CHAPTER 6

Institutional Context and Growth of New Research Fields. Comparison Between State Universities in Germany and the USA

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6.1 Introduction

This chapter examines how universities build up and expand research capacities in new and emerging scientific fields following major scientific breakthroughs. The research question is to what extent the institutional framework in which universities are embedded supports such expansion and renewal. Scientific research is oriented toward two opposing values: innovation and tradition.[1] Research thus is characterized by a fundamental tension between forces that on the one hand attempt to leave conventional paths of thought and transcend established doctrines and on the other hand seek conformity to disciplinary research and accepted frameworks. James March introduced the terms *exploration* and *exploitation* to describe this fundamental tension.[2] Exploration designates the search

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for new knowledge and overcoming of current know-how, and exploitation designates the refinement and validation of established knowledge and incorporation of new findings into existing patterns of thought. Exploration opens up new horizons and perspectives while exploitation enhances existing knowledge and technology (see editor's introduction).

The tension between *exploration* and *exploitation* can be investigated from two angles. First, we may ask which institutional conditions facilitate the emergence of research breakthroughs. From this perspective, institutional conditions for the emergence of new scientific solutions are investigated.[3] Second, we can also inquire into conditions for the propagation and diffusion of scientific inventions. If something new has been invented, how does it take hold over existing approaches? How are innovators able to overcome both the inertia and resistance of the scientific establishment? As far as the analysis of renewal in science and technology is concerned, the second perspective seems more relevant. Therefore, in this article, we investigate the capability of universities to seize upon and expand new and innovative research fields.

To do so, we chose two research breakthroughs from the recent past with an impact that can be adequately investigated from a sociological point of view: the scanning tunneling microscope (STM), developed in 1982 by Gerd Binnig and Heinrich Rohrer at the IBM research center in Rüschlikon,[4] Switzerland, and Buckminsterfullerenes (BUF), discovered in 1985 by Harold Kroto of the University of Sussex in the UK and Richard Smalley and Robert Curl of Rice University in Houston, Texas, USA. The development of STM was recognized by a Nobel Prize in Physics in 1986, and the discovery of BUF was recognized by a Nobel Prize in Chemistry in 1996.[5] By selecting these two research breakthroughs, we contribute to a long line of sociological studies on the Nobel Prize, its awardees, and research organizations recognized by Nobel prizes.[6]

Based on the selection of STM and BUF, we examined which universities seize upon such breakthroughs and how quickly they engage in follow-up research. Our analysis focuses on explaining the differences in the speed with which these breakthroughs were taken up and institutionalized within organizational units of the various universities. In this regard, we compare state universities in Germany with state universities in the USA. These two countries were the most important global centers of research in the late nineteenth century and all of the twentieth century.[7] However, the leading role of German universities in most scientific disciplines had been increasingly challenged by US universities since 1900, and in the 1930s, Germany was replaced by the USA as the new global center in scientific research. Today, in both countries, we find a lively scholarly and public policy discourse about academic leadership and excellence.[8]

For a meaningful comparison of the university systems in Germany and the USA, it has to be taken into account that the majority of German universities are funded by the Länder states. According to the classification of the German Federal Statistical Office (2010), 102 German universities have the right to award doctoral degrees, and 82 of these universities are state sponsored. In comparison, according to the Carnegie Classification (2010), 265 US universities have the right to award doctoral degrees, and 155 of them are state sponsored. Therefore, our comparison includes 82 German and 155 US state universities.

From a methodical point of view, the focus on state universities is important because it allows a direct comparison between the two countries. Taking into account the many private US universities funded by multibillion dollar endowments, such as Stanford, Caltech, Harvard, Yale, Princeton, Chicago, Columbia, and MIT, would distort the comparison. Private US universities constitute a particular institutional sector in a stratified educational system and would thus require a separate comparative analysis. However, such a comparison with the 20 private German universities would be quite difficult because the latter are only of minor importance in science and engineering. In sum, when we speak of universities in the following discussion, we are always referring to state universities in the two countries.

Our bibliometric findings demonstrate that scientists at US universities were several years ahead of their colleagues at German universities in seizing upon STM and BUF. Based on a set of hypotheses, this chapter demonstrates that universities with budgets that grew and that had a high number of professors among their scientific staff in the years following major scientific breakthroughs were among the early adopters and thus highly competitive in the new and emerging fields. In contrast, universities with stagnating budgets and a low share of professors among their scientific staff were mostly among those that engaged in follow-up research relatively late. These findings are elaborated using both longitudinal staff and funding data and retrospective interviews with key actors involved in follow-up research in various universities. We identify major differences in the university systems of Germany and the USA.

The chapter is structured as follows. The next section introduces the theoretical framework, highlighting two processes of gradual institutional change that are particularly important for renewal in science (Sect. 2).

Then, we introduce method and data (Sect. 3) as well as hypotheses and describe both the dependent variable and the explanatory variables (Sect. 4). These sections are followed by a detailed comparison of state universities in Germany and the USA (Sects. 5 and 6). Finally, we sum up our findings and draw conclusions.

6.2 Theoretical Framework

The emergence and expansion of new research areas is typically discussed with respect to disciplinary specialization and institutional differentiation. In this perspective, intellectual renewal takes place within established academic disciplines and often leads to new subdisciplines.[9] Yet this view accounts only for the result of both intellectual and institutional reconfigurations and neglects the often protracted and conflict-laden processes involved in spinning off new fields of research. The processes themselves as well as the mechanisms that propagate them and eventually make possible the successful implementation of new research areas have not been broadly studied, and both processes and mechanisms of renewal in science thus are relatively unknown territory.[10]

In recent years, sociologists and political scientists interested in explaining historical shifts in welfare state institutions have developed the approach of *historical institutionalism* that addresses institutional change from both a theoretical and an empirical perspective. In particular, Kathleen Thelen, James Mahoney, and Wolfgang Streeck have shown that institutional change in advanced economies often takes place gradually but nevertheless can result in fundamental changes to existing institutional structures. Among the gradual change processes identified by Thelen, Mahoney, and Streeck,[11] two processes, *layering* and *displacement*, are of particular importance here. *Layering* means that new research capacities are created while prior research is continued at the same or an even higher scale. In this way, new research areas are added to the existing fields. *Displacement* occurs when the creation of new research areas requires shrinking existing research fields. Like in a zero-sum game, support for new research fields is related to abandoning capacities in existing fields.

The historical institutionalism literature assumes *layering* to be the least conflict-laden process of gradual change.[12] This insight can be directly translated to renewal in science. Investments in capacities for a new research field mean no direct loss for the establishment in existing fields and thus provide a comfortable situation for innovators and early adopters.

In contrast, displacement is more conflict prone: The gains of the new field are the losses of existing fields; therefore, the scientific establishment will wield all of its influence to prevent or at least postpone changes in the status quo. Hence, in cases where the scientific establishment has strong veto power, renewal can be actively resisted.[13]

Building up research capacities in new fields requires scientific staff and financial resources, which are necessary but not sufficient conditions. We assume that the professor is the most important staff category for intellectual renewal at universities. He or she represents the smallest organizational unit that can make the decision to seize upon and invest in new scientific opportunity. There are two mechanisms for *displacement* of research areas at the level of professors. First, a professor may decide to change research areas. Because of their status, professors are entitled but also expected to make such decisions independently whereas other scientific staff and students typically require permission. The second mechanism is recruitment, which leads to renewal because newly recruited professors are specialized in new areas. As long as the absolute number of professors at a university remains constant, personnel fluctuation can lead to *displacement* of research areas. If the number of professors grows, then there is room for *layering* of additional research areas.

Regarding financial resources, we distinguish between the two broad categories of basic institutional funding and competitive grant funding because they are linked to intellectual renewal in different ways. In Germany, professorships are typically endowed with basic funding for scientific staff, laboratories, and equipment, which still made up a large share of their research budget during the 1980s, the time of the STM and BUF breakthroughs. Basic funding is flexible in the sense that it is not earmarked for specific project objectives. As long as basic funding grows, there is always some amount for investment in new topics and research opportunities. On the other hand, basic funds are tied to professorial chairs; thus, there is competition among chair holders for available basic funding. In this way, stagnating basic funding means that *displacement* is the only option for renewal whereas growth in basic funding indicates possibilities for *layering*.

The category of competitive grant funding includes public and private grants as well as other external research money that is invested in research projects. Grants are linked to intellectual renewal because they drive scientists to seek opportunities for rapidly demonstrable scientific achievement. Furthermore, grants are additional external resources that do not threaten existing research areas in which universities have invested their basic funding. Depending on the time frame under which they are allocated, grants allow for more or less stable *layering* of new research areas. But grant funding is also linked to *displacement* processes. In the USA, professorial positions are typically not endowed with staff and equipment. Professors who are unsuccessful in obtaining grants are in fact forced to abandon their research after a short time and to take up more teaching or administrative duties. As a consequence, research areas that are no longer approved by peer review or funding agencies are rapidly displaced.

6.3 Method and Data

This chapter combines quantitative and qualitative information to explain how staff structure and funding conditions influence the speed of reception of novel scientific ideas. Our focus is on findings of four case studies of universities that engaged in follow-up research of STM (two cases) and BUF (two cases). Each case was investigated in depth to find out how the influence of staff structure and funding resources played out in this particular instance of follow-up research. Summaries of case findings are organized according to the selected variables. Scientists who were interviewed are mentioned for each case study (see endnotes).

To draw generalizations from individual cases, we embedded each case in two longitudinal data sets. These data allow for systematic comparisons between cases and between the case and macro levels. The basis of the study is the construction of a strictly comparable set of state universities. The first data set consists of a bibliometric analysis of all state universities in Germany and the USA that engage in follow-up research for STM and BUF. Building on the available secondary literature on STM[14] and BUF[15] we used publication and citation data retrieved on the basis of "article flags" in Web of Science to investigate how rapid and how sustained the reception of these two breakthroughs was globally.[16]

The second macro data set consists of long-term personnel and funding data on the department, university, and state levels, which allows for a comparative analysis of institutional conditions for *layering* versus *displacement* of new research areas. These data were retrieved from the Bavarian Statistical Office, the University of California's Office of the President, the Integrated Postsecondary Education Data System, and further archival data from University of California, Santa Barbara (UCSB) and University of California, Los Angeles (UCLA). All funding data were inflation adjusted. To make scientific staff data for US universities comparable to scientific staff data for Bavarian universities, we used information on PhD graduates in US universities as a proxy for the number of scientific staff below the professoriate, the equivalent of what is called "wissenschaftliche Mitarbeiter" (scientific nonprofessorial staff) in German universities. Therefore, our values for the percentage of professors in US universities are lower and thus a stronger test compared to using raw data.

6.4 Variables and Hypotheses

The *dependent variable* in this analysis is the reception speed with which STM and BUF as research breakthroughs were taken up and expanded into research programs by scientists in state universities in Germany and the USA. Reception speed can be operationalized using the typology developed by Rogers (2003) for analyzing the diffusion of innovation. Rogers distinguishes *innovators*—that is, those who have achieved a scientific breakthrough—from *early adopters*, *early majority*, and *late majority*.[17] The early adopters are those scientists who promptly seize upon a breakthrough and adjust their own research to accommodate it; the early majority are those who get on board as the breakthrough begins to become accepted; and the late majority are those who join only in after the breakthrough has been widely adopted by peer scientists.

The analysis of STM and BUF follow-up research as documented below extends across and in part beyond 20 years. In the literature, it is common to conduct longitudinal analysis with either three- or five-year intervals.[18] We have chosen five-year periods. Accordingly, we define *early adopters* as those who started doing follow-up research within five years of the breakthrough; we define *early majority* as those who entered upon follow-up research in the second five-year period after the breakthrough; and *late majority* as those who started follow-up research more than ten years after the initial breakthrough, that is, in the third or fourth five-year period.

According to the theoretical framework outlined above, building up research capacities in new fields requires primarily scientific staff and appropriate funding. Therefore, we consider the following *explanatory variables*: relative frequency of professors among scientific staff, growth in the absolute number of professors, growth in absolute amount of basic funding, and percentage of grants in the funding structure (Table 6.1). These explanatory variables are outlined below.

Table 6.1 Hypotheses for explaining early adopters in STM and BUF

Hypothesis 1	Early adopters are found in universities with a high percentage of professors.
Hypothesis 2	Early adopters are found in universities with a growing number of professors.
Hypothesis 3	Early adopters are found in universities with growing basic funding.
Hypothesis 4	Early adopters are found in universities with a high percentage of grant funding.

The first explanatory variable is the percentage of professors among all scientific staff. It measures the extent to which universities host work units that are independent in making the decision to seize upon and invest in new scientific opportunities. Universities hosting many professors, relative to the entire scientific staff, are expected to have a short response time to research breakthroughs (hypothesis 1). This is for the following two reasons: First, hosting many professors raises the frequency by which new and emerging research opportunities are both detected and followed up by incumbent professors. Second, in any university, existing research areas are being replaced to some extent through staff fluctuation. Hosting many professors raises the frequency by which new professors are being hired, and new research topics and areas thus are imported. Therefore, the first explanatory variable is a measure of *displacement* of research areas.

In addition, the first explanatory variable is also an indicator for the average size of research groups. It carries information about working conditions and the leadership and management duties that are linked to the professorial position. According to previous research, small groups offer better environments for creative research because the group leader remains personally involved in research and because there is more frequent, more intensive, and less hierarchical communication between group leader and group members.[19] Doctoral students and postdocs in small group environments benefit from more intensive mentoring, which has been shown to be the best preparation for a successful academic career.[20] In contrast, in large groups, a professor is more involved in research management, which includes directing and supervising the implementation of a research program, acquisition and administration of grants, and more heavy coordinator and representative tasks in relation to scientific colleagues, university administration, and funding agencies. The cited advantages of small groups suggest they will on average show faster reception to new scientific ideas (*exploration*) whereas large groups enable more in-depth exploitation of already established scientific breakthroughs (*exploitation*).

The second explanatory variable is growth in the number of professors. It is interpreted as an indicator for processes of *layering* of new research areas. Recruitment of new professors is important for intellectual renewal because they are specialized in new areas. If the number of professors is growing, then recruitment frequency is above the replacement rate. In this situation, there will be less conflict and less resistance against the uptake of new research fields because there are more areas to add than to replace. Therefore, response time to novel scientific ideas is expected to be short when the number of professors is growing compared to universities where it is stagnating or declining over longer periods of time (hypothesis 2).

The third explanatory variable is growth of basic funding. Similar to growth in the number of professors, this variable measures processes of *layering*. Growth in basic funding means there are resources available for investment in new topics and research opportunities. Hence, research groups disposing of growing basic funding can react to new scientific developments swiftly and in a flexible manner. Scientists who work in the context of growing basic funding will—on average—show fast receptions to novel scientific ideas (hypothesis 3).

The fourth explanatory variable is the amount of public and private grants as percentage of basic university funding. Grants drive scientists to seek opportunities for rapidly demonstrable scientific achievement. Depending on the time frame under which they are allocated, grants allow for more or less stable *layering* of new research areas. It seems likely that universities with high portions of grants will have short response time to novel scientific ideas (hypothesis 4).

6.5 Empirical Results I: Reception Speed in German and US Universities

Our comparison includes all universities where scientists publish—on average—at least one publication per year citing the "article flags" of either STM or BUF. Therefore, we define as *early adopters* those universities who had at least five STM or five BUF publications in the years 1983–1987 and 1986–1990, respectively. *Early majority* are those universities that in the second five-year period had at least five STM or BUF publications in

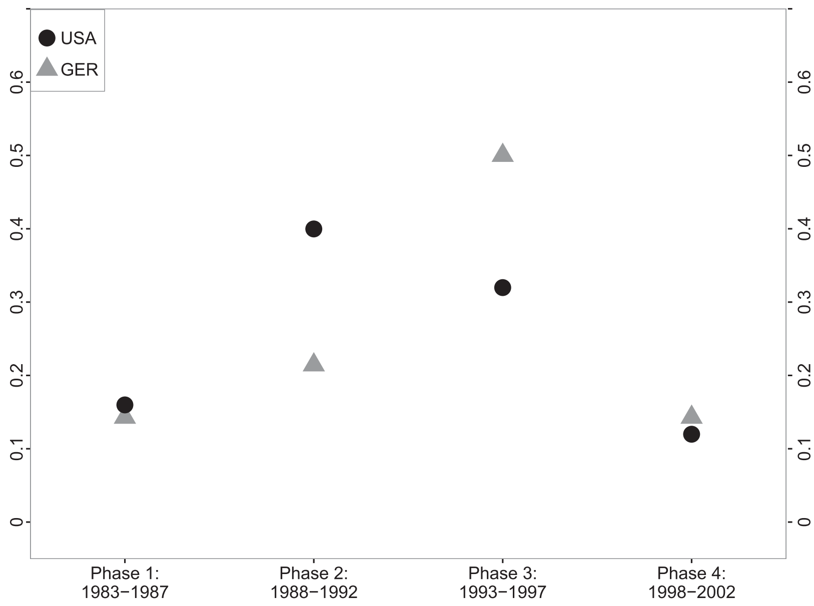

Fig. 6.1 Percentage of universities starting STM follow-up research
Source: WoS. Note: Phase 1 = Early adopters; Phase 2 = Early majority; Phases 3 and 4 = Late majority. N=14 German universities, N=25 US universities

1988–1992 and 1991–1995, respectively. *Late majority* comprised universities with an average of one publication per year and university more than ten years after the breakthrough, for STM in the years 1993–2002 and for BUF in the years 1996–2005.

The speed with which US universities compared to German universities entered follow-up research in STM and BUF is shown by their percentage in each of the five-year periods (Figs. 6.1 and 6.2). Regarding *early adopters*, there were four US universities and two German universities in STM, and six US universities but not a single German university in BUF. A second finding reinforces the first: Regarding *early majority*, there are mostly US universities, and the difference between US and German universities is more striking in BUF compared to STM. In contrast, German universities dominate in the category of *late majority*; the difference between the US and the German universities is again more striking in BUF compared to STM.

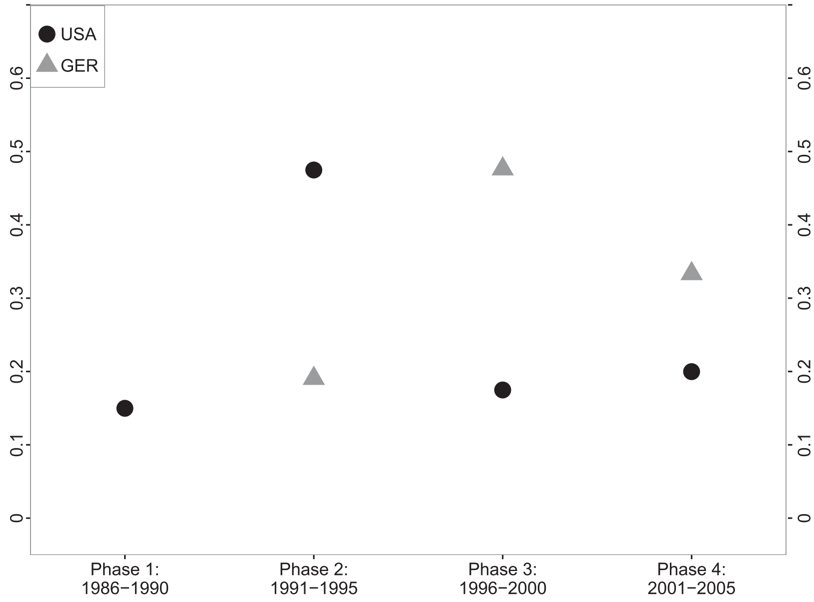

Fig. 6.2 Percentage of universities starting BUF follow-up research
Source: WoS. Note: Phase 1 = Early adopters; Phase 2 = Early majority; Phases 3 and 4 = Late majority. N=21 German universities, N=40 US universities

In sum, our bibliometric findings suggest that scientists in state universities in the USA were markedly ahead of their colleagues at German universities in seizing on both of these research breakthroughs. In the following section, we elaborate how these considerable differences in the dependent variable can be explained.

6.6 EMPIRICAL RESULTS II: CASE STUDIES OF GERMAN AND US UNIVERSITIES

Based on the bibliometric findings on the dependent variable, we established criteria for selecting university cases. For theoretical reasons, the first criterion was to choose universities that were either early adopters or early majority because the aim of the analysis is to determine which characteristics of our variables contribute to rapid follow-up research. A second criterion was the total number of STM or BUF publications that the universities published in the respective 20-year time frames.

In practice, the consistent application of both criteria was not always possible. The reason for this was that state universities in Bavaria (n = 8) and campuses of the University of California (UC; n = 10) had to be chosen because comparative longitudinal data for the independent variables could be retrieved only for these state universities. Regarding STM, Ludwigs-Maximilians-Universität München (LMU) was the first choice; in comparison to the other two Bavarian universities that engaged in STM follow-up research (Universität Regensburg, Technische Universität München), LMU is an early adopter and has a higher total number of STM publications. In the UC system, the choice was easy: UCSB is an early adopter and has the highest total number of STM publications. Regarding BUF, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) was the first choice; like to the other two Bavarian universities that engaged in BUF follow-up research (Universität Bayreuth, Technische Universität München), it is late majority, but displays higher total numbers of BUF publications. In California, UCLA and UC Berkeley (UCB) are both early adopters, and almost identical in BUF publication output. UCLA was chosen for case study.

6.6.1 Explanatory Variables for UCSB, UCLA, LMU, and FAU

The first explanatory variable (V1) is the percentage of professors among all scientific staff. At UCSB, the percentage of professors decreased from 52% in the first period (1983–1988) to 42% in the last period (2003–2008). At UCSB's physics department, the percentage of professors decreased from 54% to 35% in the same periods. At UCLA, the percentage of professors slightly decreased from 44% in the first period (1986–1991) to 40% in the last period (2006–2010). At UCLA's chemistry and biochemistry department, the percentage of professors slightly decreased from 35% to 32% in the same periods.

At LMU, the percentage of professors decreased from 22% in the first period (1983–1988) to 12% in the last period (2003–2008). Figures for the physics department are almost identical with 21% in the first period and 13% in the last period. At FAU, the percentage of professors decreased from 19% in the first period (1986–1991) to 13% in the last period (2006–2010). Figures for the chemistry department are similar, with 19% in the first and 12% in the last period.

Compared to the US cases, the two German universities had a significantly lower percentage of professors among all scientific staff over the total observation period of 25 years, indicating a lower capacity for reception to novel scientific ideas. In addition, there is a general decrease in the percentage of professors in both systems, indicating a decreasing capacity for reception to novel scientific ideas.

The second explanatory variable (V2) is growth in the number of professors. At UCSB, this number rose by 44% (38% for full professors), from 531 in 1980 (311 full professors) to 767 in 2010 (505 full professors). At UCSB's physics department, their number rose by 48% (45% for full professors), from 25 (20 full professors) to 37 (29 full professors) in the same period. At UCLA, the total number of professors rose by 24% (35% for full professors) from 1267 in 1980 (741 full professors) to 1574 in 2010 (1001 full professors). At UCLA's chemistry and biochemistry department, however, their number rose by 9% only (24% for full professors), from 45 (29 full professors) to 49 (36 full professors) in the same period. Therefore, conditions at UCLA's chemistry and biochemistry department were less conducive than at UCLA in general.

At LMU, the number of professors was 906 in 1980 and decreased to 703 in 2010, a decline by 22% (including junior professors). The faculty of physics and astronomy had 38 professors in 1980. The figure rose to 42 in 1988, then stagnated (with minor fluctuations) until 2000, and then decreased to a minimum of 35 in 2006. Thus, there was slight growth in the first five years after the STM breakthrough. In connection with funding from the Deutsche Forschungsgemeinschaft (DFG) for a "cluster of excellence," professorial positions were in part reallocated by university leadership in the mid-2000s. The general declining trend was reversed for the physics department, and the number leaped to 51 professors in 2010. At FAU, the number of professors grew from 373 in 1980 to 524 in 2010, which is equivalent of a growth of 40%. In chemistry, there were 20 professors in 1980, and in physics there were 29. These figures remained roughly constant over 25 years, so that the uptake of BUF happened during a period of stagnation. Similar to the case of LMU, the launch of a DFG "cluster of excellence" led to noticeable growth at the end of the observation period, with 26 professorships in chemistry and 36 in physics in 2010.

The characteristics of the four universities on the two staff variables are quite typical of universities in the UC system and Bavaria. The UC system had a percentage of professors of 45% in the mid-1980s, declining to 40% in the second half of the 2000s. Bavaria had 22%, declining to 12% in the same period. In the UC system, the number of professors grew by 40% (71% for full professors), from 5155 in 1980 (2955 full professors) to 8552 in 2010 (5064 full professors). In Bavaria, the number of professors increased by 19%, from 2490 in 1980 to 2952 in 2010 (including junior professors). In absolute numbers, the UC system had 2.1 times as many professors as Bavaria in 1980 but 2.9 times as many in 2010. These differences in relative and absolute figures indicate an increasing divergence in the structure of scientific staff at UC campuses and Bavarian universities.

The third and fourth explanatory variables are growth in basic funding (V3) and percentage of state and private grant funding in total financial resources (V4). Basic state funding at UCSB's physics department shows long waves of growth, rising from $4.9 million in 1983 (first year of data set) to $7.0 million 1991, dropping to $5.1 million in 1994 and rising again to $8.0 million in 2004. Over a period of 28 years from 1983 to 2010, there was overall growth of 39% in basic state funding, and growth of 19% in tuition fees, both indicating overall good conditions for layering of new research areas. Furthermore, from 1983 to 2010, the amount of state and private grant funding oscillated between $2.8 and $4.5 million annually. As a result, between 1983 and 1987, the ratio between grant and basic funding at USCB's physics department fluctuated between 0.46 and 1.00, indicating very good conditions for layering of new research areas in the period following the STM breakthrough. In the entire observation period from 1983 to 2010, grant funding as a percentage of basic funding decreased from 46% (between 1983 and 1987) to 33% (between 2006 and 2010).

At the UCLA department of chemistry and biochemistry, basic state funding shows periods of decline and some growth in between. There was a decline from $14.0 million in 1986 (the first year of the data set) to $12.3 million in 1990, followed by a further decline to $11.4 million in 1995, then substantial growth to $13.8 million in 2000, followed by another decline to $12.8 million in 2010. However, the total decline of 8% in basic state funding between 1986 and 2010 was counterbalanced by a strongly increasing inflow from tuition fees, which more than doubled from $3.4 million in 1986 to $7.0 million in 2010. Therefore, total basic funding moderately increased by 14% between 1986 and 2010, indicating some opportunities for layering of new research areas. More layering possibilities existed because the amount of state and private grant funding rose by 43%, from $9.8 million in 1986 to $14.0 million in 2010. As a result, UCLA's chemistry and biochemistry department had a very high and increasing ratio of grant to basic funding, rising from 0.57 (between 1986 and 1990) to 0.9 (between 2006 and 2010).

At LMU, basic funding for the faculty of physics and astronomy declined in the period from 1982 to 1986 from around €19 million to €17 million. Later, basic funding rose to €21 million in 1987, and then declined again to €15 million in 1994, then rose again to €22 million in 2003. This means that during the 1980s and in the first half of the 1990s there were no additional basic funds available for the layering of new research areas at LMU. State and private grant funding at the faculties of physics and astronomy grew at first slowly between 1980 and 1995, and then more rapidly from €3.6 million in 1995 to €9.5 million in 2006, after which it surged to a maximum of €19.8 million in 2009. The ratio of grant to basic funding increased steadily from 0.17 (between 1986 and 1990) to 0.48 (between 2006 and 2010). At the end of the 2000s, DFG excellence funding caused statistical outliers. During the first decade of STM follow-up research at LMU, from 1983 to 1992, the ratio between grant and basic funding was still below 0.2, indicating limited resources for layering of new research areas.

At FAU, basic funding for the department of chemistry rose from €8 million in 1980 to €14.4 million in 1997 and then decreased to €11 million in 2009. The decline in basic funding since 1997 meant that no additional basic funds were available for the layering of new research areas at the time when BUF was taken up at FAU. State and private grant funding at the faculty of chemistry rose from €0.4 million in 1980 to €4.2 million in 2005. It fluctuated in the second half of the 2000s and reached a maximum of €4.9 million in 2009. The ratio of grant to basic funding increased slowly at first, from 0.03 (from 1986 to 1990) to 0.10 (from 1991 to 1995), and then sharply to 0.36 (from 2001 to 2005). In total, increasing grant funding compensated for the decline in basic funding from 1997 to 2004. Rising shares of grant funding showed overall good conditions for the layering of new research areas during the period when BUF was taken up at FAU.

The characteristics of the four universities on V3 and V4 are in many ways typical of the universities in the UC system and Bavaria. Basic funding for UC campuses grew from a total of $2.58 billion in 1979 to a total of $4.93 billion in 2010, which is equivalent of a growth of 91% (V3, including endowment). A decomposed analysis shows that state basic funding grew only slightly, by 12%, from $2.15 billion in 1980 to $2.41 billion in 2010, whereas tuition fees increased by a factor of 6.16, from $0.36 billion in

1979 to $2.65 billion in 2010. Even though state basic funding did not grow much, rising tuition fees led to pronounced long-term growth in basic funding, supporting continued layering of new research areas over a period of 30 years. Furthermore, state and private grant funding grew by a factor of 4.5, from $1.40 billion in 1979 to $6.32 billion in 2010. Therefore, the ratio of grant to basic funding (V4) increased from 0.54 in 1979 to 1.28 in 2010, indicating excellent conditions for the layering of new research areas.

Basic funding for state universities in Bavaria grew by 54%, from €1.06 billion in 1980 to €1.63 billion in 2010 (V3). This includes tuition fees, which were introduced in the second half of the 2000s, rising from €7.8 million in 2006 to €111.4 million in 2010. The growth period extends from 1980 to 1992; afterwards, there was a period of stagnation with fluctuations until 2007. Therefore, there were good conditions for layering of new research areas until the early 1990s, followed by a period of stagnation during the 1990s and 2000s. State and private grant funding expanded strongly by a factor of 7.2, from €80.3 million in 1980 to €577 million in 2010. The ratio of grant to basic funding (V4) increased from 0.08 in 1980 to 0.35 in 2010. Although the steep growth in grant funding indicates improving conditions for layering of new research areas, the percentage of grant funding was much lower compared to the UC system.

The analysis of staff structure and financial resources shows that, apart from minor deviations, the four selected cases are representative of macro developments in the respective state university systems. The quantitative description already hints at dramatic differences in the conditions for intellectual renewal in California and Bavaria. These differences are further investigated in each of the four case studies below.

6.6.2 UCSB (STM)[21]

The story of STM adoption at UCSB is the story of the Paul Hansma laboratory. Hansma is a physicist and early adopter who stepped into STM research in 1983 when Gerd Binnig for the first time presented atomic resolution images of a 7-by-7 silicon surface reconstruction (dependent variable). Before adopting STM, Hansma had worked on inelastic electron tunneling spectroscopy and already had been introduced to STM through personal contact with Binnig in the summer of 1981, a few months after the initial discovery. Hansma was also among the earliest adopters of the Atomic Force Microscope (AFM), as he shifted his research group from STM to AFM immediately after the invention by Binnig, Quate, and Gerber in 1986. During the 1990s, his group invented applications of AFM for a variety of disciplines, while in the 2000s, the focus shifted to development of biomedical AFM applications and devising improved diagnostics for skeleton bones.

The case of UCSB highlights the percentage of professors (V1) as a significant factor for the rapid uptake of research breakthroughs. The Hansma laboratory at UCSB represents an organizational structure geared to the individual investigator and his scientific collaborations. As a group leader, Hansma appreciates the advantages of small groups, and he cares to protect his own role as a researcher against encroachment by research management duties. As Hansma emphasized in an interview, he never wanted his group to become too big for himself to work in the laboratory or build prototypes with his own hands. Hansma became known in the "instrumental community" for recruiting a long series of postdocs who expanded STM and AFM applications into broad areas of physics, chemistry, materials science, geology, and molecular biology.[22] Over time, he collaborated with a large number of scientists from physics as well as other disciplines inside and outside UCSB. One of his most important partners in AFM research was Hermann Gaub, who stayed at UCSB as a postdoc in 1988 and became a professor at LMU in 1995, creating a substantive link between the two case studies.

Given that research groups are small, the main management duty of a professor consists in the acquisition of grants (V4). As described in the previous section, the physics department at UCSB had a high share of grant funding in the period between 1983 and 1987. The case study shows that Hansma used three approaches to secure flexible long-term funding for his group. First, he was able to obtain long-term grants, most of the time from the US National Science Foundation (NSF) Division of Materials Research, a grant that was extended four times over 30 years from 1973 to 2004, and later from the US National Institutes of Health from 2002 to 2014. A second parallel funding stream was provided by grants of shorter duration from varying sources.

Second, a strong reputation allowed Hansma to adopt the principle that he would accept only postdocs who brought their own funding with them. In that way, he reduced his own acquisition load while selecting postdocs who were capable of writing grant applications independently and whose projects could stand up to peer review. Third, a close collaboration with the start-up Digital Instruments Inc., founded by UCSB physics professor Virgil Elings in 1986, provided the Hansma laboratory with significant contributions in instrumentation and patent royalties, which he could use as flexible research money. Flexible as opposed to earmarked funding is important for reception speed to novel scientific ideas.

Strong growth in the number of professors at the physics department and at UCSB more generally (V2) underpins a recruiting policy geared at individual talent. We found no institutional commitment on the part of UCSB to build up or maintain excellence in STM/AFM research. Rather, UCSB aims to recruit the best and most talented individuals while it is understood that as professors, they may decide to change research areas perhaps several times over the course of their careers. Renewal is implemented as individual reaction to opportunity (V1).

Another interesting finding from the case of UCSB concerns the investment of additional basic funding (V3) and grant funding (V4) for shared resources that are accessible to all scientists either within the same department or across several departments. According to Hansma, the physics machine shop was most significant to the success of his group because there were excellent machinists who built instruments for researchers, and professors and students could also build things for themselves. In the 1980s, the physics department still partially covered the costs of the machine shop. Today, this machine shop is financed from individual research grants (V4) on a full cost basis. Still, the same infrastructure is provided for all scientists in the department of physics. Another example is the Materials Research Laboratory, which was established at UCSB in 1992 under the framework of the NSF's "Materials Research Science & Engineering Centers" (MRSEC) program. The MRSEC seeks to reinforce the base of individual investigator and small group research (V1) by supporting research approaches of a scope and complexity that would not be feasible under traditional funding of individual research projects. In this context, Hansma formed a long-lasting interdisciplinary collaboration with Galen Stucky, Daniel E. Morse, and later J. Herbert Waite. The MRSEC combines project grants (V4) for interdisciplinary teams of professors with the provision of facilities that are shared among members of different departments (V3). In this way, collaboration among faculty is facilitated.

In sum, the UCSB case demonstrates that along with the high percentage of professors among scientific staff positions, the professor and his small group are the key unit of decision making and thus of change in science (V1). In addition, *layering* new research areas requires long-term availability of individual investigator grants (V4) and sharing equipment and laboratory space via basic departmental or university funding (V3).

6.6.3 UCLA (BUF)[23]

The story of BUF adoption at UCLA involves the research groups of Robert Whetten, François Diederich, Richard Kaner, and Karoly Holczer. Their groups were among the early adopters of BUF research. The first phase of BUF follow-up research lasted from 1985 until 1990, when Krätschmer, Lamb, Fostiropoulos, and Huffmann introduced a new process for the synthesis of C60 molecules.[24] In 1990, when Whetten heard Krätschmer lecture on the C60 manufacturing processes at a conference in Germany, he immediately paid him a visit at the Max Planck Institute for Nuclear Physics in Heidelberg and, together with Diederich, started to produce C60 at UCLA. Whetten and Diederich were thus among the first scientists worldwide to enter the race for the chemical characterization of fullerenes (dependent variable). Together with Kaner and Holczer, they formed a team of complementary specialists and quickly attained a central position in the emerging field. In the period between May 1991 and September 1993, Whetten, Kaner, and Holczer co-authored 19 articles while Whetten and Diederich had another 20 co-publications.

Even though the percentage of professors in UCLA's chemistry and biochemistry department was lower than at UCLA in general, the case study illustrates the advantage of early scientific independence, which is linked to a high percentage of professors among scientific personnel (V1). Whetten was born in 1959 and thus barely over 30 years old when he stepped into C60 research. By the age of 26, he had already been an assistant professor. Diederich was born in 1952, and by age 33, he had completed his habilitation at Heidelberg before coming to UCLA in 1985. Despite the fact that Diederich was comparatively young when he completed his habilitation, he attained an independent research position seven years later than Whetten. As Kaner explained in an interview, the US system offers scientists the opportunity to succeed or fail at a very young age. Well below the age of 30, scientists may be given a laboratory with the equipment, students, and resources necessary to do whatever they are capable of doing. In contrast, their peers in Germany would typically work under supervision of a more established professor until their late thirties and early forties.[25]

The case of UCLA also illustrates how tenure track is linked to the acquisition of grant funding (V4). The tenure-track system works as an incentive structure that rewards rapid uptake of new scientific opportunity. When Diederich, Whetten, and Kaner stepped into BUF research in 1990, Diederich had shortly before been promoted to full professor, Whetten was an associate professor, and Kaner was an assistant professor. At the time of their appointment, they had been equipped with substantial starting capital from UCLA. As Kaner explained in an interview, Whetten advised him to expend his starting capital and more in order to earn scientific credit. Consequently, Whetten and Kaner both followed a deficit-spending strategy, consisting of rapid investment to come up with findings that would expedite the acquisition of new grant money. Judged by the criteria of the tenure track process, their strategy paid off. The scientific visibility and reputation that the group achieved in the initial BUF boom phase earned them rapid promotion to the status of full professor. Yet it was also risky because newly acquired research grants had to be used to settle previous debts, and the future revenue in external funding was never certain. Kaner was relieved from deficit spending in 1989 when he obtained a Hewlett Packard Fellowship worth $100,000 per year for a period of five years. Whetten, on the other hand, believed in the deficit-spending philosophy, and up until 1993, when he left UCLA, had accumulated massive debts on university accounts.

The case of UCLA also illustrates how the strong dependency of professors on grant funding (V4) may end a successful scientific collaboration. An apex of follow-up research at UCLA was the isolation of potassium-doped C60 compounds, demonstration of a single superconducting phase, and analysis of the crystal structure of K3C60. These findings were published in a race for priority with a group from Bell Labs. At the height of productivity, however, the collaboration disintegrated. In 1992, Diederich left UCLA for a professorial chair at Eidgenössische Technische Hochschule (ETH) Zürich; in 1993, Whetten accepted a professorship at the Georgia Institute of Technology in Atlanta. Holczer was appointed professor at UCLA in 1993 but felt compelled to change research fields after Whetten had left. Kaner stayed to continue on at UCLA with fullerene research. Compared to the 1991–1992 peak, the number of BUF follow-up publications dropped significantly.

In US universities, professorships are not endowed with staff positions, so except for the starting package professors may receive when accepting a professorial position, the entire laboratory, scientific group, students, and equipment must be sponsored through research grants. Diederich left UCLA to establish a much larger institute based on more extensive basic funding at the ETH Zürich, (V4). Twenty years later, his laboratory has issued a total of over 660 publications, awarded 106 doctoral degrees, and hosted 94 postdocs, attesting to differences in group size that are linked to the percentage of professors among scientific staff (V1). Whetten accepted the offer from the Georgia Institute of Technology, which allowed him to pay the debts he had accrued during his work at UCLA. Thus, it was the pressure to acquire grant money (V4) in a general climate of declining basic state funding that led to a premature disintegration of a highly productive collaboration in the case of UCLA's chemistry and biochemistry department.

In sum, the UCLA case demonstrates that the high percentage of professors among scientific staff (V1) made it possible for a team of four professors to build a coalition and, by means of some basic departmental and university funding (V3), but more importantly: by means of external grants (V4), successfully compete for a central position in the emerging research field. Although follow-up research at UCLA lasted from 1990 to 1993 only and thus shows that *layering* of new fields might be temporary, it was extremely productive during this period and represents an instance of rapid and successful response to novel scientific opportunity.

6.6.4 LMU (STM)[26]

STM follow-up research at LMU set in directly after the original breakthrough (dependent variable). This finding is not surprising given the fact that Gerd Binnig, one of the inventors of STM, came to LMU in 1987 as an honorary professor and for ten years led the IBM physics group there, an outpost of IBM Zürich. Other scientists involved in STM/AFM follow-up research include Wolfgang Heckl, Hermann Gaub, and Khaled Karrai.

Binnig set up his own laboratory at the institute of Theodor Hänsch, a physicist and pioneer of laser spectroscopy at LMU (Nobel laureate 2005). However, the IBM physics group seems to have exerted less influence than might be expected. This is displayed in a decreasing number of STM publications in the late 1980s and early 1990s. Binnig's title of honorary professor did not involve regular teaching duties or the right to supervise habilitations. As for his team, academic career options were either not readily available (V1, V2) or not attractive enough, so that most scientists moved on to other IBM projects and locations once the cooperation with LMU ended. Exceptions of team members who entered academia were Franz-Joseph Gießibl, who left the IBM physics group after his dissertation in 1991 and became a professor of experimental physics at Regensburg in 2006, and Wolfgang Heckl, who was a professor at LMU from 1993 to 2004.

The careers of Heckl and Gaub illustrate the scarcity of professorships (V1) and their decline in absolute numbers (V2) as a severe constraint on recruitment and thus on the uptake of new research areas at LMU in the late 1980s and 1990s. Heckl had been a doctoral student under Profs. Helmuth Möhwald and Erich Sackmann at the Institute of Biophysics at Technical University Munich (TUM) when Binnig recruited him. He joined the IBM physics group in 1989 as a postdoc. Because Binnig was not in a position to supervise his habilitation, Heckl became Hänsch's assistant in 1990 but continued to work with Binnig. The IBM laboratory was excellently equipped, and Heckl recalls a spirit of optimism and innovation there. Although his habilitation on the structure of DNA bases was awarded the Philip Morris Research Prize in 1993, at the age of 35, he could not be recruited to the physics faculty at LMU because between the late 1980s until the mid-2000s, the number of physics professors at LMU dropped from 42 (1988) to 35 (2005).

Therefore, he accepted an associate professor position for experimental physics at LMU's Institute of Crystallography in the faculty of geosciences in 1993. This move changed his working environment and conditions for the worse: He received little support among the full professors (chairholders) in geosciences, who perceived STM methods as unrelated to the core of their discipline. Because it is chairholders who are in the position to compete for and dispose of basic funding in German universities (V3), Heckl was left to finance his research group exclusively through external grants (V4). In 2004, Heckl was appointed director general at the German Museum in Munich. Even though his main responsibility there was science communication, he established an STM ultrahigh vacuum laboratory at the German Museum. In 2009, he was appointed full professor of science communication at TUM.

Gaub, like Heckl, had been a student of Prof. Sackmann and taken his doctorate in 1984 at TUM. He completed a postdoc at Stanford in 1984 and came to UCSB as a visiting scholar in 1988. There, he was introduced to AFM by Hansma, who handed him one of the first AFM prototypes.

The two scientists started a fruitful collaboration, co-publishing 12 papers on biophysical applications of AFM between 1990 and 1999. After Gaub had completed his habilitation and spent another year at Stanford, at the age of 38, he was appointed associate professor at TUM and in 1995 to full professor of applied physics at LMU. Gaub's recruitment to LMU was possible only because in 1995, the number of professors in physics almost reached the level of 1988 before it started to drop until 2005 again. Therefore, had there been more and a growing number of professor positions at LMU, Gaub, whom Hansma referred to as one of the most talented scientists he had ever collaborated with, could have possibly been recruited there much earlier.

Another finding concerns an institutional constraint on collaboration among faculty at LMU. Although the rise of the nanosciences since the early 1990s created a strong need for interdisciplinary collaboration among subspecialties of physics and other disciplines, professorial chairs at LMU showed little inclination for scientific exchange and collaboration because they competed individually for additional basic funding of their own chair-based research institutes that were operated by chairholders as self-contained hierarchical units (V3). In this situation, semiconductor physicist Jörg Peter Kotthaus together with a group of younger colleagues at LMU, including Heckl and Karrai, among others, created the Center of Nanosciences (CeNS) in 1998. CeNS brought together scientists who would open the doors of their laboratories to their colleagues as a precondition for CeNS membership, modeled after Kotthaus' experience at UCSB's department of physics. This organizational innovation reportedly unleashed a spirit of enthusiasm. CeNS was, in fact, one of the first of several nanoscience centers that have since been created in Germany and the USA.

In sum, the LMU case study shows that despite the presence of nobel laureate Gerd Binnig at the faculty of physics, the reception of novel scientific ideas was constrained by a low percentage of professors among scientific staff (V1) and by declining absolute numbers of professors both at the faculty of physics and at LMU (V2) during the late 1980s until the mid-2000s (*displacement*). Therefore, the opportunities to recruit outstanding scientists in the emerging field of STM/AFM follow-up research were severely inhibited.

6.6.5 FAU (BUF)[27]

FAU entered BUF follow-up research ten years after the original breakthrough (late majority). The case study begins in 1995 when Andreas Hirsch was appointed full professor at the Institute of Organic Chemistry (dependent variable). Hirsch formed a close collaboration with computer chemist Timothy Clark and physical chemist Dirk Guldi in the area of carbon allotropes. Since the beginning of the 2000s, the number of professors involved in this new research area increased through strategic activities both at the department and FAU level. Today, BUF follow-up research at FAU covers carbon nanotubes and graphene as well as fullerenes and involves collaborations among the departments of chemistry, physics, and material sciences.

The FAU case again highlights recruitment of professors as a key mechanism for intellectual renewal and suggests that a low percentage of professors among scientific staff (V1) causes late adoption of breakthroughs. When Hirsch was appointed in 1995, five years after the invention of C60 mass synthesis by Krätschmer et al.,[28] he was the only professor at FAU who had any experience in BUF-related research. Similar to the case of LMU, Hirsch reimported the topic from UCSB, where he had stayed from 1990 to 1991 as a postdoc with Fred Wudl, one of the first adopters of BUF research worldwide. Even though Hirsch was among the first adopters of fullerene chemistry in Germany, he first had to complete his habilitation in Tübingen before being recruited to an associate professorial position in Karlsruhe in 1995 and then to a full professor position at FAU in the same year. At FAU, Hirsch swiftly formed a collaboration with computer chemist Clark, who had been professor at FAU since 1976, and physical chemist Guldi, who despite having completed his doctoral thesis in 1991, one year after Hirsch, was appointed full professor at FAU as late as 2004.

When fullerene research started at FAU, it did so in a context of stagnating numbers of professors at the chemistry department, as well as the university as a whole (V2). However, during the mid-2000s, there was a unique opportunity for intellectual renewal. Within a period of only a few years, 100 full professorial positions and 58 associate professorial positions were open for recruitment due to massive retirement. Facing this rare opportunity, FAU university leadership started to build strategic clusters in selected research fields. During this time, Hirsch and Clark had already built a collaboration that received departmental and university level support. Since 2000, university leadership defined carbon allotropes as part of FAU's profile in the strategic field of new materials research. This university strategy resulted in the appointment of a total of ten professors with research specialties related to carbon allotropes, five in the department of chemistry and five together in the departments of physics and material sciences; this is equivalent to *displacement* of existing by new research areas. In the context of organizational restructuring in 2007–2008, another three full professor positions were created in the "Interdisciplinary Centre for Molecular Materials"; this is equivalent to *layering* of new research areas on top of existing ones.

The concentration of basic funding (V3) into carbon allotropes was dependent on the successful acquisition of grant funding, especially from DFG. The percentage of grant funding (V4) in the department of chemistry had increased slowly from 3% (from 1986 to 1990) to 10% (from 1991 to 1995). During the first decade of BUF follow-up research, it climbed to 20% (from 1996 to 2000). Hirsch and Clark had received individual investigator grants from DFG for BUF follow-up research since 1996. From 2001 to 2012, they both led research groups within the DFG collaborative research center "Redoxactive Metal Complexes" (SFB 583). Then Clark was among the coordinators for FAU's acquisition of a DFG "cluster of excellence" in the field of advanced materials, which involves professors from several disciplines. This cluster yielded €41 million from DFG and additional €41 million together from the state of Bavaria, the German federal government, and industry for a period of five years from 2007 to 2012. Between 2012 and 2017, DFG granted another €34 million. Hirsch is director of the DFG collaborative research center "Carbon Allotropes" (SFB 953) for the period 2012–2017, coordinating 15 research groups in the departments of chemistry, physics, and engineering. Therefore, the percentage of grant funding (V4) in the department of chemistry increased to 36% (from 2001 to 2005).

As argued in the case of LMU, the professorial chair system operating with a small percentage of full professorships (V1) who then compete for additional basic funds (V3) tends to create self-contained units that impede collaboration. At FAU, this problem was addressed in an organizational reform in 2007–2008: Departments were created as administrative units below the level of faculties, replacing the former disciplinary institutes. The main objective of this reform was to make university administration more efficient and to improve administrative services. The department structure has been cited in interviews as a facilitating condition for collaboration among professorial chairs. However, apart from the sharing of administrative resources, the hierarchical professorial chair system remained intact. At the end of the 2000s, funding from the DFG excellence program allowed for some growth in the number of professors (V2) in the departments of chemistry, physics, and material sciences. At the same time, however, the numbers of scientific staff rose from an already high level, resulting in still lower percentages of professors and increased average group size (V1). Therefore, it is expected that the DFG excellence program has not sped up today's reception time for more recent research breakthroughs compared to the 1980s and 1990s.

In sum, the FAU case study shows how the reception of novel scientific ideas was constrained by a low percentage of professors among scientific staff (V1) and by stagnating absolute numbers of professors (V2) during the 1990s until the mid-2000s. Intellectual renewal happened at FAU with considerable delay only when, because of a retirement wave, a considerable number of professorial positions were open for recruitment (*displacement*), and when the university leadership took this opportunity to build strategic research areas and at the same time invested additional resources (V3) in these new areas, including professorial positions (*layering*). It also illustrates how large-scale grant funding (V4) ignited the systematic exploitation of carbon allotropes as an already recognized and established research field.

6.7 Conclusions

This chapter examines the capabilities of universities to rapidly build up and expand research capacities in new and emerging scientific fields following major scientific breakthroughs. Based on STM and BUF, two research breakthroughs in physics and chemistry from the early/mid-1980s, we investigated how quickly scientists in German and US state universities built up follow-up research in response to these breakthroughs. Most importantly, we explored to what extent the institutional framework in which universities are embedded supported such expansion and renewal. For this purpose, we distinguished between *layering* and *displacement* as gradual processes of renewal in science. Using longitudinal staff and funding data as well as case study evidence, we have provided original insights into mechanisms shaping these two renewal processes.

Our bibliometric findings (dependent variable) demonstrate that scientists in US universities were several years ahead of their colleagues at

German universities in seizing on STM and BUF. US scientists were more often early adopters and early majority than German scientists while the latter were mostly late majority. Our institutional findings (explanatory variables) suggest that in the years following STM and BUF, the UC system provided better institutional conditions for scientific renewal than universities in Bavaria. Universities in the UC system had many opportunities for taking up new and emerging fields, mostly via *layering* of new resources, including additional professorial positions, and via *displacement* of old by new research specializations that came with continuous replacement of professorial positions in universities with a high share of such positions among all scientific staff. In contrast, Bavarian universities operated under less supportive conditions: stagnating basic funding primarily invested in hierarchical, self-contained professorial chairs in combination with a relatively low level of external grant funding and scarcity of professorial positions caused delayed responses to novel scientific developments. Below are our results:

First, a high percentage of professors among scientific staff (V1) is conducive to intellectual renewal via *displacement* of established fields by new research fields, as stated in the first hypothesis. Two mechanisms are involved: A high percentage of professors raises the frequency by which new research opportunities are both detected and followed up by those who are expected to conduct independent research; in addition, a high percentage of professors raises the frequency by which new peers are hired, and new research topics and areas thus are imported in exchange for existing ones.

As the four cases have shown, the percentage of professors provides valuable information about the chance structure for academic careers. A low percentage of professors, as in Germany, indicates that many more young scientists work in the academic system than can be possibly absorbed into professorial ranks. As a consequence, there is a bottleneck at the transition to professorial status, leading to prolonged periods of dependency and job insecurity in academic biographies. In the US system, the transition to assistant professor, and thus scientific independence, takes place earlier in the biography, thus providing favorable conditions for seizing upon new and promising scientific opportunities.

Second, the chapter demonstrates that an increasing number of professors (V2), growth in basic funding (V3), and a high ratio of grant to basic funding (V4) are key factors positively associated with renewal via *layering* of new research areas on top of existing commitments in established research fields and disciplines, as stated by the second, third, and fourth hypotheses. In fact, a declining or stagnating number of professors (V2) severely constrains the capability of universities and their departments to build up swiftly new and emerging research fields by recruiting outstanding scientists, as demonstrated in the cases of LMU and FAU. Furthermore, as the case of UCSB shows, if growth of basic funding (V3) is channeled into facilities and laboratories that are widely shared by professors both inside and across departments, opportunities for particularly effective collaborations in new and emerging fields are created. Yet, as the case of UCLA illustrates, in a context of declining basic state funding, too strong dependency of professors on grant money and too high competitive pressure for external research resources (V4) may inadvertently end successful scientific collaborations before all fruits are harvested.

Third, our findings point to considerable and increasing differences in the university systems of California and Bavaria with major implications for renewal in science. Although the percentage of professors (V1) has decreased in both states since the 1980s, this decrease has happened in very different ranges: from 45% to 40% in California, and from 22% to 12% in Bavaria. Therefore, given our empirical findings on V1, the conditions for renewal in science in Bavarian universities are worse today than they were in the 1980s, in contrast to California.

Furthermore, basic funding (V3) for UC campuses grew from a total of $2.58 billion in 1980 to $4.93 billion in 2010 (91% growth) with tuition fees and grant funding providing the lion’s share in growth. In contrast, basic funding for state universities in Bavaria grew from €1.06 billion in 1980 to €1.63 billion in 2010 (54% growth), including tuition fees (since 2007). Yet, following a more general political trend against tuition fees in all German Länder states, the Bavarian parliament abolished tuition fees in 2013. Tuition fees will not be charged in the future, thus reducing the level of basic funding in Bavarian universities. Therefore, based on our empirical findings on V3, the financial conditions for renewal in science in Bavarian universities are worse than in California.

In addition, there is also a major gap regarding the share of grant funding (V4) between the two states. In UC campuses, state and private grant funding grew from $1.40 billion in 1980 to $6.32 billion in 2010 (growth factor of 4.5), which is equivalent to an increase from 0.54 to 1.28 of grant relative to basic funding. In Bavarian universities, state and private grant funding expanded from €80.3 million in 1980 to €577 million in 2010 (a factor of 7.2), which is equivalent to an increase from 0.08 to

0.35. While the steep growth in grant funding indicates improving conditions for layering of new research areas in Bavaria, the ratio of grant to basic funding is still much lower compared to the UC system. In fact, the growth of state and private grant funding in Bavaria seems decoupled from the growth in the number of professors (V2): In Bavaria, the number of professors has grown by 19% while UC campuses have a growth of 40%. In comparison with the growth in state and private grant funding (Bavaria: 7.2, UC system: 4.5), much of the grant funding in Bavaria is channeled into scientific staff positions below the professorial level, which is typically not entitled to conduct scientific research independently—a key condition for renewal in science, as this chapter has shown.

In methodological terms, the chapter has demonstrated that interpreting qualitative results from the four case studies requires triangulation with longitudinal quantitative data on staff structure and funding streams. Without these quantitative data, it would be difficult to generalize results. In fact, the four cases represent the two university systems so well that findings at both the department and the university levels oftentimes match with variables for the two systems as a whole. In this way, the chapter strives to link the historical narrative of particular cases with more general institutional developments in the systems in which these cases are embedded.

NOTES

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