CHAPTER 7

Organizing Space: Dutch Space Science Between Astronomy, Industry, and the Government

David Baneke

7.1 Introduction

Whenever a new technological or scientific field emerged after the Second World War, Dutch scientists, government officials, and industrial companies feared being left behind. Especially in strategically important fields such as nuclear physics, radio astronomy (radar), and computing, scientists, industrial companies, and the government cooperated to initiate research efforts. These cooperative projects led to what the editors of this volume call "investments in exploration"[1]: the creation of several major new research fields in the Netherlands. One interesting example in the early 1960s is space science. A striking feature of all these projects was the role of Philips Electronics, one of the largest and most powerful Dutch companies. Philips did not always remain active in the new fields, but even

D. Baneke (✉)
Utrecht University, Utrecht, Netherlands

T. Heinze, R. Münch (eds.), *Innovation in Science and Organizational Renewal*, DOI 10.1057/978-1-137-59420-4_7

if it pulled out, it had often contributed significantly to the establishment of a new research infrastructure.

By following space science in the Netherlands from its beginning until the 1980s, we can investigate the interplay between national, industrial, and academic considerations in the establishment of a new scientific and technological field, reconsidering, for example, the importance of political considerations and commercial constraints, the role of management cultures, and the adaptation of institutions to changing contexts. This will enrich our understanding of the various roles that academic science, industrial companies, and the government (the three sectors that together form the so-called "triple helix," although that notion has been specifically applied for a more recent kind of cooperation)[2] played in the science infrastructure. These roles were not always clearly delineated.

In a 2006 paper, Philip Scranton called for a richer understanding of the role of non-market (government) actors in defining problem sets for innovation in the post-war period.[3] Scranton focused mainly on national security issues during the Cold War. The "military-industrial complex" of that era, or comparable networks of industry, academia, and government institutions, was a model of institutional cooperation in innovation and development between the three "triple helix" sectors in the post-war decades. Different models existed as well, however. Unlike in the USA, Britain, France, or Sweden, the military played only a small role in Dutch big science projects. Industry did, with an especially central role for Philips Electronics.

This chapter starts with an introduction of Philips Electronics and Fokker Aircraft and their roles in the Dutch national innovation system. Then I will describe their involvement in the establishment of a Dutch space program, focusing on the Astronomical Netherlands Satellite (ANS) project. Interestingly, the two companies drew different lessons from the project. I will analyze this difference by comparing their aims and ambitions, internal organizations, and the place of technological capability and innovation in the corporate identity of either firm. If we want to understand why Philips was such an important node in the scientific infrastructure, we have to realize that the boundaries between commercial, scientific, and national security considerations were not clear-cut. Philips was a commercial firm, but it also had internalized roles that are traditionally assigned to government or academia. Different parts of the company cooperated in almost the same way as university laboratories and industrial companies would. The case of Fokker was different. There, the notion of a "development pair" would be more applicable. A recent book about Swedish technology development used this notion for the close cooperation between a private company and a government institution in high-tech development projects, in which the government funds a private development project and acts as a guaranteed first buyer. A special version is an "auxiliary development pair," in which the government's support is not aimed at developing and procuring a specific product, but at indirectly supporting whole industrial sectors to build up their institutional infrastructure.[4]

The chapter ends with a brief discussion of the second Dutch satellite project, the Infrared Astronomical Satellite (IRAS), and the new innovation policy that emerged in the 1980s—a policy that was aimed at creating an innovation infrastructure that resembles what later became known as "mode 2" knowledge production.[5] As we shall see, this policy stimulated some forms of cooperation but terminated others. Notions such as "military-industrial complex," "non-military academic-industrial complex," "development pair," and "auxiliary development pair" all describe models of cooperation between governments, industry, and universities that predate the oft-discussed mode-2, but they do not resemble in any way the "mode 1" knowledge production as it is often summarily described in the mode-2 literature. As others have observed before, mode-1, like the "ivory tower" university or the "linear model" of scientific innovation, never existed except as an idealized model to clarify its opposite.[6]

The case of space science is especially interesting because the field did not just pose scientific and technological challenges but also organizational ones. For the emergence of space science as a new discipline, institutional and management innovation was as important as scientific and technological innovation. New forms of management knowledge had to be imported, in this case especially from? the National Aeronautics and Space Administration (NASA). Space projects were notoriously complicated, not only because of the extreme demands on quality and precision but also because of the number and variety of institutions that were involved. They were training areas for cooperation between scientists, engineers, business leaders, and government officials, and in many cases military officers as well.[7] Especially Fokker considered it crucial to learn how to manage large technological development projects, in other words: how to manage technological innovation. The accompanying management jargon formed a major part of the new communal language that all the actors in the new research field of space science had to master in order to be able to cooperate.[8]

Innovation was a central feature of the corporate identity of both Philips and Fokker. It was a part of their role as national champions and arsenals of knowledge and skill. For several reasons, building a scientific satellite was an excellent means to develop desirable skills. The "pure" scientific research that was done with the satellite was almost a by-product of the technology, not the main goal—a spin-off, so to speak. But in the long run, the science was perhaps the most important outcome. Especially IRAS produced ground-breaking new knowledge. This is a reversal of the standard narrative about the relation between science and technological applications.[9] It provides an interesting perspective on one theme of this book: the relation between institutional and intellectual change.

7.2 The Role of Philips in Post-war Dutch Science

In the 1950s and 1960s, Philips Electronics produced a wide range of products, including of course lighting, but also domestic appliances, medical systems, and scientific instruments.[10] The company was constantly expanding. In the early 1970s, at the height of its power, Philips had more than 400,000 employees, including nearly 100,000 in the Netherlands (population at that time: 13 million). In the Netherlands, it was by far the largest company in its sector. Philips was considered to be a national champion: by the government, by the public, and also by itself. Traditionally, the company supported a wide range of social and cultural projects in the Netherlands. Especially in the Eindhoven area, Philips was omnipresent in housing and health projects, sports, and many other aspects of society (*Philips Sport Vereniging*, PSV, is still one of the major soccer teams of the country). These activities strengthened the company's standing as a national institution.

Engineering capability featured prominently in Philips' self-image. The firm's motto in the 1950s was "Triumph of Technology" (*Triomf der Techniek*). Obtaining technological knowledge in new fields was thought to reinforce the company in more ways than just future profitability. It was closely related to national political concerns about the (presumed) Dutch technological lag behind leading nations after the Second World War, and the ambition to maintain national capability in strategic fields. This "arsenal of knowledge" argument played an important role in national industrial policy.[11] Although Philips was not directly supported by the government, at least not openly, the firm always maintained close relations with the Economic Affairs ministry in The Hague.

The company invested heavily in research, spending up to 6% of the turnover on research and development in the 1950s. This money went to the development laboratories attached to each product division, but 1% of the turnover went to the *Natuurkundig Laboratorium* (Physics Laboratory, usually known as NatLab), an independent entity within the company.[12] NatLab founder Gilles Holst and his successor Hendrik Casimir were proud to make their laboratory an academic-style institution which spent significant sums on fundamental research.[13]

Together with Royal Dutch/Shell, by far the largest Dutch (or rather Dutch-British) company, Philips was the largest employer of physicists and chemists in the Netherlands. Recruiting talented students was a prime concern for the two multinationals. For that reason, they carefully cultivated their connections to universities. Several Philips scientists, including the directors of NatLab, had part-time professorships in Leiden or Delft, and academic professors regularly lectured at NatLab seminars.[14] Philips and Shell were important actors in the national research infrastructure. In the 1930s, they lobbied to establish graduate programs in Applied Physics at various universities. In the Interwar years, up to one third of the physics PhDs found jobs at those two companies.[15] The physics students of the Free University of Amsterdam even composed a special hymn for graduates who obtained a job at Philips.[16] After the Second World War, Philips and Shell donated large sums of money toward the founding of new laboratories and technology institutes. Philips was also represented in the governing boards of several universities. The exchange of staff between the universities and the industrial laboratories increased as well. According to Baggen, Faber, and Homburg, the companies significantly influenced academic research topics.[17]

An important aspect of Philips' corporate philosophy was that the company had to be involved in all major new fields of science, regardless of short-term expectations of profit or practical use. Board members Frits Philips and Th. Tromp considered cultivating a broad in-house scientific and technological capability to be crucial for the future of the company.[18] It would put the company in a position to quickly understand new developments and react to them if necessary. One never knew which technology would be the "next big thing," so one needed to have an arsenal of knowledge to draw upon. For this reason, novelty by itself was a motivation to invest in a new field, regardless of its immediate usage perspective.

Another reason was to make the NatLab an appealing employer for talented students with scientific ambitions.[19]

According to Casimir, the best way to get involved in scientific research was to develop scientific instrumentation.[20] One prime example was the production of electron microscopes, but Casimir was also interested in semiconductors and superconductivity, for example. After the Second World War, Philips became involved in new research organizations for, among other subjects, nuclear science and computing. In all cases, it provided instrumentation, most famously a cyclotron. It also got involved in uranium enrichment, first through a research institution and later as a stakeholder in the company Urenco.[21] Another new post-war research organizations was devoted to radio astronomy. During the war, Dutch astronomers Jan Oort and Henk van de Hulst had made plans for post-war radio astronomical research. After the war, Philips joined Leiden and Utrecht observatories in founding the Foundation for Radio Astronomy (SRZM). Over the next few decades, Philips supplied receivers and other technology for several radio telescopes. The combined interests of industry and scientists had enabled the foundation of a new field.[22]

The scope of Philips' activities made the company an important node in the national innovation system. In the context of government–industry–university relations, treating Philips simply as industry would be a mistake in this period. It had internalized elements of all actors. No other company had a comparable position. The embodiment of its scientific clout was NatLab's director H.B.G. Casimir, the most prominent Dutch physicist after the Second World War, who later became President of the Royal Netherlands Academy of Sciences. Another notable Philips alumnus was C.J. Bakker, who was involved in Philips' cyclotron project and later became director-general of the European Organization for Nuclear Research (CERN).

7.3 Fokker: The Importance of Being Creative

Fokker was not a member of the select group of companies that were responsible for the lion's share of R&D spending in the Netherlands.[23] It was, however, the only Dutch aircraft manufacturer, which made it a flagship company with a high national profile. It was a matter of national policy that the Netherlands should retain an independent and "creative" (*zelfscheppende*) aircraft industry, meaning that it should have the capacity to design, develop, and produce new aircraft models.[24] In order to support and fund this capacity, the government founded the Dutch Institute for Aircraft Development (NIV) in 1947.[25] In theory, Fokker would repay the cost of development projects to the NIV out of the profits made from those projects. Those funds could then be used for new projects, making the NIV a so-called "revolving fund." In practice, however, this rarely happened. Government funding for the NIV was a subsidy rather than an investment.

Because of its "creative" identity, engineering capability was at least as important for Fokker as for Philips, but other than for Philips, scientific novelty was less important than technological independence. Its focus was on development rather than research. Fokker had no academic-style laboratory, nor did the company try to be involved in all new high-tech fields. It had a well-defined core business, which it strove to strengthen by technological innovation. At the same time, its national flagship status and the government support through the NIV sometimes clashed with commercial considerations. This sometimes caused tensions in the company's management. For example, it was understood that Fokker needed foreign partners to survive commercially, but its (government-backed) insistence on an independent Dutch engineering department made it difficult to cooperate successfully. Joint ventures with the German Vereinigte Flugtechnische Werke (VFW) as well as with McDonnell Douglass, Aerospatiale, and British Aerospace proved unsuccessful in the long run, in no small part for that reason.[26]

The relationship between Fokker and the NIV could be viewed as a "development pair," except that in the case of Fokker, the Dutch government could not guarantee to act as a first buyer of the end products of the joint development projects. The national airline KLM was independent enough to purchase other aircraft models if it wanted (which it often did), and the Defense ministry often chose not to buy Fokker models that were adapted for military use.[27] This obviously caused some frustration at Fokker.

7.4 Establishing a New Field: Space Research

Scientific research with instruments outside the Earth's atmosphere started after the Second World War. In the USA, the Soviet Union, and (on a smaller scale) in France and Britain, captured German V2 rockets were used to observe, for example, the earth's magnetic field and cosmic radiation. These experiments were difficult, yielding only a few minutes of observations per flight, with a high failure rate. For most scientists, systematic space research became a realistic possibility only after 1957, when Sputnik proved that a longer stay in space on a relatively stable platform was possible.

Satellites were, of course, dependent on military rocket (missile) technology to put them into orbit. In the 1950s, only the USA and the Soviet Union possessed this technology. For scientists from other countries, space came (literally) within reach after American diplomats announced an offer to launch foreign scientific experiments on American rockets. This was a part of their strategy to emphasize their openness and peaceful intentions, in contrast to the secretive Soviet Union.[28]

In the Netherlands, discussions about a national space program started in 1959, when Dutch minister of Foreign Affairs (and future Secretary General of NATO) Joseph Luns wondered how the Netherlands could get involved in space activities. Luns stated that for political, scientific, technological, and commercial reasons, the Netherlands could not afford to be left behind. The Dutch ambassador in the USA had already warned that NASA officials, who were looking for foreign partners, had gotten the impression that there was no relevant Dutch institution to talk to. The ambassador had pointed specifically at the opportunities that space activities offered for Fokker and in the field of "electronics."[29] Among the first to react to Luns' inquiries were the astronomers Jan Oort and Henk van de Hulst. They had no experience with space research—both were active in radio astronomy—but Van de Hulst was president of Committee on Space Research (COSPAR), an international committee of scientists for the advancement of the scientific use of space technology. Around the same time, Eduardo Amaldi and Pierre Auger launched a plan for European cooperation in space, modeled after CERN. Van de Hulst was involved in the discussions about this plan because they took place in the margins of COSPAR meetings.

Luns wanted to join the European space effort, "both because of the countries that will join this European organization, and for financial, personal and scientific reasons."[30] He hoped that the new organization would cooperate with the USA, to benefit from America's technological prowess. Simply joining the talks was not enough, however: he wanted the Dutch opinion to carry weight in the negotiations. The best way to ensure influence would be to have a "modest but sophisticated" (*bescheiden maar weloverwogen*) domestic space program. Luns expected that the national science community and the flagship companies, with their arsenals of knowledge, would enable the Netherlands to enter this new field with relative ease. At the same time, those same institutions stood to be the main beneficiaries.

It took until 1964 before a European space organization was founded—or rather, two organizations: the European Space Research Organization (ESRO) and the European Launcher Development Organization (ELDO).[31] Until ELDO had produced its rocket, ESRO would make use of the American offer to launch foreign experiments. The Netherlands joined both organizations. The Dutch contribution to the ELDO launcher was coordinated by the Institute for Aircraft Development and the Dutch Aeronautical Laboratory (NLL). Both Fokker and Philips (especially its telecommunications division) participated in it. The Dutch participation in ESRO was coordinated by the Geophysics and Space Research Committee (GROC) of the Royal Academy of Sciences.[32] This committee was dominated by astronomers, with Van de Hulst acting as chairman. This rather informal, ad hoc organization coordinated Dutch space science until the mid-1980s.

During the next few decades, all major Dutch space research projects were astronomical experiments.[33] There are several reasons why the astronomers were able to monopolize the field. Most importantly, they had created a strong institutional infrastructure that enabled them to react quickly to new developments and to cooperate on a national level. They had both organizational experience and excellent contacts in political and industrial circles, including with Philips (via radio astronomy). Besides, the Dutch "school" of astronomy had an excellent international reputation.[34]

7.5 The Need for a Large National Project

Fokker, Philips, and the Dutch government had hoped to secure large development contracts from the new European space organizations, but after a few years it became clear that this would not happen. Both companies blamed their lack of proven experience in space projects, but also the fact that the contracts of these organizations were awarded proportionally to a nation's contribution, which in the Dutch case was relatively small. For that reason, the companies lobbied for a significant expansion of the national space program.[35] A large domestic project would provide them with experience and know-how, while at the same time offering the opportunity to demonstrate their capabilities to potential customers.

Acquiring new technical knowledge was not the main argument of the two companies. The "spin-off" effect of space technology for aircraft development was expected to be fairly small. The transfer of skills the other way around was expected to be much more significant: both Philips and Fokker expected to be able to enter the new field easily, cashing in on the arsenal of knowledge it had built since the war. One Fokker engineer called this “spin-in” instead of spin-off.[36]

Crucially, Philips and Fokker both argued that organizational knowledge and managerial experience were at least as important as technological innovation. This argument was used and repeated by industry lobbyists, ministry officials, and politicians alike.[37] In the 1960s, project management was regarded as crucial to innovation. “Systems Management” became a key modern technology in the era of big development projects that had to deal with many actors from various disciplines and institutions, large uncertainties, complex flows of information, and especially constantly changing objectives and design specifications. Developed by the US Air Force and aerospace industry, it was perfected in the Apollo project, generally hailed as a triumph of management as well as technology. The European space organizations ESRO and ELDO tried to emulate this success, with varying results. Especially ESRO looked at NASA as a model for project management.[38]

Obtaining and demonstrating the capability to manage complex development programs was especially important for Fokker. While Philips traditionally entered new fields by developing components or instruments, Fokker wanted to work on the highest “system” level. The emphasis on management skills was related to the national policy of maintaining a “creative” national industry, which attached much value to technical development activities. Fokker’s space activities were not expected to be commercially profitable in the short or even medium term, but rather to support the company’s (and by extension the nation’s) corporate standards, project management skills, quality control, and morale.[39] The management techniques of space projects, with their emphasis on reliability, quality control, and integral system engineering, were directly applicable to aircraft development.

At Philips, similar arguments were used. It had a rather complex internal structure, with many semi-independent units, including national branches in several countries, specialized product divisions, and the NatLab. There were no multi-disciplinary development projects on the scale of Fokker’s aircraft development. Still, Philips’ Central Technical Efficiency and Organization department promoted systems management, attempting to streamline development and production efforts and to make the various departments cooperate more efficiently.[40] Besides, J.H. Spaa of Philips’ Central Development Bureau argued that high-profile development projects boosted corporate confidence.[41] At the same time, as we shall see, market considerations and profitability played a more important role at Philips than at Fokker.

7.6 The ANS

In response to the industrial lobby, the Dutch government sent a call for proposals for an extended national space program to industry, and also to the Royal Academy of Sciences. Fokker, Philips, and the astronomers carefully coordinated their answers. They all proposed to build an astronomical satellite, to be launched with one of the rockets that the American government had offered for foreign science instruments. This became the ANS.

Fokker and Philips mainly wanted to build a satellite; they did not much care about what it would be used for. For several reasons, an astronomical satellite perfectly matched their ambitions: the international prominence of Dutch astronomy justified a large public investment; the project would be unique; astronomy was easy to popularize, making the project visible; it would provide ample opportunity to exhibit technological skill; and finally it was not so politically complicated as, for example, communications satellites.[42] Another reason, not mentioned by the companies, might have been that since ESRO was the main potential client, it was important for industry to demonstrate that it could cooperate with scientists.

Both industry and the astronomers wanted the satellite to be eye-catching, the former because it wanted to advertise, the latter because they wanted to operate at the forefront of science. The satellite would get an innovative stabilization and pointing system, for example. For similar reasons, Philips provided an advanced reprogrammable on-board computer.[43] Fokker built the satellite frame. The scientific instruments were provided by the universities of Utrecht and Groningen. According to Utrecht astronomer De Jager, Philips and Fokker accepted the scientific instrument proposals without any discussion.[44] It was clear that for the companies, as for the government, science was not the main goal of the mission.

ANS was to be launched on an American Scout rocket. NASA even provided a slightly larger launch vehicle, in order to be able to add an American instrument to the mission, which was interpreted by the Dutch as a vote of confidence in the project.[45] But NASA also provided support in the form of rigorous reviews at moments of design "freezes," as well as advice on procedures for component specifications and quality assessment, and how to manage design changes on various levels. These standardized procedures were new to both Philips and Fokker. Additional support was provided (for a fee) by General Electric (GE). Besides, Fokker staff spent several months at GE and Republic Aviation (owned by Fairchild) to learn some aspects of space technology.[46]

ANS was launched in 1974. Due to a minor malfunction, its orbit was more elliptic than planned. Philips' eagerness to show off paid off in this case: much of the observation program could be saved by reprogramming the on-board computer. The science results were respectable but not spectacular; however, the technological performance of the satellite was excellent. The total cost of the mission was estimated to be close to ƒ100 million, almost twice the original estimate. Fokker and Philips reported that they invested ƒ13 million for design studies, fees for GE, and renounced profit.[47] Unofficially, Philips' estimated investment was higher (see below).

One could describe the relation between the government and industry in the ANS project as a "development pair." Most of the funding came from the ministry of Economic Affairs, with a smaller contribution of the ministry of Science and Education. The (government-funded) astronomical community was pushed forward as the first buyer of a space satellite, with the explicit intention of paving the way for future commercial customers. Of course, one has to remember that a satellite was not a new type of car or even jet fighter. Serial production would not be an option in space technology for many decades to come.

The conditions were specified in a contract, which included strict conditions about the price in case of delays or cost overruns. This type of government sponsoring by development contract was a novelty at the time, and it was expected that more would follow. For that reason, Spaa advised the Philips board that the company's contribution should not necessarily be large, but it should be highly visible, for political reasons. In a later stage, board member and NatLab director Casimir also argued that Philips should accept financial loss on this project in order to secure the government's goodwill for future projects.[48]

7.7 Lessons from ANS: Difference Between Philips and Fokker

Around the time of the launch of ANS, representatives of industry and astronomers discussed the possibility of an "ANS-B," a second Dutch satellite based on the same design, again with American cooperation.[49] The proposals referred to the same arguments about the importance of technical and managerial experience for industry and innovation. A new argument was added however: space technology neatly matched the new economic policy aims of the government in the 1970, because of its relatively small use of raw materials and energy and its potential application to monitor environmental problems.[50]

The new satellite was mainly promoted by Fokker. Philips supported the lobbying effort, but behind the scenes the company's management had already decided to pull out of the space business. This was the result of an internal evaluation of the ANS project. The remarkable difference between the two firms' evaluations reveals the different corporate strategies concerning innovation, which directly influenced their role in space science, the field that they had helped to build.

At Fokker, the space activities had been concentrated in a dedicated department, to which staff was allocated on a temporal basis as the project required. This matched the existing company structure: large, multidisciplinary development projects with tight quality constraints were part of the normal way of operating in aircraft manufacturing. That is also why the company was so interested in NASA's project management procedures. ANS was a large and complex project in which every design change, no matter how small, had consequences throughout the system, which was exactly what made it so interesting to Fokker.

Things at Philips were different. The company had a venerable tradition in scientific research and high-tech development, but ANS was the first project of this magnitude.[51] Work on the project had been divided over several of the relatively independent units within the company. Much of the most innovative technical work was done by a relatively isolated group within the NatLab; the on-board computer was built by the subsidiary Hollandse Signaalapparaten, a defense contractor, while the Telecommunications division (*hoofdindustriegroep* PTI) provided components, as did other divisions. This complex institutional structure had impacted the project in several ways. Philips was a microcosm, in which various features and problems of university–industry cooperation were visible. Some divisions complained that weight and power allowances within the satellite were not distributed fairly between the components, making the margins for their work extra tight. At NatLab, staff complained that its mission was to do research, not coordinate large-scale projects. Apparently, the interest in management was stronger at the central company level than in the NatLab or the divisions. Meanwhile, the telecommunications division complained that it had been left with relatively uninteresting but costly work. The components themselves were not so novel as to require innovations that could be used in other products, while the quality constraints were a thousand times stricter than the division was used to. The division was compensated for this work—it was treated as a subcontractor—but still, manager N. Rodenburg was very worried about the financial consequences of the project.[52] In an evaluation of the management aspects of ANS, Philips engineer P. van Otterloo concluded that the complexity of ANS had been underestimated.[53] Project planning procedures had struggled to keep up with the frequent design changes, while paperwork and quality assessment had cost much more time than expected, resulting in delays and cost overruns. As the government contracts specified a fixed price with only a partial reimbursement of budget overruns, ANS left Philips with an estimated loss of c. *f*17.5 million.[54]

Despite these problems, Van Otterloo considered ANS a useful project for Philips, not least because it was a "valuable exercise in the application of Systems Management in a Research and Development project."[55] During the project, the company's staff had learned the new language of component specifications, systems design reviews, failure mode and effect analysis, and other management procedures. These notions were increasingly regarded as useful tools in both development and production. Van Otterloo suggested that ANS could be a useful case study for the company's training program for talented young staff members for this reason.

An independent consultant, General Technology Systems Ltd, also concluded that the fragmented internal organization negatively impacted the firm's prospects in space activities. For example, the isolated position of the ANS project group at NatLab made it hard for other Philips departments to benefit from the gained technical knowledge.[56] In the end, Philips' leadership concluded that it had no future in space. Only Hollandse Signaalapparaten would remain active in the field. The project had been an interesting technological challenge, but the multi-disciplinary aspect of the project was not very interesting to the company, especially compared to the huge administrative effort and the amount of staff and resources that had been invested. Space projects were too complex and too unpredictable, and they did not fit the company's structure.[57] Besides, Philips was increasingly skeptical about the commercial outlook for space products. The international market was difficult to penetrate, while the national market was simply too small. Similar reasons had led Philips to abandon its ambitions in the field of nuclear energy.

Fokker's role more traditionally matched that of industry, though it was shielded from direct market pressure by direct and indirect government support. Other than Philips, Fokker had no ambition to do academic-style scientific research, though it was keen on producing new knowledge, both in technology and in management. Fokker was not put off by bureaucratic complexity and extreme quality constraints. Learning how to manage those was crucial for its core business. Nor was it deterred by commercial uncertainty, as that too was common in the aircraft business. The company's monolithic structure made it relatively easy to allocate staff to temporary programs within the company. Besides, the semi-public NIV bore most of the financial risks of its development projects. Just as with aircraft development projects, Fokker promised to repay the NIV's investment with profits obtained from future contracts, but in the case of ANS no one really expected any profit in the short or even medium term.[58] Fokker got exactly what it wanted out of the project—except international contracts, which was why it wanted to build another, more ambitious, national satellite.

7.8 IRAS and the Policy Changes in the 1980s

Both Fokker and the astronomers were pleased with the ANS project, and eager to initiate a second project along similar lines. Although they were disappointed about Philips' decision to terminate its space activities, they obtained Philips' promise to politically support a campaign for a second scientific satellite.[59] The campaign was successful: the government agreed to a second national satellite, again mostly funded by the ministry of Economic Affairs. This became the IRAS.

IRAS was a much more ambitious project than ANS, not least because it included cryogenic cooling of the complete telescope system. It became even more complicated when NASA decided to merge it with several American proposals for infrared satellites. IRAS became a joint American–Dutch project, with the Americans supplying crucial technology and half of the total funding. Great Britain also participated in the project, providing the ground station. Throughout the project, IRAS was plagued by problems, both technologically and organizationally.[60] The satellite was launched in 1983. It provided the first infrared survey of the sky, including observations of interstellar dust clouds and thousands of new objects. The IRAS catalogues of observations became starting points for much subsequent astronomical research. The cryogenic technology was later used in several other satellites, including the Cosmic Background Explorer which earned its principal researchers a Nobel Prize, and Gravity Probe B.

Of course, both Fokker and the astronomers were eager to build a third satellite. This time, the astronomers proposed an X-ray observatory. An influential government council advised negatively, however. The Dutch government had funded ANS and IRAS to help Dutch industry to enter a new market; it was about time that the space sector should become economically independent. But it was not only reluctance to keep funding one economic sector that withheld the government. More generally, views on the government's role in industry and innovation had changed. Politicians had become wary of directly subsidizing large industries after the messy bankruptcy of the Rijn-Schelde-Verolme (RSV) shipyards in 1983. Besides, there were increasing European regulations against state support for industry. Finally, changing views on market (de)regulation also worked against supporting individual companies. In the political and economic context of the 1980s, direct government support for large companies was not as natural as it had been before, although both Fokker and Philips kept receiving support behind the scenes (e.g. with the controversial "Technolease" construction).

For these and other reasons, government policy changed from targeted support to a more general "innovation policy," which explicitly would also include small and medium-sized companies. The new aim was to stimulate market-driven cooperation between industry and academia, preferably without too much government interference or funding. The government attempted to do this by creating favorable institutional frameworks and incentives.[61] This meant that space science and nuclear science, two of the main beneficiaries of post-war science policy, lost their privileged position.

Together with other developments at universities and in industry, the new policy opened the way for the emergence of what is often described as "mode 2" knowledge production frameworks, or something closely related.[62] At the same time, this meant the end of the kind of cooperation that produced ANS and IRAS. As we have seen, this was as much the result of changes in economic policy as in innovation or science policy. The immediate result was that there would be no third national satellite. Henceforth, all space activities would take place in the context of NASA and European Space Agency (ESA) missions, "as befits a small nation," in the words of Science minister A. Pais.[63] This was both because the cost of space missions had increased and because after years of struggling, ESA had finally become a successful organization with its own launch capability (the Ariane launchers).

The Netherlands no longer tried to maintain an independent capacity to build entire satellites, but rather specialized in specific components.

The changing political climate also had direct consequences for the institutional organization of space research. The informal structure of the Royal Academy Committee on Space Science (GROC) was replaced by a more formal organization, modeled after the existing organizations for nuclear physics and radio astronomy. One could say that, space science became a "normal" scientific discipline. The new Space Research Organization (SRON) was still funded by the government, but it was also supposed to earn 15% of its budget by doing contract research for industry. This is an example of way the government tried to press institutions to enter new partnerships. The government suggested that its skills in high-precision manufacturing, miniaturization, and robotics might be useful for medical appliances, for example. In practice, this proved to be difficult. The largest contracts came from science organizations such as ESA and CERN, all government-funded organizations.[64]

The changed socio-economic context also had consequences for Philips and Fokker. They felt the increased market pressure, but again, they chose radically different solutions. Philips finally gave up its ambition to maintain a complete arsenal of knowledge. In a series of radical reorganizations, the company terminated or scaled down its activities in many fields, focusing on a number of core areas such as lightning and medical systems. The number of staff also decreased significantly. In the best-known reorganization, "operation Centurion" in the early 1990s, the complex structure of the firm was streamlined, reducing the number of divisions and departments. One could perhaps say that financial and commercial pressure forced a change in emphasis from engineering to commerce. The NatLab was also downsized and its "pure science" ambitions were toned down, although it remained by far the largest industrial laboratory of the Netherlands. Philips focused more on its role as a commercial industrial firm and less on the academic and national warehouse of knowledge aspects. So ironically, in the era of increasingly dynamic cooperation between industry, research institutions, and government organizations, some types of crossovers ended.

Fokker chose an opposite approach. Its focus on engineering and large-scale development increased rather than decreased. Fokker's space department finally managed to obtain several contracts, usually as part of international consortia. After IRAS, it did not build complete spacecraft, but gradually specialized in components such as solar panels. In the mid-1980s, Fokker also started two major new aircraft development projects (F50 and F100). These projects proved to be too ambitious, however. The company became increasingly dependent on government subsidies. Foreign partners were sought, but as before, this was complicated by the Dutch insistence of maintaining an independent engineering unit in the Netherlands.[65] In 1996, Fokker had to file for bankruptcy. The space department survived, as it had become independent company shortly before the bankruptcy. Under the name Dutch Space, it is now part of Airbus Defense and Space, a European aerospace company.

7.9 Conclusion

The establishment of space research as an academic research field in the Netherlands was the result of a complex mixture of political, economic, scientific, and institutional developments. It was the Foreign Ministry that first raised the subject, but Philips and Fokker were the driving forces behind the Dutch national space program in the 1960s and 1970s. Their political clout provided astronomers with some of the most expensive scientific instruments ever built in the Netherlands. Astronomy benefited as vehicle for government support as "first buyer," in an institutional setup that resembled a "development pair."

ANS and IRAS were scientific instruments, used by the traditional academic discipline of astronomy. They became the flagship projects of a new research field: space research. But big science is never just about science.[66] The case of Fokker illustrates the importance of development rather than research. It also illustrates that companies do not need to do fundamental science to have a major impact on the development on a scientific field.

Many arguments were used to legitimize government spending on space technology. Significantly, the introduction of innovative management systems was one of them. Scranton has stressed the importance of management techniques in post-war innovation.[67] Cold War era development projects were so complex and unpredictable that cost and risk management was extremely difficult. Controlling them became a key technology in itself. In this case, a demand for institutional renewal motivated the establishment of a new research field as much as the other way around!

The importance of management skills also illustrates that universities or industrial research laboratories are not the only source of innovation. Important types of new knowledge were produced at other levels. Focusing on academic-style research as the main source of new knowledge misses important aspects of innovation. Similarly, the arguments for cooperating with NASA show that importing knowledge was as much a source of new skills as in-house innovation. This goes especially for institutional innovation.[68]

Philips' unrivaled position in the Dutch economic and scientific landscape was crucial for the formation of several new research fields. Even when the company was not able to gain a strong position in a new market, its efforts had a lasting impact on the Dutch scientific infrastructure, and thus to the renewal of Dutch science (see editor's introduction). Few technological companies had a similar broad and deep presence in their home country. The most comparable case might be Sweden, where SAAB and other Wallenberg group industries also acted as national institutions as well as commercial firms. The relation between Philips and academic institutions was so systematic that it can be compared to Eisenhower's military-industrial complex, except that in this case the military were not involved.

Scranton has mentioned several ways in which governments can stimulate industrial innovation: by stimulating innovation in state-owned firms or by initiating "projects" in cooperation with industry.[69] Other models include cooperation in a "development pair," large-scale government (military-) industrial "complex," or governments acting as a guaranteed first buyer of an innovative product. Governments, private companies, and research institutions were involved in ever-changing institutional setups throughout the twentieth century (and probably also before). The view of science as a "source of strategic opportunity," one of the characteristics of "mode 2" knowledge production, is by no means recent or new.[70] The history of innovation since the Second World War is much richer.

Only in the late 1970s did the government start to develop an innovation policy. The idea itself was not new; the novel aspect was the fact that it was an explicit policy instead of a seris of ad hoc decisions. This gave rise to new tools and concepts. ANS was never part of an "innovation policy"; it was industrial policy and science policy. When this specific kind of industrial policy fell out of favor in 1980s, this led to the cancellation of a third national satellite. The emergence of mode-2 as model favored by policy makers meant the end of some other models. Interestingly, science policy since the 1980s has been increasingly aimed at using science to support innovative industry. In this case, however, the opposite happened: industrial policy supported the emergence of a new scientific field. This was not the main goal, but it was perhaps the most notable effect.

Notes

1. See editor's introduction, in this volume.
2. Henry Etzkowitz and Loet Leydesdorff, "The Dynamics of Innovation: from National Systems and 'Mode 2' to a Triple Helix of University-Industry-Government Relations," *Research Policy* 29 (2000); Henry Etzkowitz, "Innovation in Innovation: the Triple Helix of University-Industry-Government Relations," *Social Science Information* 42 (2003).
3. Philip Scranton, "Technology, Science and American Innovation," *Business History* 48 (2006): third proposition.
4. Per Lundin, Niklas Stenlås and Johan Gribbe, *Science for Welfare and Warfare: Technology and State Initiative in Cold War Sweden* (Sagamore Beach, MA: Science History Publications, 2010), 45, 147, 255.
5. Michael Gibbons et al., *The New Production of Knowledge: the Dynamics of Science and Research in Contemporary Societies* (London: Sage, 1994); Helga Nowotny, Peter Scott, and Michael Gibbons, "Introduction: 'Mode 2' Revisited: the New Production of Knowledge," *Minerva* 41 (2003); Dominique Pestre, "Regimes of Knowledge Production in Society: Towards a More Political and Social Reading," *Minerva* 41 (2003).
6. Pestre, "Regimes of Knowledge"; cf. David Edgerton, "The 'linear model' did not exist: Reflections on the history and historiography of science and research in industry in the twentieth century," in *The Science-Industry Nexus: History, Policy, Implications*, ed. Karl Grandin and Nina Wormbs (New York: Watson, 2004).
7. Stephen Johnson, *The secret of Apollo: systems management in the American and European space programs* (Baltimore: Johns Hopkins University Press, 2002).
8. Space research can be regarded as a 'fractionated trading zone' as described by H. Collins, R. Evans, and M. Gorman, "Trading zones and interactional expertise," *Studies in History and Philosophy of Science* 38 (2007): 660–62, in which various disciplinary cultures remained visible next to each other while sharing important material cultures (the projects were centered on space instruments) and a communal language (systems management).
9. Cf. Scranton, "American Innovation," second proposition.
10. On the history of Philips after the Second World War: I.J. Blanken, *Een industriële wereldfederatie: Geschiedenis van Koninklijke Philips Electronics N.V., vol. V* (Zaltbommel: Europese Bibliotheek, 2002).
11. On the notion of "arsenal of knowledge": John Krige, "Building the arsenal of knowledge," *Centaurus* 52, no. 4 (2010).
12. Blanken, *Een industriële wereldfederatie,* 129, 147.

13. Kees Boersma, *Inventing Structures for Industrial Research: a History of the Philips NatLab 1914–1946* (Amsterdam: Aksant, 2002); Marc de Vries, *80 years of research at the Philips Natuurkundig Laboratorium 1914–1994* (Amsterdam: Pallas Publications, 2005).
14. Marijn Hollestelle, *Paul Ehrenfest: Worstelingen met de Moderne Wetenschap, 1912–1933* (Leiden: Leiden University Press, 2011), 186.
15. H.G. Heijmans, *Wetenschap tussen universiteit en industrie: de experimentele natuurkunde in Utrecht onder W.H. Julius en L.S. Ornstein 1896–1940* (Rotterdam: Erasmus Publishing, 1994), esp. 160–161; cf. P. Baggen, J. Faber and E. Homburg, "Opkomst van een kennismaatschappij," in *Techniek in Nederland in de twintigste eeuw VII: Techniek en modernisering: balans van de twintigste eeuw,* ed. by J.W. Schot et al. (Zutphen: Walburg Pers, 2003).
16. A. Flipse, " 'Geen weelde, maar een offer'. De band tussen Vrije Universiteit en achterban, 1880–1950," in *Universiteit, Publiek en Politiek*, ed. by L.J. Dorsman and P.J. Knegtmans (Hilversum: Verloren, 2012).
17. Baggen, Faber and Homburg, "Opkomst".
18. Blanken, *Een industriële wereldfederatie,* esp. Chap. 4.
19. Ibid., 133.
20. De Vries, *80 years of research*, 234.
21. Friso Hoeneveld (Utrecht University) is working on a PhD dissertation on the history of the nuclear science institution (FOM). Abel Streefland (Leiden University) is working on a PhD dissertation on the Dutch uranium enrichment project. Albert Kersten, *Een organisatie van en voor onderzoekers: ZWO 1947–1988* (Assen: Van Gorcum, 1996); F. Hoeneveld and J. van Dongen, "Out of a clear blue sky? FOM, the bomb and the boost in Dutch physics funding after World War II," *Centaurus* 55 (2013).
22. On radio astronomy: Woodruff T. Sullivan, *Cosmic noise: a history of early radio astronomy* (Cambridge: Cambridge University Press, 2009); Astrid Elbers, "The establishment of the new field of radio astronomy in the post-war Netherlands: a search for allies and funding," *Centaurus* 54 (2012).
23. For most of the twentieth century, those companies were Philips (electronics), Shell (oil), Unilever (food and consumer products), AKZO and its predecessor AKU (chemical industry), and DSM (mining, later chemical industry). Currently, the largest R&D investors also include two former Philips subsidiaries, ASML and NXP (both semiconductor industry).
24. On Fokker: Marc Dierikx, *Uit de lucht gegrepen: Fokker als Nederlandse droom, 1945–1996* (Amsterdam: Boom, 2004); A.A.M. Deterink et al., *Onderzoek naar de oorzaak van het faillissement van Fokker* (Deventer: Kluwer, 1997).
25. Ed Muller, *50 jaar Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart* (Katwijk aan Zee: Satellite Services, 1997).

26. Deterink et al., *Onderzoek*.
27. Dierikx, *Fokker als Nederlandse droom*.
28. John Krige, *American Hegemony and the Postwar Reconstruction of Science in Europe* (Cambridge, MA: MIT Press, 2006a); John Krige, "Technology, foreign policy, and international cooperation in space," in *Critical issues in the history of spaceflight*, ed. Steven J. Dick and Roger D. Launius (Washington, DC: NASA, 2006b).
29. GROC file 165/347-16: J.C. Kruisheer to J. Luns, 10 May 1960; Henk van de Hulst, "Seizing opportunities: some comments on the Dutch national space science programme of the sixties and seventies," in *Science beyond the atmosphere: the history of space research in Europe*, ed. Arturo Russo (Noordwijk: ESA, 1992). On the history of Dutch space research: Niek de Kort, *Ruimteonderzoek: de horizon voorbij* (Amsterdam: Natuur & Techniek, 2003); David Baneke, "Space for ambitions: the Dutch space program in changing European and transatlantic contexts," *Minerva* 52 (2014).
30. Letter from Luns, 23 January 1960, National Archives, The Hague, Algemene Zaken records, file 5714.
31. John Krige and Arturo Russo, *A history of the European Space Agency 1958–1987, vol. I: the story of ESRO and ELDO 1958–1973* (Noordwijk: ESA, 2000).
32. Klaas van Berkel, *De stem van de wetenschap: geschiedenis van de Koninklijke Nederlandse Akademie van Wetenschappen, vol. 2* (Amsterdam: Uitgeverij Bert Bakker, 2011), 328–37.
33. A list of experiments are provided by De Kort, *Ruimteonderzoek*, 206.
34. David Baneke, "Teach and travel: Leiden Observatory and the renaissance of Dutch astronomy in the interwar years," *Journal for the History of Astronomy* xli (2010).
35. NA, Binnenlandse Zaken records, file 5577: letters from industry.
36. Interview by the author with Jan de Koomen (26 April 2011); cf. file 821:921.94 no.1b: "Some considerations on a scientific satellite", July 1963; cf Krige and Russo, *European Space Agency*, 73; J.H. Spaa, "Enige konklusies uit het ANS-projekt vanuit het Philips standpunt," Philips Company Archives, file 821:921.94 no. 4, 1975.
37. See, for example, NA, Binnenlandse Zaken records, file 5577; remarks in Parliament by Minister Nelissen (Economic Affairs) 12 November 1970, Handelingen van de Tweede Kamer 1970–1971, pp. 940–941; Jaaradvies RAWB 1976, Handelingen van de Tweede Kamer 1975–1976 document no. 13918 p. 28.
38. Johnson, *The secret of Apollo*.
39. Interviews by the author with Reinder van Duinen (26 August 2010) and Jan de Koomen (26 April 2011).

40. P. van Otterloo, "Management aspecten van het ANS project," Philips Company Archives, file 821:921.94 no. 4, 1973, 11.
41. Spaa, "Enige konklusies".
42. PCA file 821:921.94 no. 1, *Voorstel van de Nederlandse electronische- en vliegtuigindustrie voor de ontwikkeling van een Nederlandse astronomische satelliet* (1966).
43. *De Vries, 80 years of research,* 234–37.
44. Kees de Jager, "ANS, de eerste Nederlandse satelliet," *Zenit* (2009); interview by the author with Kees de Jager, 7 April 2011.
45. For example, in a memo to the prime minister, 24 June 1976, NA, Algemene Zaken records, file 10110. See also NA, Binnenlandse Zaken records, file 5591.
46. PCA, file 821:921.94 no. 1, *Voorstel van de Nederlandse electronische- en vliegtuigindustrie voor de ontwikkeling van een Nederlandse astronomische satelliet* (1966); interview De Koomen.
47. Handelingen van de Tweede Kamer 1973–1974 document no. 12932. Muller, *50 jaar Nederlands Institut*, 86, estimated the total costs at *f*150M, possibly correcting for inflation.
48. PCA file 821:921.94 no. 2, meeting report, 4 December1970.
49. Various correspondence about this in PCA file 821:921.94 no. 3; see also GROC file 347–6, minutes of the meeting of 28 September 1973.
50. For example: report *Ruimtevaart en nationale doelstellingen,* 1976, NA, Algemene Zaken Records, File 10110.
51. PCA file 821:921.94 no. 4: K. Woensdrecht to Pannenborg, 28 March 1974.
52. Ibid. no. 3: letter by N. Rodenburg to Casimir and Pannenborg.
53. Van Otterloo, "ANS project".
54. PCA file 821:921.94 no. 4: memo "totaal verlies van Philips aan de ANS", 25 March 1975.
55. Van Otterloo, "ANS project".
56. PCA file 821:921.94 no. 4: Final Report on a Study of ANS Benefits by General Technology Systems Ltd, 1977.
57. Ibid. no. 3: reports of a meeting on 3 March 1971.
58. Dierikx, *Fokker als Nederlandse droom,* 171–172.
59. Blanken, *Een industriële wereldfederatie,* 97–98; PCA 821:921.94 no. 3 and 4.
60. On IRAS: Mitchell Waldrop, "Infrared Astronomy Satellite," *Science,* 220 no. 4604 (1983); Wallace Tucker and Karen Tucker, *The Cosmic Inquirers: modern telescopes and their makers* (Cambridge, MA: Harvard University Press, 1986); Baneke, "Space for ambitions".

61. Ton van Helvoort, *De KNAW tussen wetenschap en politiek: de positive van de scheikunde in de Akademie in naoorlogs Nederland* (Amsterdam: KNAW, 2005); Van Berkel, *De stem van de wetenschap.*
62. See also Harry de Boer and Jeroen Huisman, "The New Public Management in Dutch Universities," in *Towards a New Model of Governance for Universities?,* ed. D. Braun and F.X. Merrien (London: Jessica Kingsley Publishers, 1999).
63. Letter from Minister A. Pais, 5 November 1980, GROC file 347-9/10.
64. Annual reports of SRON.
65. Deterink et al., *Onderzoek.*
66. Robert W. Smith, *The space telescope: a study of NASA, science, technology, and politics* (Cambridge and New York: Cambridge University Press, 1989); Peter Galison and Bruce Hevly, ed., *Big science: the growth of large-scale research* (Stanford, CA: Stanford University Press, 1992); Cooper H. Langford, and Martha Whitney Langford, "The evolution of rules for access to megascience research environments viewed from Canadian experience," *Research Policy* 29 (2000).
67. Scranton, "American Innovation," 322.
68. Cf. Bent Dalum, Björn Johnson and Bengt-Åke Lundvall, "Public Policy in the Learning Society," in *National Systems of Innovation: towards a theory of innovation and interactive learning*, ed. Bengt-Åke Lundvall (London and New York: Pinter, 1992).
69. Scranton, "American Innovation," 321.
70. Cf. Olle Edqvist, "Layered Science and Science Policies," *Minerva* 41 (2003).

Acknowledgments This chapter is based on research that was supported by a Guggenheim Fellowship at the National Air and Space Museum in Washington, DC and an NWO grant at the VU University of Amsterdam. I thank David DeVorkin, Frans van Lunteren, Harm Habing, and the editors of this volume for their helpful comments and suggestions.

References

Baggen, P., J. Faber, and E. Homburg. 2003. Opkomst van een kennismaatschappij. In *Techniek in Nederland in de twintigste eeuw VII: Techniek en modernisering: balans van de twintigste eeuw*, ed. J.W. Schot, H.W. Lintsen, A. Rip, and A.A. Albert de la Bruhèze, 141–173. Zutphen: Walburg Pers.

Baneke, David. 2010. Teach and travel: Leiden Observatory and the renaissance of Dutch astronomy in the interwar years. *Journal for the History of Astronomy* xli: 167–198.

Baneke, David. 2014. Space for ambitions: The Dutch space program in changing European and transatlantic contexts. *Minerva* 52: 119–140.

Blanken, I.J. 2002. *Een industriële wereldfederatie: Geschiedenis van Koninklijke Philips Electronics N.V., vol. V*. Zaltbommel: Europese Bibliotheek.

Boersma, Kees. 2002. *Inventing structures for industrial research: A history of the Philips NatLab 1914–1946*. Amsterdam: Aksant.

Casimir, H.B.G. 1958. *Voorzieningen ten behoeve van de research binnen de faculteiten der wis- en natuurkunde der Nederlandse universiteiten*. The Hague: Staatsdrukkerij- en Uitgeverijbedrijf.

Collins, H., R. Evans, and M. Gorman. 2007. Trading zones and interactional expertise. *Studies in History and Philosophy of Science* 38: 657–666.

Dalum, Bent, Björn Johnson, and Bengt-Åke Lundvall. 1992. Public policy in the learning society. In *National systems of innovation: Towards a theory of innovation and interactive learning*, ed. Bengt-Åke Lundvall. London/New York: Pinter.

de Boer, Harry, and Jeroen Huisman. 1999. The new public management in Dutch universities. In *Towards a new model of governance for universities?* ed. D. Braun and F.X. Merrien, 100–118. London: Jessica Kingsley Publishers.

de Jager, Kees. 2009. ANS, de eerste Nederlandse satelliet. *Zenit*, p. 465.

de Kort, Niek. 2003. *Ruimteonderzoek: de horizon voorbij*. Amsterdam: Natuur & Techniek.

de Vries, Marc. 2005. *80 years of research at the Philips Natuurkundig Laboratorium 1914–1994*. Amsterdam: Pallas Publications.

Deterink, A.A.M., et al. 1997. *Onderzoek naar de oorzaak van het faillissement van Fokker*. Deventer: Kluwer.

Dierikx, Marc. 2004. *Uit de lucht gegrepen: Fokker als Nederlandse droom, 1945–1996*. Amsterdam: Boom.

Edgerton, David. 2004. The 'linear model' did not exist: Reflections on the history and historiography of science and research in industry in the twentieth century. In *The science—industry nexus: History, policy, implications*, ed. Karl Grandin and Nina Wormbs. New York: Watson.

Edqvist, Olle. 2003. Layered science and science policies. *Minerva* 41: 207–221.

Elbers, Astrid. 2012. The establishment of the new field of radio astronomy in the post-war Netherlands: A search for allies and funding. *Centaurus* 54: 265–285.

Etzkowitz, Henry. 2003. Innovation in innovation: The Triple Helix of university-industry-government relations. *Social Science Information* 42: 293–337.

Etzkowitz, Henry, and Loet Leydesdorff. 2000. The dynamics of innovation: From national systems and 'Mode 2' to a Triple Helix of university-industry-government relations. *Research Policy* 29: 109–123.

Flipse, A. 2012. 'Geen weelde, maar een offer'. De band tussen Vrije Universiteit en achterban, 1880–1950. In *Universiteit, Publiek en Politiek*, ed. L.J. Dorsman and P.J. Knegtmans, 67–82. Hilversum: Verloren.

Galison, Peter, and Bruce Hevly (eds.). 1992. *Big science: The growth of large-scale research*. Stanford: Stanford University Press.
Gibbons, Michael, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow. 1994. *The new production of knowledge: The dynamics of science and research in contemporary societies.* London: Sage.
GROC. *Papers of the Geophysics and Space Research Committee*. Amsterdam: Royal Netherlands Academy of Sciences.
Heijmans, H.G. 1994. *Wetenschap tussen universiteit en industrie: de experimentele natuurkunde in Utrecht onder W.H. Julius en L.S. Ornstein 1896–1940.* Rotterdam: Erasmus Publishing.
Hoeneveld, F., and J. van Dongen. 2013. Out of a clear blue sky? FOM, the bomb and the boost in Dutch physics funding after World War II. *Centaurus* 55: 264–293.
Hollestelle, Marijn. 2011. *Paul Ehrenfest: Worstelingen met de Moderne Wetenschap, 1912–1933.* Leiden: Leiden University Press.
Johnson, Stephen. 2002. *The secret of Apollo: Systems management in the American and European space programs.* Baltimore: Johns Hopkins University Press.
Kersten, Albert. 1996. *Een organisatie van en voor onderzoekers: ZWO 1947–1988.* Assen: Van Gorcum.
Krige, John. 2006a. *American hegemony and the postwar reconstruction of science in Europe*. Cambridge, MA: MIT Press.
Krige, John. 2006b. Technology, foreign policy, and international cooperation in space. In *Critical issues in the history of spaceflight*, ed. Steven J. Dick and Roger D. Launius, 239–260. Washington, DC: NASA.
Krige, John. 2010. Building the arsenal of knowledge. *Centaurus* 52(4): 280–296.
Krige, John, and Arturo Russo. 2000. *A history of the European Space Agency 1958–1987, vol. I: The story of ESRO and ELDO 1958–1973.* Noordwijk: ESA.
Langford, Cooper H., and Martha Whitney Langford. 2000. The evolution of rules for access to megascience research environments viewed from Canadian experience. *Research Policy* 29: 169–179.
Lundin, Per, Niklas Stenlås, and Johan Gribbe. 2010. *Science for welfare and warfare: Technology and state initiative in Cold War Sweden*. Sagamore Beach: Science History Publications.
Muller, Ed (ed.). 1997. *50 jaar Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart*. Katwijk aan Zee: Satellite Services.
NA. National Archives, The Hague.
Nowotny, Helga, Peter Scott, and Michael Gibbons. 2003. Introduction: 'Mode 2' revisited: The new production of knowledge. *Minerva* 41: 179–194.
PCA. Philips Company Archives, Eindhoven.
Pestre, Dominique. 2003. Regimes of knowledge production in society: Towards a more political and social reading. *Minerva* 41: 245–261.

Scranton, Philip. 2006. Technology, science and American innovation. *Business History* 48: 311–331.

Smith, Robert W. 1989. *The space telescope: A study of NASA, science, technology, and politics*. Cambridge/New York: Cambridge University Press.

Spaa, J.H. 1975. Enige konklusies uit het ANS-projekt vanuit het Philips standpunt. Philips Company Archives, file 821:921.94 no. 4.

Sullivan, Woodruff T. 2000. Kapteyns influence on the style and content of twentieth century Dutch astronomy. In *The legacy of J.C. Kapteyn: Studies on Kapteyn and the development of modern astronomy*, ed. P.C. van der Kruit and K. van Berkel, 229–264. Dordrecht: Kluwer.

Sullivan, Woodruff T. 2009. *Cosmic noise: A history of early radio astronomy*. Cambridge: Cambridge University Press.

Tucker, Wallace, and Karen Tucker. 1986. *The cosmic inquirers: Modern telescopes and their makers*. Cambridge, MA: Harvard University Press.

van Berkel, Klaas. 2011. *De stem van de wetenschap: geschiedenis van de Koninklijke Nederlandse Akademie van Wetenschappen*, vol. 2. Amsterdam: Uitgeverij Bert Bakker.

van de Hulst, Henk. 1992. Seizing opportunities: Some comments on the Dutch national space science programme of the sixties and seventies. In *Science beyond the atmosphere: The history of space research in Europe*, ed. Arturo Russo, 125–138. Noordwijk: ESA.

van Helvoort, Ton. 2005. *De KNAW tussen wetenschap en politiek: de positive van de scheikunde in de Akademie in naoorlogs Nederland*. Amsterdam: KNAW.

van Otterloo, P. 1973. Management aspecten van het ANS project. Philips Company Archives, file 821:921.94 no. 4.

Waldrop, Mitchell. 1983. Infrared astronomy satellite. *Science* 220(4604): 1365–1368.