrical engineering field. First, two different levels of innovation existed: in high-voltage technology, product and process innovations had temporarily come to an end, whereas low-voltage technology was marked by a huge innovative potential. Second, a gradual but fundamental shift in basic science, from electron-based physics to quantum and solid-state physics, had a strong impact on both the electric light and the radio and telecommunications industries [17].[3]

AEG

Until the end of World War I, AEG had extended its technology, based in the high-voltage sector, primarily by purchasing foreign patents. Until the late 1920s, the company had only small development departments operating in close relation to the manufacturing units and charged with modifying patents to work with AEG's own production line. AEG contributed very little research of its own, securing only one patent, related to electric lamps.

It is interesting to examine how a bounded model of research reacted to the success of innovative technology in the low-voltage field. In a few years the company underwent a remarkable change from a marketing and development orientation to a research orientation, strongly shifting to low-voltage technology. In the early 1920s, the management of AEG coped with the strategic problem of whether to maintain its reliance on foreign technology or to implement new intra-firm R&D. AEG's situation is a typical example of conditions of strong substantive uncertainty when relevant parameters of the decision environment are unknown.

Several early attempts to establish a central research laboratory had received no response from company leaders, and it was only in 1928, with the coming of Herman Bucher as head of the executive board, that the *Forschungsinstitut* of the AEG was established. The AEG laboratory, headed by the experimental physicist Karl Ramsauer, pursued an original strategy to manage R&D and its organizational linkage within the whole company. Work in the Forschungsinstitut was aimed primarily at basic research to provide the company with a new technology base; it was not charged with solving the day-to-day manufacturing and developmental problems of the plants. The main problems of the Forschungsinstitut, however, were how to endure as a central research unit in a heavily decentralized company and how to disseminate scientific results among the different units.

Ramsauer solved these problems in two ways. First, some research departments were transferred to the manufacturing units when they had finished the basic research for a product or process innovation. This was only a short-term solution, because these transfers damaged the capabilities of the *Zentrallaboratorium* in the long run. The *Technisch-Physicalischen Werkstatten* represented a second way to cope with the problem. It had the tasks of testing the

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[3] The mainstream of industrial research took place in the area of basic science, where an invention could suddenly create vast new markets for an industry. In the same way, marketing areas that were still profitable and carrying large investments could quickly be overtaken by new products. These factors placed severe pressure on traditional R&D investment and on the organizational strategies of firms, and then produced impulses for change that completely reshaped R&D organizational routines.

output of the *Forschungsinstitut* for manufacturing on a large scale and of ensuring product quality to speed adoption by the production plants.

The slump of the mid-1930s severely affected AEG, but the company survived because of the link it had established between pure science and manufacturing. The *Forschungsinstitut* was representative of the type of modern research laboratory established at the end of the 1920s, not only in the electrical industry but in others as well. AEG management had the advantage of not having to deal with an established research tradition or organization or with obsolete technological expertise.

Thus the innovation split in electrical engineering technologies impelled AEG to change its research strategy and organization model radically according to its new principles, which were aimed at greater flexibility and developing mechanisms to coordinate the activity of subunits.

Siemens

The central research laboratory at Siemens represented both a different strategy and a different tradition. Since the late 1890s, Siemens had pursued the whole spectrum of electrical engineering and had to a great extent exploited the inventions of its own physicists. Its organizational structure for R&D provided a strict division of central research - one part directed toward Siemens & Halske (primarily in the telephone and telegraph industries) and the other toward Siemens & Schukert (primarily in electric lighting and power).

Among the firms considered, Siemens was the only one to reshape its R&D organization dramatically when faced with the technological discontinuity of the second half of the 1920s. Up to that point, Siemens had focused on electrical generating plants, which had already reached the phase of a dominant design and cumulative technological paths and had adopted a more integrated organization. Because of the the new developments in low-voltage currents, the departments for research and development grew. Research work was transferred to the *Zentrallaboratorium* in the Werner Works Z of Siemens & Halske, to the *Messgeratelaboratorium* (Technical Laboratory) of Werner Works M, and to the *Abteilungsspeziallabor* (Special Departments Laboratory) at Werner Works F.

In the 1920s, with growing corporate decentralization resulting from technological diversification, Siemens management faced two problems: divisional research outweighed centralized research, and R&D programs often overlapped, making necessary a revision of the financing and control of the company's research activities. Despite the early institutionalization of R&D at Siemens, the Central *Forschungslaboratorium* had always had to struggle for acceptance within the firm. For example, to promote the transfer of research results, Gerdien (head of the Forschungslaboratorium) and the scientists of his department tried to enter into the manufacturing units, hoping to persuade plant managers to rearrange production according to their innovations.

But the rapid technological development had already led to the overlapping of research fields that previously had been strictly separated between the *Forschungslaboratorium* and the *Zentrallaboratorium.* This sometimes resulted in the duplication of research work, or in research done in the *Zentrallaboratorium* that the divisions found infeasible to replicate commercially. Beginning in 1926, both the goals and the funding of the *Forschungslaboratorium's* research activity had to be approved by the departments. A committee of managers, including Siemens & Halske and Siemens & Schukert directors, had the final decision.

The economic depression pushed management toward stricter oversight. Both laboratories suffered deep cuts in R&D funding and research personnel, while research projects were more and more frequently transferred to the specialized laboratories of the production units. The testing workshops of the Forschungslaboratorium and the *Zentrallaboratorium* were combined, and the various research fields were coordinated, merged, and redistributed to the reorganized research laboratories. The *Forschungslaboratorium* now had to conduct all physical research, the *Zentrallaboratorium* of Werner Werks F did all semiconductor research, and the *Zentrallaboratorium* of Werner Werks Z concentrated on the whole spectrum of theoretical and applied chemistry.

The basic problem of technological convergence within Siemens's research system thus had been solved, but the blurring between research and development, between basic or pure research and technical or applied research, and between central and developmental laboratories still existed. Therefore, in 1935, another reorganization took place. Central research was divided into *Forschungslaboratorium* 1 and *Forschungslaboratorium 2*, and the latter became the intra-firm center of basic science and research, concentrating its focus on the new quantum, solid-state, and atomic physics.

The Siemens story is interesting from two different points of view. First, Siemens responded to the technological discontinuity of 1920-36 with strategies similar to those of AEG: greater flexibility and the strengthening of coordinating mechanisms. Second, because its R&D organization had been shaped by a more stable technology and because it was more costly for the company to change, Siemens encountered greater difficulties than AEG in adapting to the new technological phase. In electric bulb and especially in radio technology, Siemens tried to farm out its research.

The Farming Out of R&D: Telefunken and Osram

The practical problem within Siemens's R&D organization can best be seen in connection with Osram and Telefunken, jointly founded by Siemens and AEG. Before World War II, Siemens and AEG had pooled their research (and patent) findings in communications technology. Through the newly created Telefunken, they sponsored the establishment of Osram, where they coordinated their scientific knowledge and experience in electric bulb physics.

Both joint ventures became powerful companies in the interwar period, representing very different types of technology-based and research-oriented organizations. Telefunken was conceived as an "invention company" with an elaborate research branch (in high-frequency and low-frequency communications, in television, and in electrical generators), whose scientific basis was the huge reservoir of patents from the mother companies. Because manufacturing had remained at Siemens and AEG, and only a marketing department supplemented Telefunken's corporate organization, there was no need to choose between centralized and decentralized research. Nevertheless, the flow of research results between the subsidiary and the parent companies raised several problems. The rapid innovations in communications technology led to the overlapping and duplication of research work and to increasing difficulty in interfirm coordination.

Osram, in contrast to Telefunken, had been conceived primarily as a manufacturing and marketing company, whose research capacity was confined to developmental work and defensive "patent research," because no great innovative potential existed in bulb technology at that time. The high degree of cartelization of the whole electric bulb market also provided no incentive to intensify basic research.

Conflicts arose between Siemens and AEG in this area as well, over the interpretation of patent law and over their respective contributions to patents and research. In November 1932, for example, Siemens criticized the low level of research activity at Osram, complaining that insufficient attention was being given to progress in the fields of gas-discharge and fluorescent lamp technology, which was too late and hesitant in getting started. In 1929, the head researcher at the Siemens transistor laboratory, Walter Schottky, painted a very desolate picture of the research situation in Telefunken. Because R&D activity was split apart without any reliable coordinating unit, the development of new products suggested by research findings or new ideas was hampered. In 1931 the managements of Siemens and AEG openly stated that Telefunken, in its present technological and scientific form, was no longer a viable entity.

Farming out thus revealed itself to be an inefficient way of organizing R&D to cope with the convergence of high- frequency and low-frequency research into one great carrier-frequency technology for communications engineering. Indeed, at the end of the interwar period, the complex network of interfirm cooperation that had been characteristic of so much research in the German electrical industry seemed to have come to an end.

Philips

When compared to Siemens, Philips reveals two distinct features. First, the company was from its beginning a firm specializing in the electric lamp industry, whereas Siemens was involved in the entire range of electrical products. Second, Philips did not organize an R&D department until 1924, and the later start favored its adaptation to the changing technological environment of the mid-1920s. As a "latecomer," Philips could see the advantages of adopting a more flexible organization, making it relatively more successful in exploiting the new technology of radio communication.

Until 1914 R&D at Philips was limited to development work aimed at imitating and adapting foreign technology. The First World War stimulated intra-firm research at Philips more than at any other electrical engineering company: Dutch neutrality allowed Philips to concentrate its research activities on the new electric light technology and on the whole area of consumer electronics. Because the company was not expending any effort on defense contracts, it was able to develop and market some of the world's first radio tubes for public use, and it could spend time studying gas-discharge phenomena, which gave the firm a significant advantage over competitors when the war was over.

Although the organization of R&D at Philips was only slightly different from that of others in the electrical industry, its research strategy was fundamentally different from those of the German firms. Despite the early institutionalization of its laboratory as a central research unit, the organizational and conceptual framework of Philips's industrial research system was not fully established until 1924, when a hundred scientists and engineers worked in five research departments on light/gas-discharge, radio/acoustics, chemistry/metallurgy, x-ray, and mathematics/fundamental physics; the laboratory expanded in 1934 to 370 employees.

The *Natuurkundig Laboratorium* became totally independent, and the separation of research from development had effects on the financial and managerial links within the company. For example, even in the early 1920s, along with key research work on radio transistors and gas-discharge tubes, the *Natuurkundig Laboratorium* pursued new product lines, although Philips's board of directors still backed the established light technology. The company's policy was not only influenced but essentially determined by the *Natuurkundig Laboratorium* and the "research community." The applied or "technical research" at Philips was conducted in the so-called Chemical Lab V and in some test departments under the same roof as the manufacturing divisions.

During the 1920s, Philips's research underwent a remarkable diversification and changed its focus somewhat. Radio research especially was expanded, focusing on tube and rectifier research as well as on developing a theoretical background in carrier-frequency physics. By 1925, research on light bulbs had almost ceased at the *Natuurkundig Laboratorium*, and therefore there were underutilized staff and materials that could be directed toward new research fields. Research began on television in 1927, and in 1930 Philips entered the field of telecommunications. This decision was made in full awareness of the economic depression; the managing board felt that the depression might have a serious effect on the radio market, and they conceived telephony as a commodity that would offer more stable prospects.

The *Natuurkundig Laboratorium* increasingly became a force in establishing company policy at the highest level, and it played an especially important role in the making of two crucial decisions. The first was to shift the company from component thinking to system thinking with regard to communications technology, especially in radio research, and to move from producing highly developed components to manufacturing complete systems. Choosing technological systems brought a more differentiated view of the objects of research and their scientific interdependence (thus helping to manage the problem of technological convergence, with which Philips's German competitors were also confronted). The second fundamental decision, forced by the *Natuurkundig Laboratorium* in 1930 - some years earlier than at Siemens - was to enter the new field of solid-state physics and semiconductor research.

During the Depression Philips also undertook a reorganization of its research systems. The long-established patent department had developed into a coordinating and controlling unit for research matters, comparable to the *Zentrallaboratorium* at Siemens. The reorganization only slightly affected the organizational structure of the *Natuurkundig Laboratorium*, whose independence was already institutionalized; indeed, it was strengthened by the correlation of the research budget to the firm's overall earnings. The most fundamental change was in the developmental research department: by the mid-1930s, Philips had a highly developed system of industrial research, with a well-balanced and discrete organization of centralized and departmental research similar to that of AEG. Thus, impelled by the *Natuurkundig Laboratorium*, the Philips Company underwent a fundamental change from an imitative incandescent lamp manufacturer to a highly diversified and innovative electrical engineering company.

The experience of Philips, when compared to those of the German firms, demonstrates two important points. First, an unstable technological environment induces different firms to adopt similar organizational models. Second, the history of an enterprise matters in shaping its relative success in the adaptation process.

Inter-Firm R&D Strategies

After the First World War, the rapidly expanding markets for light bulbs and radio valves gave the electrical industry a sound basis for prosperous years. At the same time, in industrial research laboratories as well as in the universities, a remarkable period of innovation and scientific stimulation preceded the Depression, leading to the invention and development of products and technologies that then carried the postwar boom of the 1940s and 1950s. Semiconductor and solid-state research as well as product and process developments in television and recording started on their way during the interwar period.

Each of the technologies, at times overlapping or converging in their emerging product lines, required a special organization and management of intra-firm R&D. In electric light technology, defensive improvement work prevailed, whereas in electron tube technology the main emphasis was put on R&D activities; solid-state and atomic research, though still in their infancy, were at the center of fundamental research, as scientists attempted to understand their theoretical bases.

Through cartels - the marketing and price agreements among the competitors - the markets for the "high-tech" products of the interwar period developed a rather rigid structure. Through patent pooling and tightening of their marketing regions, the European companies attempted not only to control market fluctuations, but also to prevent the American electrical industry from advancing into the European market.

There was a peculiar swing between competition and cooperation in the electrical industry that provided the setting for industrial research. Beginning in 1921, for example, there was a cartel of "The Big Four" in the radio industry - Marconi, CGT, RCA, and Telefunken - promoting a close exchange of patents and research results. But the existence of the cartel did not prevent Philips from confronting Telefunken with an aggressive strategy of intruding into and eventually dominating the market. In 1925, Telefunken succeeded in signing a contract with the Dutch company that prevented Philips from entering the German radio valve market. In 1929, however, Philips found a loophole through which to enter.

Similarly, their own sharp competition did not preclude Philips and Telefunken from coming to an understanding on how to eliminate other companies from the European tube market. They developed and jointly produced a cheap tube, which was an effective tool to suppress the activities of smaller or newly entering tube companies. In 1931 Philips and Telefunken signed an agreement specifying close technological cooperation, but, at the same time, each firm had procured exclusive rights to new transistor patents from RCA, which gave rise to further competition and conflicts.

In 1922 there was also an agreement in which Osram, Philips, and General Electric bound each other both to exchange patents and technical expertise and to respect their home markets in order to divide the whole lamp market. Two years later this agreement was institutionalized in an electric lamp cartel named Phoebus. Nevertheless, there were constant rivalries between Philips and Osram over the business leadership, culminating in 1933/34, when a conflict arose over mutual rights and duties regarding patents for the new gas-discharge lamps. Despite long negotiations, they never reached a new market-sharing agreement.

Technological evolution on the eve of World War II resulted in the joint presence of many research trajectories, leading to the multiplicity of firms' behavior. Particularly where a dominant design prevailed, as in "high-tech" industry, cooperation and other forms of firm integration appeared, but firms still strugled to enlarge their "flexibility space" to research and develop new products, as in the electric lamp field, by mixing cooperation and competition. These examples provide further confirmation of the theoretical propositions presented earlier.

Conclusions

From this analysis, we can infer that, being faced with unstable and changing markets, German and Dutch firms had to deal with two fundamental problems: 1) the linking problem: how should companies link technology and research strategies, or the R&D laboratories, with the rest of their organization? 2) the architectural problem: how should large research fields and connected production activities be organized?

In regard to the first question, we showed that the organizational models adopted had common characteristics. New internal rules were established to broaden the interaction between strategic and research centers to exploit more efficiently knowledge flows between research and production activities. Philips and the German electrical companies came up with different answers, which seem to have little to do with national patterns, but more to do with their respective technological traditions and histories. Siemens and AEG tried to concentrate on the new technological and scientific fields by farming out certain branches of developmental and applied research to other firms like Telefunken and Osram, whereas Philips succeeded in maintaining its concept of strict intra-firm separation of R&D, thus keeping at its disposal a more flexible system of industrial research.

As for the second question, during phases characterized by drastic technological and scientific change, the firms that enlarged the range of their research lines met with greater success.

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