CHAPTER 1

Editors' Introduction: Institutional Conditions for Progress and Renewal in Science

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1.1 Progress and Renewal in Science

In the history, philosophy, and sociology of science, there is a consensus that the primary goal of scientific research is the continuous renewal of knowledge and technology. In this context, renewal refers not only to the generation of new ideas, theories, methods, and instruments or to the discovery of previously unknown phenomena but also to the diffusion of innovative scientific developments, and the institutionalization of such advances in existing scientific communities and ultimately as new academic fields. Accepting the premise that the renewal of knowledge and

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technology is the objective of scientific research, we can then ask what are institutional conditions for successful renewal.

This edited volume contributes to the debate about renewal in science by addressing two interrelated questions. First, this volume explores the capability of research organizations to generate original and transformative intellectual contributions, such as new theories, methods, instrumentation, and empirical discoveries. Second, this volume addresses the capability of national research systems and research organizations to absorb new intellectual developments and to institutionalize new fields of research. Through detailed historical and comparative case studies, this volume presents new and thought-provoking evidence that improves our conceptual knowledge and empirical understanding about how new research fields are formed, how research organizations adapt to changes both in the sciences and in their societal environment, and how research sponsors strike the balance between support for new research areas and continuity for established lines of disciplinary research.

Investigating the complex connections between scientific innovation and institutional change requires a long-term perspective. Therefore, the volume assembles scholars in science history, as well as in sociology of science and research policy. Yet, the distinctive contribution of this volume is that while being firmly based in science history, it strives for broader and more general sociological and policy propositions regarding renewal in science. Through the juxtaposition between science history and the sociology of science and research policy, we attempt to narrow the gap between detailed microhistories of particular entities or episodes and overgeneralized sociological propositions on institutional change in science.

In this introductory chapter, we argue that renewal within the organizations that conduct scientific research, as well as within their environment, is contingent upon at least three institutional conditions: *(1) investments in exploration, (2) facilitation of meso-level competition, and (3) organizing interdisciplinary research*. What follows below is a discussion of these three institutional conditions, how each chapter in this edited volume contributes to their analysis, and finally, extended abstracts of all chapters.

1.2 Investments in Exploration

Generally speaking, scientists face two opposing expectations. First, they are expected to seek fundamentally new knowledge and to move beyond established doctrine. Second, they are expected to develop and maintain an inventory of disciplinary knowledge that can be passed on from generation to generation. These two expectations are conflicting, and they operate as antipodal values under various labels: innovation versus tradition, originality versus relevance, dissent versus conformity, rebellion versus discipline, exploration versus exploitation, search versus production, experimentation versus implementation, or risk taking versus refinement.

Michael Polanyi argues that the tension between these two opposing expectations pervades the entire institutional structure of scientific research: "This internal tension is essential in guiding and motivating scientific work. The professional standards of science must impose a framework of discipline and at the same time encourage rebellion against it. They must demand that … an investigation should largely conform to the currently predominant beliefs about the nature of things, while allowing in order to be original it may to some extent go against these."[1]

That there is a fundamental tension between seeking new and refining existing knowledge implies that depending on historical circumstances and institutional context there may either be a delicate balance between the two, or one pole will dominate the other. Polanyi argues that the institutional structure of science—in general—tends to be biased toward the refinement of existing knowledge. Taking peer review as an example, he claims that publications are primarily evaluated in terms of their plausibility and scientific value, and thus with respect to their contribution toward an inventory of disciplinary knowledge. Publications have to be plausible and valuable extensions of existing knowledge for them to be accepted by the scientific community. In contrast, publications of sufficient plausibility and scientific value may vary considerably with respect to their originality, that is, the degree of surprise which they arouse among scientists. Hence, not every publication, no matter how plausible and valuable it may be, is novel and original.

In a similar vein, Richard Whitley argues that despite the strong institutional commitment to the exploration of fundamentally new knowledge in modern science, "the extent of originality and novelty in research goals and procedures is restricted by the need to convince specialist colleagues of the significance of one's work in reputational work organizations. … The degree of innovation is thus diminished and constrained by the necessity of showing how new contributions fit in with, and are relevant to, existing knowledge."[2] Hence, Whitley asserts that the scientific elite holds the innovators in check. Novel ideas and artifacts are accepted only if they can be connected to previous knowledge and thus prove their scientific relevance.

The view that the institutional structure of science gives considerably more weight to the plausibility of contributions and their connectability to previous research than to originality and surprise has garnered empirical support in recent years. Many commentators argue that during the past three decades, the funding of public research organizations has increasingly shifted toward external, peer-reviewed sponsorship despite that such funding tends to favor mainstream and risk-averse projects.[3] Thus, the proliferation of peer review in funding decisions most likely has deepened existing knowledge paths at the expense of finding fundamentally new ones.

In his essay on exploration versus exploitation in organizational learning, James March warns that "systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal stable equilibria." He concludes that "maintaining an appropriate balance between exploration and exploitation is a primary factor in system survival and prosperity."[4] In this respect, it is interesting that several private and public research sponsors, among them the Volkswagen Foundation, the Wellcome Trust, the MacDonnell Foundation, the Howard Hughes Medical Institute, and the European Research Council, set up funding programs dedicated to the support of unconventional research that has the potential for groundbreaking results.[5] Many of these programs are intended to counterbalance the dominant exploitation-mode inherent in research council funding. Yet, typically they command small budgets, operate under heightened evaluation requirements, and rely a fortiori on traditional peer review.[6]

The two observations in the literature that the institutional structure of science tends to be biased toward the refinement of existing knowledge, and that research funding in recent decades has strengthened established knowledge paths have led sociologists of science and organizational scholars alike to reconsider institutional conditions in support of explorative and path-breaking research. The common theme in these contributions is that the forces of exploration need to be strengthened to balance the two conflicting orientations in the institutional structure of science. This plea for *investments in exploration* is articulated either from a comparative historical perspective,[7] from an organizational sociology perspective,[8] from an individual's research strategy view,[9] or from a research policy viewpoint.[10]

The present volume contributes to this renewed discussion by asking (1) how and why *investments in exploration* have occurred historically and (2) more generally, how the two opposing orientations of innovation and tradition are balanced in different institutional settings. In contrast to the current emphasis on funding structure, this volume puts emphasis on new organizational forms and internal organizational change. Several chapters in this volume present evidence that *investments in exploration* are made by building entirely new forms of research organizations, such as the university-based microfabrication user facility (Mody), the National Center for Ecological Analysis and Synthesis (Hackett and Parker), and the space research laboratories and consortia that built the two satellites ANS and IRAS (Baneke); or new forms of conferences, such as the Solvay Conferences or the Seven Pines Symposia (Stuewer). These new organizations or conferences are examples of an ongoing process of renewal in the institutional arrangements of science that have considerable effects on intellectual opportunities and innovations. In addition, several chapters in this volume present cases of adaptation and internal change of existing research organizations, including the Deutsches Elektronensynchrotron (DESY) and the Stanford Linear Accelerator Center (SLAC) (Hallonsten and Heinze), or the Goddard Space Flight Center at the National Aeronautics and Space Administration, NASA (Launius). As shown by these chapters, internal organizational changes oftentimes occur gradually, particularly in institutional environments in which entrance of new forms of research organizations is either difficult or impossible, or in cases where existing research capacities can serve as platform for building new ones. Therefore, both founding new organizational forms and supporting gradual internal adaptations of existing research organizations are two equally important investments in exploration.

1.3 Facilitation of Meso-Level Competition

In addition to the tension between exploration and exploitation, *competition* pervades the entire institutional structure of scientific research. A classical view on competition in science is Karl Popper's falsificationist account on how theories are used to explain phenomena and to make forecasts.[11] If a theory fails to explain or forecast a phenomenon, this may constitute an anomaly that has no immediate impact on the theory. However, frequent occurrence of such anomalies weakens a theory's foundation. As soon as a new theory is available that is more successful at explaining and predicting observed events, the old theory should be abandoned. Thus, the driving force of scientific progress is *competition between theories* for better explanations.

In his discussion of Popper's approach to scientific progress, Imre Lakatos points out that theories must first be constructed and then initially protected against criticism, since otherwise they would be abandoned before fully blooming.[12] The establishment of research programs serves precisely this goal. Such programs pursue a specific knowledge goal in a given field of research, using a particular set of theoretical basic assumptions and methods. According to Lakatos, the differentiation of research programs into a protected core of basic assumptions and a peripheral area of special hypotheses produces a balance between stability and change that serves progress in knowledge better than ubiquitous and aggressive criticism. It can also be considered beneficial for scientific progress when the protagonists of a research program do their utmost to protect their program against possible criticism, and leave it to their competitors to launch criticism and offer alternatives. Hence, in Lakatos' view, competition between theories is less important than *competition between research programs.*

According to classical sociology of science, the competition between either theories or research programs is socially embedded in scientific fields where scientists compete for reputation and intellectual control.[13] In this regard, Whitley points out that "scientific fields are a particular kind of work organization which structure and control the production of intellectual novelty through competition for reputations from national and international audiences for contributions to collective goals."[14] However, scientists are not just seeking personal acclaim from colleagues for their scientific achievements, "they also seek to direct others' research along particular lines and ensure that their interests, problems, and standards are accepted by colleagues in their own research."[15]

In addition to the argument that individual scientists seek reputation and intellectual control, sociology of science discusses how *nation states compete for global leadership in science and technology.* For example, Joseph Ben-David demonstrates that ever since the emergence of the modern sciences in the seventeenth century in Renaissance Italy, competition for global scientific and technological leadership has been a driving force in science.[16] More recent history and sociology of science studies corroborate this view in that such international competition has influenced the emergence of new science and technology fields, particularly during the Cold War, including fields such as earth sciences, space science, oceanography, seismology, and biotechnology.[17]

This brief outline illustrates that competition in science is a multilevel phenomenon, including cognitive aspects, such as competition between theories or research programs, and social and historical aspects, such as individuals competing with colleagues for scientific reputation and intellectual control or nation states competing for global scientific, military, and technological leadership. However, the *meso-level of research organizations* has been largely neglected in scholarly discourse on competition as an institutional condition for scientific progress and renewal. Although some studies have shown that both the distribution of scientific productivity and the number of major scientific achievements are highly skewed among universities and non-university research laboratories,[18] we know relatively little about the institutional conditions that increase the scientific competitiveness of universities and other public and private research laboratories, neither do we know much about capabilities of research systems to flexibly adapt their organizational infrastructure to heightened global scientific and technological competition.

Therefore, the present volume aims at contributing to a better understanding of *meso-level competition* in science by asking (1) which factors are conducive to research organizations' capabilities to seize upon new scientific opportunities, and thus successfully compete in emerging fields of science and technology, and (2) how new research capacities are built up to strengthen national competitiveness in response to global scientific and technological pressures.

Several chapters in this volume present evidence in this regard: in a comparison between public universities in Germany and the USA, it is shown that the capability of universities to support new fields of research critically depends on both their funding and scientific staff structures (Jappe and Heinze); furthermore, it is demonstrated that inter-university competition was a major driver in the proliferation of the microfabrication user facility in the USA, and that the leading contenders in this competition were universities that could demonstrate a long-term track record of partnership with industry (Mody); yet another chapter argues that the small community of Dutch astronomers forged an alliance between policy makers and two major Dutch companies, Philips and Fokker, to build very expensive scientific instruments (satellites), and thereby considerably improved their global scientific and technological competitiveness (Baneke).

1.4 Organizing Interdisciplinary Research

In addition to investments in exploration and the facilitation of meso-level competition, the *emergence of new disciplines and specialties* is often regarded as emblematic for progress and renewal in science. In his late writings, Thomas Kuhn argues that similar to speciation of new biological organisms, new disciplines emerge when scientists increasingly rely on a new lexicon that excludes non-specialists from scientific communication. Therefore, breakdowns in communication between scientists are "crucial symptoms of the speciation-like process through which new disciplines emerge, each with its own lexicon, and each with its own area of knowledge."[19] Most importantly, Kuhn argues that "very likely it is the specialization consequent on lexical diversity that permits the sciences, viewed collectively, to solve the puzzles posed by a wider range of natural phenomena than a lexically homogeneous science could achieve."[20] Hence, the increasing specialization of lexicons reduces communication between different research areas, but at the same time, it increases the diversity of scientific approaches, and thus our knowledge to understand the (physical) world. It is by the division of specialized scientific communication that knowledge grows: "the limited range of possible partners for fruitful intercourse is the essential precondition for what is known as progress in both biological development and the development of knowledge."[21]

Kuhn's strong emphasis on incommensurability between disciplinary lexicons as a prerequisite for scientific progress and renewal can be contrasted with the concept of intellectual "trading zones"[22] which instead focuses on "interdisciplinary partnership in which two or more perspectives are combined and a new, shared language develops."[23] Quite in general, studies in interdisciplinarity, multidisciplinarity, and transdisciplinarity agree that disconnected branches of scientific research can be effectively linked.[24]

Evidence from science history and the sociology of science suggests that both private and public sponsorship, and the establishment of new types of research institutes both inside and outside universities, played an important role in effectively *organizing interdisciplinary research*. For example, Ben-David argues that interdisciplinary research centers in universities in the USA, established across discipline-based departments, were more successful scientifically than discipline-based institutes that prevailed in Germany.[25] Both David A. Hounshell and John Kenly Smith and John W. Servos show that the emergence of physical chemistry as a new field of research was supported by the fruitful application of physics tools and techniques to chemistry, and sponsored by large chemical corporations both within their own laboratories and through grants to major research universities.[26] In addition, Robert E. Kohler describes the Rockefeller Foundation's dedication to funding scientists who applied the tools and techniques of physics and chemistry toward the advancement of knowledge of biological processes, and how this played an important role in building research capacity in molecular biology.[27] More recent studies, including J. Rogers Hollingsworth, Jerald Hage, and Jonathon Mote, suggest that research laboratories, which were internally structured into groups rather than discipline-based departments, were highly effective in establishing productive work relationships between scientists from various specialties and fields.[28]

In light of the discussion above, the contribution of this edited volume is threefold. First, it assembles contributions that provide considerable support for the argument that effective communication across disciplinary boundaries is facilitated by new types or forms of research organizations: the university-based microfabrication user facility (Mody), the National Center for Ecological Analysis and Synthesis, and the Resilience Alliance (Hackett and Parker) are recent examples that add further substance to the existing literature.

Second, several chapters show research organizations have considerable adaptive capabilities when research across disciplinary boundaries is required: NASA established, alongside its main mission, a multidisciplinary earth system science program (Launius); DESY and SLAC gradually replaced particle physics by the study of materials by X–rays as the main purpose of accelerators, and established units for multidisciplinary photon science inside their formal organizational structure (Hallonsten and Heinze); the two companies Philips and Fokker, together with several Dutch university institutes, were engaged in research consortia to which scientific and engineering staff from various disciplines was recruited for conducting space-related research and development (Baneke).

Third, several chapters argue that interdisciplinarity is anchored not only in centers or institutes but also in scientific careers: NASA encouraged many individuals to migrate from planetary to earth science, helping to create earth science as a cohesive entity (Launius); abundant research opportunities in emerging scientific fields that were adjacent to where scientists had worked before, provided the opportunity structure to effectively link different methods and competences (Jappe and Heinze);

and academic astronomers were in a good position to move into space research, provided they were able to attract people with technological and managerial competence into their research groups (Baneke).

Last but not least, the final chapter in this volume shows how interdisciplinary research has been initiated and shaped by national science policy, and that recent shifts toward funding interdisciplinary research at the expense of mainstream disciplinary research, and increasing requirements for accountability and evidence of performance on the part of those receiving public-sector support have produced tighter funding conditions for academic researchers, even as total science-agency budgets have increased (Feller).

1.5 Contributions to the Edited Book

Cyrus Mody's *Fabricating an Organizational Field for Research: US Academic Microfabrication Facilities in the 1970s and 1980s* (Chap. 2) examines the emergence and diffusion of the university-based microfabrication user facility in the USA. This new organizational form arose in the 1970s to foster greater interaction among stakeholders in industry, academia, and government, thereby facilitating new and innovative research in materials science. Mody describes the mechanisms by which this new organizational form was replicated and spread, and how it coevolved with shifts in industrial structure, including the decline of basic research in semiconductor companies, as well as shifts in federal science policy, primarily the decline of defense-related R&D. This new type of facility diffused widely in the USA today constitutes an entire organizational field of its own.

Edward Hackett and John Parker's *From Salomon's House to Synthesis Centers* (Chap. 3) analyzes synthesis centers as an innovative form of scientific organization that promotes the integration of scientific diversity and its engagement with real-world problems. Placed in historical perspective, such centers are examples of an ongoing process of renewal in the organizational and institutional arrangements of science, and they have consequences for the character and effects of scientific knowledge. Hackett and Parker describe how intellectual and institutional innovations emerge and are entwined within such centers, then draw upon ideas from science studies, small group dynamics, and the creativity and interdisciplinarity literatures to identify the patterns and processes of social interaction responsible for the centers' performance.

Roger Stuewer's *The Seventh Solvay Conference: Nuclear Physics, Intellectual Migration, and Institutional Influence* (Chap. 4) demonstrates how new types of conferences promote mutual learning of scientists from different national and institutional contexts. The chapter shows how the seventh Solvay Conference in 1933 lay at the crossroads in the history of experimental and theoretical nuclear physics when new experimental techniques and instruments were being developed and new theoretical ideas and concepts were being generated, all of which were diffused to physicists in many countries of the world. Stuewer shows the influence that the Solvay Conferences exerted as a model for future conferences in physics and in the history and philosophy of physics, particularly the Seven Pines Symposia.

Olof Hallonsten and Thomas Heinze's *"Preservation of the Laboratory is not a Mission." Gradual Organizational Renewal in National Laboratories in Germany and the United States* (Chap. 5) examines the gradual but transformative changes inside two national laboratories in the USA (SLAC) and Germany (DESY) from single-mission particle physics laboratories in the early 1960s to multipurpose research centers for photon science in the 2000s. The authors describe how the field of synchrotron radiation research increasingly challenged, and ultimately succeeded, particle physics as the established discipline in these laboratories. Their focus is on the processes that led to intra-organizational change, including conversion of large technical infrastructures, gradual replacement of particle physics by the study of materials by X–rays as the main purpose of accelerators, and layering of new organizational units for photon science. By investigating the complexity of institutional change at the micro-level of two laboratories, the chapter contributes important conceptual tools for a more detailed understanding of organizational adaptation and renewal.

Arlette Jappe and Thomas Heinze's *Institutional Context and Growth of New Research Fields. Comparison between Universities in Germany and the United States* (Chap. 6) shows that differences in funding and staff structure of state universities in Germany and the USA affect the capabilities of their research groups and departments to rapidly seize upon research breakthroughs. Using the Scanning Tunneling Microscope, STM (Nobel Prize in Physics, 1986) and the discovery of Buckminster Fullerenes, BUF (Nobel Prize in Chemistry, 1996) as empirical examples, they demonstrate that universities whose budgets grew and had a high number of professors among their scientific staff were among the early adopters of STM and BUF, and thus highly competitive in the newly emerging research fields.

In contrast, universities whose budgets stagnated and had a low share of professors among their scientific staff were mostly among those who engaged in follow-up research relatively late.

David Baneke's *Organizing Space: Dutch Space Science between Astronomy, Industry and the Government* (Chap. 7) shows that whenever new technological or scientific fields emerged after the Second World War, scientists, government officials, and industrial companies in the Netherlands feared being left behind. Especially in strategically important fields such as nuclear physics, radio astronomy, and computing, these three groups collaborated intensively to keep up with international developments; and Philips as a major company played an important role in these collaborations. Using space science as an example, Baneke demonstrates how the small community of Dutch astronomers, with the help of Philips and Fokker, managed to build two of the most expensive scientific instruments ever built in the Netherlands: the two satellites ANS and IRAS. The new research capacities that were created both in Dutch universities and in Philip's and Fokker's laboratories considerably improved the scientific and technological competitiveness of the Netherlands.

Roger Launius's "*We will learn more about the Earth by leaving it than by remaining on it.*" *NASA and the Forming of an Earth Science Discipline in the 1960s* (Chap. 8) argues that despite recent criticism that NASA in the 1960s failed to recognize and make a part of its core mission "earthly environmentalism," this chapter responds by discussing the manner in which NASA in a subtle but transformative way encouraged the collaboration of scientists from many different disciplines focused on Earth to transcend disciplinary boundaries using space technology to treat Earth as an integrated system. Indeed, from limited cooperative efforts in the 1960s overseen by NASA, emerged the broadly interdisciplinary efforts to understand the interactions of Earth in the last quarter century. While such efforts never dominated the agency and were resisted in some quarters, the seeds of the earth system science discipline were planted during this era. Launius shows that NASA encouraged many individuals to migrate from planetary to earth science, helping to create earth science as a cohesive entity.

Irwin Feller's *Interdisciplinary Research and Transformative Research as Facets of National Science Policy* (Chap. 9) argues that the total resources required to satisfy the claims for continued support of established academic disciplines on the one hand, and for underwriting the reconfigurations of these disciplines into new research fields on the other hand, push up against and invariably exceed whatever level of total resources are provided by the collectivity of sponsors. Therefore, the strong emphasis in the USA's national science policy on interdisciplinary research, and more recently on transformative research, is emblematic for the ongoing debate about how important public-science funding should be, and what levels and forms of funding are most appropriate. Feller argues that recent shifts toward funding interdisciplinary research at the expense of mainstream disciplinary research, and increasing requirements for accountability and evidence of performance might lead to adverse conditions for academic researchers in disciplinary settings, even as total science-agency budgets continue to increase in absolute terms.

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