COLD ATOMS – HOT RESEARCH: HIGH RISKS, HIGH REWARDS IN FIVE DIFFERENT AUTHORITY STRUCTURES

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ABSTRACT

Bose-Einstein condensation is a scientific innovation in experimental physics whose realisation required considerable time and resources. Its diffusion varied considerably between and within five countries that were comparatively studied. Differences between countries can be explained by the variation in the national communities' absorptive capacities, while within-country differences are due to the impact of authority relations on researchers' opportunities to build protected space for their change of research practices. Beginning experimental research on Bose-Einstein condensation required simultaneous access to the university infrastructure for research and to grants. The former is largely limited to

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professors, while the latter made researchers vulnerable to the majority opinion and decision practices of their national scientific community.

Keywords: Scientific innovation; emergence of fields; authority relations; absorptive capacity; experimental physics; academic careers

INTRODUCTION

Anyone who wants to introduce a major scientific innovation in experimental physics faces a challenge because designing and constructing a new experimental system requires considerable time and resources. In 1995, physicists around the world were facing such a challenge if they wanted to respond to a major scientific breakthrough, namely the first production of a so-called Bose-Einstein condensate of cold atoms. A Bose-Einstein condensate (BEC) is a specific state of matter that occurs when gases of atoms or subatomic particles are cooled to near absolute zero (<100 Nanokelvin), that is a state of very low energy. A large fraction of the atoms collapse into the lowest quantum state, at which point quantum effects occur on a macroscopic scale. The occurrence of the phenomenon was theoretically predicted by Bose and Einstein in 1924. The first BEC of atom gases were produced in 1995 by two US atomic and molecular optics (AMO) groups, which innovatively combined several recently developed cooling technologies (Cornell & Wieman, 2002; Griffin, 2004; Ketterle, 2002).

Meanwhile, BECs have proven useful in the exploration of a wide range of problems in fundamental physics (particularly quantum theory), which has led to an explosive growth of experimental and theoretical activities. Physicists are using BEC as methods or try to manipulate this new state of matter for a wide variety of applications in the more distant future, which include atom lasers and quantum computers.

There are two reasons why the development of BEC research is of sociological interest. First, BEC developed in the national experimental physics communities at very different velocities. For example, it was taken up immediately in 1995 in the Netherlands and Germany, while Spain followed eleven years later. The extent to which BEC has become a significant part of national community's research activities also varies. Research about and with BECs has become a substantial and still growing part of physics research in Germany, while it has disappeared from the agenda in Sweden.

Second, experimental BEC research remained very expensive and risky for several years until the early 2000s. Researchers who wanted to develop the innovation had to make an explicit decision, had to invest their whole research capacity in this enterprise, and had to control above-average resources for above-average time horizons. This is why BEC research was (and some of its strands still are) very sensitive to variations in the national and organisational governance of research.

These two aspects are likely to be linked, although in ways that are poorly understood. The aim of our article is to answer the question how scientific innovations can be developed by individual researchers – on the micro-level – under conditions of changing community expectations and in different systems of governance and research management. With this answer, we want to bridge the divide between macro-level diffusion studies of fields and micro-level studies of individual research practices.

CONCEPTUAL FRAMEWORK

The development of scientific innovations and of the fields that sometimes emerge with them has interested scholars in the sociology of science for a long time. After Kuhn (1962) introduced the notion of a paradigm and a corresponding scientific community, sociologists became interested in the emergence of new paradigms. Classical studies include those by Mullins (1972) on the phage group and the genesis of molecular biology, Law (1973) on X-ray Protein Crystallography, Mullins (1973) on ethnomethodology, and Edge and Mulkay (1976) on the emergence of radio astronomy (see also Chubin, 1976, for a critical review of this research). From a current perspective, many factors one would consider crucial for the emergence of a specialty are curiously absent from these studies. The impact of national science policies and organisational conditions for research on the opportunities for the proponents of new fields to change their research practices is not discussed, and the social conditions that are discussed (e.g. information exchange, mobility, a shared identity, access to graduate students) were not linked to organisational or policy decisions. The same holds by and large for many of the constructivist studies that include the diffusion of new research practices (e.g. Cambrosio & Keating, 1995, 1998; Collins, 1998; Fujimura, 1988, 1992; Pickering, 1980, 1995; Pinch, 1980).

There are several reasons why these studies have neglected many conditions for changes of research practices that we would today consider essential.

Conditions for research have changed considerably. In particular, temporary positions and competition for grants, which make much of current research precarious, are relatively recent developments, as are the higher education reforms that increase the power of university management in many countries (see Whitley, this volume). Furthermore, the laboratory studies' focus on the micro-level made it difficult to observe the impact of macrostructures such as institutions (Kleinman, 1998, pp. 285−291; Knorr-Cetina, 1995, pp. 160−163; Mayntz & Schimank, 1998, p. 751).

Although these reasons for the neglect of macro-level conditions are less persuasive then two or three decades ago, more recent studies of the emergence of new research fields still struggle with the micro-macro link. They still seem to address either the macro-level of the diffusion of new findings (e.g. Fagerberg & Verspagen, 2009; Heinze, Heidler, Heiberger, & Riebling, 2013; Raasch, Lee, Spaeth, & Herstatt, 2013) or the micro-level of innovators (Mody, 2004). Studies on exceptional research ('creative achievements', 'breakthroughs') include organisational factors and sometimes grant funding but were so far unable to establish systematic relationships between specific conditions created by governance and specific kinds of achievements (Heinze, Shapira, Rogers, & Senker, 2009; Hollingsworth, 2008).

Studying the micro-macro link requires empirically investigating both macro-conditions and micro-level changes, establishing how the former are translated into conditions for the latter, and demonstrating how micro-level changes are aggregated. In order to establish causal links, specific macro-level conditions must be compared with regard to their impact on micro-level changes. Although we limit our empirical study to this latter task (leaving the study of aggregation processes to further work), we still need a conceptual framework that solves three problems. The framework must enable a strict comparison of macro-level conditions, that is of national research systems and influences exercised by scientific communities, the comparative investigation of translations of these macro-level conditions into conditions for individual researchers who decide to change their research practices, and a comparison of conditions for research that explain the differential success of researchers who want to change their practices. We use the concept of authority relations for the first and the concept of protected space for the second and third tasks.

For an integrated assessment of changes in public science systems we draw on the authority relations perspective (Whitley, 2010). This focuses on how different authoritative agencies (the state, research organisations, organisational elites, external funding agencies and national as well as international scientific elites) exercise authority over specific matters of governance, which we can specify for our purposes as research goals. Its basic assumptions are (a) that the changes that public science systems are undergoing have implications for the relationships between actors and the way that they are able to realise their interests and (b) that authority relations as regards the selection of research goals are the main channel through which changes in the knowledge production system are effectuated.

Authority over research goals can only be exercised through a few channels, namely the allocation of resources, reputation and career opportunities. The relative authority of actors depends on their control of these channels, which enables the construction of a framework for the integration of national governance processes into comparable patterns. By applying the authority relations perspective, authoritative agencies at the macro-level become linked to meso-level and micro-level actors because authority relations include all actors who exercise authority regardless of the level at which they are located.

Our framework for comparing micro-level conditions and linking them to authority relations builds on the definition of scientific innovations like BEC as research findings that affect the research practices of a large number of researchers in one or more fields (i.e. their choices of problems, methods or empirical objects). Changing research practices incurs costs and may be risky in several respects because

- they partly devalue the knowledge and equipment a researcher has accumulated working on previous topics,
- a researcher's reputation may suffer if the change requires learning or experimental redesigns and thereby delays opportunities to publish results, and
- the new line of research may deviate from the mainstream of the researcher's community, which again creates the risk of losing reputation.

Variations in authority relations affect the creation or diffusion of innovations by providing different opportunities for researchers to bear the risks and meet the costs of changes in their research practices (Gläser, Laudel, & Lettkemann, 2014). We use the concept 'protected space' for comparing these opportunities as they are provided in our investigated countries (Gläser et al., 2014; Whitley, this volume). We define protected space as the *autonomous planning horizon for which a researcher can apply his or her capabilities to a self-assigned task*. Two dimensions of this variable are important here. The first dimension is the *time horizon* for which the capabilities are at the sole discretion of the researcher, that is the period of time in which the researcher is protected from external interventions into his or her epistemic decisions and external decisions on the use of capabilities. The *resource* dimension reflects the research capacity the researcher controls in this time horizon (personnel over which the researcher has authority, time available for research, equipment, consumables etc.).

Researchers create and extend protected space mainly by career decisions (the search for positions that provide protected space) and the acquisition of funding from various sources including their organisations. The building of protected space links the decisions about research to authority relations. Applying these concepts to our empirical analysis makes it possible (a) to identify the authority relations the investigated researchers were embedded in when building their protected space and (b) to assess the scope of protected space, that is the numbers of researchers in different career stages whose organisational position makes it possible to build the protected space that is necessary for a change of research practices (Gläser et al., 2014).

METHODS AND DATA

We use data from a larger comparative project that studies the impact of changing authority relations in four countries on conditions for intellectual innovations (RHESI), to which we added a case study about experimental BEC in Spain. Our main focus was on research groups who attempted to produce BEC of cold atom gases. We identified these groups from publications using the keywords 'BEC' or 'Bose-Einstein Condensation', from internet searches of experimental physics groups at universities and from 'snowballing,' that is by asking interviewees about their national communities. Our attempt to include groups that were prevented from conducting BEC research by authority relations despite their interest failed because such cases are almost impossible to identify empirically.

Table 1 provides an overview of the interviews. For all countries except Germany, whose BEC community is too large by now, we interviewed researchers from all atomic physics groups that conducted BEC research (usually the group leaders and in some cases also group members). One Dutch group leader and two German group leaders declined to be interviewed. However, there is only one German group about which we have little information because no former group members could be interviewed. In order to get a better picture of the structure of relevant physics

Table 1. Overview of Conducted Interviews.

	Netherlands	Germany	Switzerland	Sweden	Spain
AMO BEC groups	5 (7 interviews)	8	2 (7 interviews)	1 (2 interviews)	1 (2 interviews)
Other BEC groups	–	–	3 (6 Interviews)		–
Other physics groups	2 experimental AMO physics	–	5 (8 interviews with BEC theoreticians, 1 from another physics field)	3 (1 BEC theoretician, 1 experimental AMO physicist, 1 other field)	–
Other informants	2 officers of funding agency	1 officer of funding agency	–	–	1 former funding advisor to ministry
Total number of interviews	11	9	21	5	3

communities, we conducted additional interviews with other physicists. We also interviewed officers of funding agencies.

The interviews were conducted as semi-structured face-to-face interviews.[1] A shared interview guide was used for interviews with BEC researchers in order to ensure comparability of data. Interviews with researchers consisted of two main parts. In the first part, the interviewee's research was discussed. We explored the development of the interviewee's research since the PhD project, with an emphasis on thematic changes and the reasons for them. In this part of the interview, developments in the interviewee's national and international communities were also discussed. The discussion of the research content was prepared by analysing documents including internet sites, Nobel lectures (Cornell & Wieman, 2002; Ketterle, 2002; Phillips, 1998), and publications at various levels of sophistication from popular science to an interviewee's research publications. The preparation also included a bibliometric analysis of the interviewee's publications for thematic links publications. A visualisation of this publication network was used to prompt narratives about the content of the research at the beginning of the interview (Gläser & Laudel, 2009a, see also Laudel et al., this volume).

In a second part of the interview, conditions of research and the factors influencing them were discussed. Topics included the knowledge, personnel, equipment required to produce BECs, source of material support and opportunities as well as constraints provided by the interviewee's academic posts. The interviews lasted 60–120 minutes. All but one were recorded and fully transcribed.

The analysis of interviews focused on the variables of the theoretical framework. The comparison of cases from the five countries is based on an assessment of the necessary protected space for early BEC experiments, which could be derived from the interviews. We then reconstructed an important macro-level condition for all researchers who attempted to change their research practices, namely the international diffusion of BEC research in the contexts of opinions and preferences in the international and national scientific communities. For each attempt to begin the experimental production of BECs, the building of protected space, the authoritative agencies involved, and the consequences of the exercise of authority were determined and compared. Reasons for delayed and failed attempts to produce BECs were also traced back to authority relations and interests of the actors involved. Our comparison of changes of research practices at the researcher level follows the distinction between supported, delayed, and prevented cases because this distinction emphasises the impact of authority relations. The empirical analysis is followed by a generalising discussion of the macro-micro link and conclusions.

EPISTEMIC PROPERTIES OF EXPERIMENTAL BEC RESEARCH AND ITS REQUIRED PROTECTED SPACE

From the first attempts until the early 2000s, manufacturing BECs of atoms was an exceptionally complex, risky, and expensive undertaking, even by standards of the wider field in which it is located, experimental low temperature physics. Manufacturing a BEC was strategically uncertain because it was not clear that the effect could be experimentally produced and technically uncertain because it was not clear how, by what specific experimental setting, the effect could be produced (on these notions of strategic and technical uncertainty see Laudel and Gläser, 2014). The strategic uncertainty concerned the question whether any gas of cold atoms would stay gaseous at the low temperatures and relatively high densities required for BEC. It was quite plausible that all atom gases except hydrogen would become liquids or solids if cooled so far. This question stood anew for each new kind of atom for which BEC was attempted; replications of such experiments were the only exception. The technical uncertainty was high for all researchers who tried to produce a BEC for the first time. Setting up the experimental system required a researcher to go through a long sequence of steps of adjusting and fine-tuning the equipment. In many cases, parts of the equipment were built to order by technical workshops. This is why for a long time (at least until the early 2000s), building and fine-tuning a BEC experiment took several years. It was always possible that the researcher could not solve the technical problems involved, in which case the experiment failed. Although the technology for BEC production has advanced during the last two decades, setting up a BEC experiment for the first time remains a risky and demanding endeavour for a research group.

These epistemic properties of BEC research correspond with a large protected space in terms of resources, and long and often unpredictable time horizons. Achieving BEC in atomic gases required the combination of the most advanced techniques for cooling atoms and trapping those with the lowest energy. The research involves complex task-specific equipment, which is usually built from components by the researcher. Depending on the research prior to the move to BEC, several of the more expensive components might already exist in the laboratory. The equipment for a BEC experiment could cost 100,000–500,000 Euros depending on what was available in the laboratory. Consumables (mostly very expensive cooling liquids) caused additional recurrent costs. At least two full-time researchers (almost always PhD students) were needed to build and adjust the experimental setup; parallel work of more PhD students or postdocs would be an advantage to accommodate the technological uncertainty.

Owing to the inherent uncertainties, the time horizon of the experiment (from setting up the experimental system to publishing the results) may extend beyond the usual three-year grant cycle. The reputational risk involved is high because the experiments can fail entirely and because little can be published until the experiment is successful.

INTERNATIONAL AND NATIONAL DYNAMICS OF BEC RESEARCH

The development and diffusion of experimental BEC can roughly be divided in four phases. Attempts to produce BECs began in the 1980s, after a new cooling method (laser cooling) was developed. This first phase ends with the first successes in summer 1995. For about three years afterwards, responses to this success were mixed because the experiments were too difficult to replicate and the potential of BECs for further research remained unclear. With the first successful replications and BECs of other atoms BEC research began to grow in the AMO community after 1998. Since the early 2000s the manufacture and use of simple BECs became routinised, and BECs began to be used as a method in other areas of physics.

Phase 1 First Attempts to Manufacture BECs (1980s to Summer 1995)

Since it had always been clear that the experimental realisation of BEC in atom gases depended on achieving extremely low temperatures, experiments aimed at producing BECs seriously began only after a new cooling technique – laser cooling – had been developed. Still, the majority of the scientific community believed that producing BECs was impossible because the atom gases would turn into liquids or solids when cooled down to the temperatures necessary for BEC. Some believed hydrogen to be the only possible exception, which is why major experimental efforts began in the

1980s when a few condensed matter physics groups tried to produce BEC in spin-polarised hydrogen gas by combining several cryogenic methods. At the beginning of the 1990s they were considered the leading experts in BEC research. However, most AMO physicists doubted that a breakthrough could be achieved in the near future. A different route towards BEC was pursued by a small minority of researchers in the US, who began to cool atom gases of alkalis. This idea was met with even stronger scepticism than the hydrogen route.

> Bose-Einstein condensation was a vision of the past [early 1990s] and many people did not believe in it. They said this is not possible. This will not work for all sorts of reasons. Just before the first Bose-Einstein condensate was produced in 1995, there were predictions that it is not possible. (German BEC researcher)

> Of course, all people who worked with cold atoms wrote in their applications about the 'Holy Grail', that this will at some time lead to BEC. But this was so far away for everybody that we thought that we will never achieve it. Just imagine, you always work with buckets of water on a great plain, and there are puddles everywhere, and suddenly somebody sets out to fill an ocean. It is clear that it becomes more when I have more buckets but it is unimaginable that it will work in the foreseeable future. (German BEC researcher)

In the early 1990s, only two of the five national physics communities included in our study featured strong AMO physics communities. The German and Dutch communities had made major contributions to laser-cooling techniques. Both national communities shared the international majority opinion, namely that BEC cannot be experimentally achieved. None of the German AMO groups pursued BEC at that time. Researchers who did consider attempts to produce BEC felt disheartened by the vast advantage of the US groups in both resources and experience. Since the new method of laser cooling had created many new research opportunities, there was no reason to pursue the 'holy grail' of BEC whose realisation was doubtful anyway.

In the Netherlands, the strong tradition of low temperature physics and a strong AMO physics provided a supportive background for BEC research. One of the Dutch research groups worked on BEC in atomic hydrogen. The Dutch group leader belonged to the pioneers that paved the way towards the first BEC. His major scientific achievements and being backed by the hydrogen community probably helped to continue this research despite the AMO community's doubts. Another Dutch researcher became interested in BEC in the early 1990s but could not begin for lack of funding.

The situation in the three other countries was quite different. Switzerland and Spain had no tradition in AMO physics, and were unaffected by the experimental development. Switzerland has a strong tradition in nuclear and condensed matter physics instead, while Spain's experimental physics has been dominated by nuclear and particle physics which had little epistemic connections to AMO physics, cold atoms and BEC research. Sweden has a long tradition in the field of AMO physics with many strong experimental groups. However, most research concentrated on molecular spectroscopy, building on the tradition of Nobel Prize winners Manne Siegbahn (1924) and Kai Siegbahn (1981). This narrow focus was criticised by an international evaluation committee in 1992:

> 'Sweden for many years has been strong in Atomic Molecular and Optical Physics ... almost all the work is of high quality and some is outstanding', but also recommends: '... there should be less emphasis on traditional molecular spectroscopy and more on newer fields of atom trapping, laser cooling, laser optics, etc'. (Bradshaw et al., 1992, pp. 16–17)

The fields whose strengthening was recommended were those on which experimental BEC built.

Phase 2 Responses to the First Experimental Success (Summer 1995–1997)

In the summer of 1995, first empirical evidence of BEC was presented at an international physics conference at Capri. Until the end of the year, three US research groups were successful in producing a BEC from alkali gases. This was immediately regarded as an outstanding contribution by AMO physicists and by the wider physics community. However, the international AMO community was undecided whether these achievements marked the end of the long quest for the 'Holy Grail' of BEC or the beginning of a new research area. Would it open up opportunities for interesting new physics or was it just the experimental confirmation of a theoretical prediction? In the year following the Capri conference, it was unclear what direction research would take.

Most German researchers tended to share the general beliefs of the international community: it was not clear whether BEC would indeed open a new research direction.

> Q: [After the 1995 Capri conference], was the entire German community of the same opinion?
>
> A: *(Laughs out loudly)* It was very mixed. Some [people] just went quiet and reverent and saw that this is the Holy Grail. But I would say that what you can do with it, that

> it opens up an entirely new parameter space, and that you can make a completely new physics, was recognized only by few back then. (German BEC researcher)

Secondly, the problem of the competitive advantage of the US groups had not vanished. Thirdly, other AMO fields promised better career chances. Against this general trend in the German AMO physics community, three groups (two professors, one junior group leader) began BEC research after the first experimental success was announced at the Capri conference in mid-1995. Although the community approved of grants only reluctantly, all three researchers could immediately begin with the first steps of building the experiments, which included simulations and invitations to the innovators from the United States in order to learn the tricks of the trade from them. The first German BEC (and first BEC outside the United States) was achieved in 1997.

In the Netherlands, the researcher who had originally worked on BEC in hydrogen switched to the alkali route because the technology had become superior to the complicated cryogenic approach for BEC in hydrogen. Four more researchers became interested in pursuing BEC research in alkalis in this phase. However, only one professor and a researcher whose move was tolerated by his professor could start in that period. Two researchers' change of research practices was delayed by authority relations, as we will explain in more detail in the following section.

Phase 3 Growth of BEC Research within AMO Physics (Since 1998)

The year 1998 witnessed new BECs being produced in many countries. The research now moved beyond the replication of the original results because it became obvious that BECs provided many opportunities for interesting theoretical and experimental research. Since then, more than a hundred research groups worldwide have produced BECs. BECs of atoms of other elements, photons, and molecules have been produced. The technologies for producing BECs have been improved, which made it possible to use BECs as tools in several other research areas. The growth of BEC research was thus accompanied by an internal differentiation.

Again, the German AMO physics community's attitude towards BEC paralleled that of the international community. The great potential of BEC experiments became widely accepted. More groups began BEC research, and the experiments of all German BEC groups moved beyond the replication of original experiments in new directions. Today, about 15 German AMO physics groups work on BEC.

The new attitude of the German AMO community was also reflected in the decisions on project funding. Grants for BEC research were approved without problems, and the delays in producing BECs were tacitly accepted by approving grants for researchers who had already had a grant but were not successful within the first three years.

In the Netherlands, the growth period of BEC in AMO physics was briefly reflected in a dedicated grant programme for the support of BEC research. Two further Dutch atomic physics groups began their BEC research. Different from Germany, the community's attitude to BEC was less favourable.

> But the situation in Holland was not very favourable [several years] after the first BEC was observed ... Some people thought why are you going to do this now? Other countries are ahead of us, why should we do that? There was one experiment in Amsterdam where they achieved Bose Einstein condensation, and some thought, well, perhaps this is sufficient, why do you need four groups. (Dutch BEC researcher)

Different to their German counterparts, the Dutch funding agency became impatient soon and downsized the funding programme when no BECs were produced after three years. Further grant funding was concentrated on two groups, one of which already had produced a BEC in 1999. The funding problems caused delays and forced one group to give up their attempts altogether. In the end, three more groups achieved BEC between 2004 and 2006. Currently, four groups continue BEC research.

From 1998 onwards, BEC research began in the three other investigated countries, too. In 1998 a young Swedish researcher on a 4-year fellowship position began BEC research which he intended to conduct parallel to another line of research that was also based on laser cooling. In spite of the researcher's appointment as professor at a Swedish university, his group did not succeed due to funding difficulties. In 2009, the group leader left the country without having achieved BEC and the Swedish group dissolved.

The Swiss physics community caught up with BEC research by recruiting 'ready-made' BEC researchers. This was not completely premeditated: The universities recruited whom they considered as the best candidates in quantum physics, who happened to be BEC researchers. However, the decision was likely to be influenced by the high potential of the BEC field. In 2000, the first AMO physics groups began to work on BEC, a second group followed recently. Both groups expanded rapidly with several parallel BEC experiments, with at least one group belonging to the international elite.

The situation in Spain was unusual in that the first BEC experiment in Spain was initiated by a researcher from a different community, namely the theoretical physics community of non-linear optics. He had conducted theoretical BEC research since the late 1990s and had made important contributions to the field. But it was only after he became a full professor that he considered the move towards experimental BEC and he started in 2006. Taking into account his limited access to resources, he wanted to produce what could be considered a 'standard BEC' at that time (a BEC of Rubidium atoms). However, this intention was not enthusiastically met by the national community, which doubted the value of a Spanish 'simple' BEC given how far other groups worldwide had moved ahead. The community's prevailing attitude was that it would be better 'value for money' if he continued to produce theory papers. Being fully autonomous as a university professor, the researcher tried nevertheless but failed because he did not receive grant funding.

Phase 4 Utilisation of BEC in Other Areas of Physics (Since the Early 2000s)

With BEC increasingly proving its usefulness as an instrument for fundamental research questions in physics and beginning to show remote application opportunities, the production of BECs became interesting for other areas of physics such as condensed matter physics. In Germany several groups worked on BEC topics related to condensed matter physics.

This diffusion of BEC in other fields of physics is most pronounced in Switzerland, where the strong condensed matter community turned to BEC research. Around 2001 a condensed matter physicist began BEC research because he wanted to add a BEC research line to his research portfolio. Due to the high technical uncertainty it took around seven years to achieve success, which was immediately recognised as a major achievement by the international community. Two more condensed matter physicists worked on BEC with completely different approaches. In one case BEC was a serendipitous discovery, while the other researcher is only marginally interested in BEC and has not yet produced a BEC after eight years.

Fig. 1 summarises the diffusion dynamics of BEC research in cold atoms in the five countries we studied. The Netherlands and Germany had started early on with BEC research, Switzerland and Sweden followed relatively late, and Spain only recently started. Germany has the strongest BEC community now with several groups belonging to the international elite. The Netherland's BEC community consists of four groups that are internationally recognised. Switzerland has one group belonging to the international elite

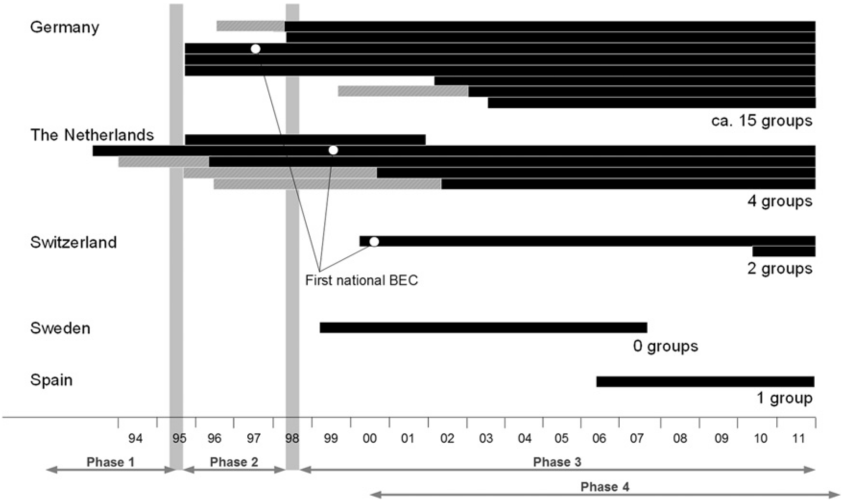

Fig. 1. Diffusion Pattern of BEC Research in Five Countries.

and another strong group.[2] Several groups could not immediately start BEC research (the delays are marked grey).

HOW VARIOUS SETS OF AUTHORITIES ALLOW, HINDER, PREVENT BEC RESEARCH

Having established interests and influences of international and national scientific communities, we now turn to a second set of macro-level conditions and their link to changes of research practices. We begin at the micro-level of individual changes by asking how changes of research practices were accomplished. A first comparison across all countries reveals that a large number of these changes were supported by the set of authority relations in which they were made, while other attempts to produce BECs were delayed or even prevented by the exercise of authority, as summarised in Table 2.

The dynamics of the changes in research practices vary considerably within countries. The shortest time between the start of BEC research and successful publication is one year (for the researcher in Switzerland who had successfully produced BECs before), the longest time is ten years (for a Dutch researcher whose move to BEC was delayed by authority relations).

Table 2. Impact of Authority Relations on Changes of Research Practices.

	Impact of Authority Relations on Changes of Research Practices		
	Supported	Delayed	Prevented
Occurrences	Germany Netherlands Switzerland	Germany Netherlands	Netherlands Sweden Spain
Time from first intention to begin of work (years)	Immediate start	Germany: 2–7 Netherlands: 3–6	Immediate start
Time from begin of work to achieving BEC (years)	Germany: 2–7 Netherlands: 3 Switzerland: less than 1	Germany: 2 Netherlands: 4–9	–
Time from begin of work to publication of results	Germany: 3–8 Netherlands: 4 Switzerland: 1	Germany: 3–8 Netherlands: 6–10	–

The delays and failed attempts certainly were also influenced by the capabilities of researchers, which we could not reliably compare across all cases in five countries (see Gläser & Laudel, 2009b on that problem). However, we can trace the reasons for delays and failures back to particular patterns of authority relations, which systematically differed from those of the supported cases.

Since the variance in dynamics is bigger within countries than between countries, we begin our analysis by comparing supported, delayed and prevented cases. Findings on countries will be synthesised in a subsequent step.

Authority Relations Supporting BEC Research

The ideal-typical situation of a researcher whose move to BEC research was supported by authority relations was somebody who controlled an adaptable infrastructure and had access to external grants in a way that supported the unpredictable time horizons. Researchers in Germany, the Netherlands, and Switzerland found themselves in that situation. They held professorial positions, which granted them discretion over the necessary infrastructure (laser equipment) and some personnel. Building or changing the infrastructure for BEC research was supported by resources provided by the university, which were granted as start-up packages on appointment as professor or as loyalty packages if a professor received an invitation to work elsewhere but stayed at the university. Many professors already had substantial parts of the necessary equipment (e.g. the lasers), and thus often needed only relatively small amounts of additional funding of ca. €100,000. Technical support provided by the research organisations was crucial for building the experimental setups. In terms of the required knowledge, the AMO physics groups were either themselves familiar with laser optics and cooling technologies or they hired postdocs who had learned it in the leading laboratories abroad.

With the exception of one German professor whose start-up package was so generous that he could work without external grants for several years, the money for additional equipment and personnel came from external grants. For that (personnel) and for specific equipment, additional resources were needed. This made professors dependent on their scientific communities, whose attitudes towards BEC and grants for it changed over time. As we saw in the previous section, the majority opinion in scientific communities was not in favour of BEC in the first two phases. The German community would nevertheless provide grants, albeit reluctantly so.

> The application was in June '95. In May, I believe, was the [Capri] meeting. In June, I sent the application out for review. This review process was stopped by the DFG [...] The approval of my application is, well I would have to look it up, but I think that it lasted almost two years. It was approved when I achieved the BEC (laughs). Maybe it was just one or one and a half years or something like that. So, it was extremely tough. They posed further questions, they did not answer for months and it was terrible. (German BEC researcher)

The Dutch community did not approve of any grants for BEC except those for the early innovator until the late 1990s, and cut funding soon again in the early 2000s (see Gläser et al., 2014, for a comparison of German and Dutch decision practices on BEC grants). This attitude contributed to several delayed cases (see the following section).

For professors who held non-BEC grants, their communities' reluctance did not matter due to another practice, namely the complete transfer of authority over the use of the money to researchers once the grant was approved. 'Bootlegging' – the use of the grants for different purposes – was tacitly approved by both the German and the Dutch funding agencies. This led to the paradoxical situation that a community did not explicitly approve of grants for BEC but let researchers use grants on BEC that were approved for other purposes.

Another tacit practice helped adjust the grant funding to the long and often unpredictable time horizons of BEC research. Grants were usually given for three (Germany) or four years (Netherlands), while producing a BEC could take much longer. The scientific community responded to this discrepancy by awarding new grants regardless of the experimental success of previous ones.

> Well, I must say that we have always been supported by the *Deutsche Forschungsgemeinschaft* especially with these high-risk projects. So in the case of BEC, which as I said took seven years, you could have said many times 'that's it' and 'there will never be results'. Nevertheless, we have always been successful in writing applications. (German BEC researcher)

The same pattern occurred in Switzerland in the 2000s, where a condensed matter group received consecutive grants for its non-atomic BEC and succeeded after seven years.

The ideal-typical pattern thus consists of a professor who controls a laboratory infrastructure and some personnel, has access to technical workshops, and can utilise grants for a change of research practices. There were two deviations from this pattern, which nevertheless still included authority relations that made the change of research practices possible.

Several researchers started BEC on non-professorial positions. In these cases, the necessary access to infrastructure and personnel was not given, which made the researcher dependent on others. German and Dutch researchers below the professorial level could start their BEC work because their professors (or directors of institutes) approved and granted them access to their infrastructure. Researchers whose professors did not grant that access were delayed in their move (see the following section). In one case, this access was granted by a Dutch faculty, which wanted to compensate for the lack of grants for BEC.

The other deviation from the ideal-typical pattern is that of the two Swiss researchers who produced BECs of atoms. Both researchers succeeded in a very short time due to prior experience and above-average funding. They both had produced their first BEC abroad, and had to re-create experimental setups they were already familiar with when they moved to Switzerland. Both researchers received considerable start-up funding from their university departments for equipment and several PhD and postdoctoral positions. In addition, one of them was permitted by his former lab leader to take the equipment for his previous BEC experiment with him. Both researchers extended their protected space quickly by external grants from the Swiss National Science Foundation (SNF).

The ideal-typical pattern and the deviations from it make the authority relations that supported the move to BEC research clearly identifiable. Researchers had to have authority over infrastructure and personnel, which was granted by their universities to professors. They also needed grants, which the scientific community was initially reluctant to give directly. This exercise of authority concerning dedicated BEC grants was compensated for by the transfer of authority over the use of grants to researchers. Thus, the transfer of authority over resource by both universities and scientific communities enabled the building of the large protected spaces.

Authority Relations Delaying BEC Research

In several Dutch and German cases, authority relations delayed changes of research practices because researchers could not build the necessary protected space. Either of the two processes identified above – the transfer of authority over infrastructure from universities to professors and the transfer of authority over grants from scientific communities (through funding agencies) to researchers – could be absent or halted. If this was the case, some researchers waited for authority relations to improve, which caused the delays.

The most frequent reason for delays was the lack of access to infrastructure. Two Dutch researchers on tenured but non-professorial positions had to postpone their BEC research in the late 1990s because their professors were not interested in BEC research and therefore would not 'lend' their infrastructure for this topic. This lack of opportunities to build protected space contributed to their fears of not being able to compete with the groups in the US. Thus, they only started around five years later with BEC research. Two German researchers were also delayed by missing access to infrastructure. One of them had to wait for a professorial position, while the other had become appointed but did not receive the start-up package for several years. He had successfully negotiated when he was recruited but did not receive the money due to financial difficulties of his university.

Missing project funding was a reason for delays in the Netherlands. The main funding agency for physics research, *Stichting voor Fundamenteel*

Onderzoek der Materie (FOM), was initially reluctant to fund BEC research. In the first phase, prior to the first experimental success, only one researcher received grants for research on BEC in hydrogen. Another researcher, who wanted to take up the idea of BEC in alkalis before the success in the United States, did not receive grants and had to postpone the start of BEC research.

At the end of the 1990s Dutch researchers joined forces and wrote a bottom-up funding proposal dedicated to BEC research. This proposal was reviewed and had to be revised, which delayed the funding programme until 2000. This funding programme gave researchers who wanted to produce BECs access to dedicated grants. The programme was evaluated after three years and was stopped because no further BECs were achieved after the first success in 1999.

> A: And then there was the […] programme on cold atoms, starting somewhere in 2000 and that lasted only three years and then it was stopped by FOM because they thought there was not enough progress.
>
> Q: In form of publications?
>
> A: In the form of Bose Einstein condensates. Because you have to realize, it started in 2000, and then we of course promised Bose Einstein condensate here in Holland, and two years later there were still no Bose-Einstein condensates. And then the funding agency said we stop the programme. (Dutch BEC researcher)

The funding agency FOM established a second funding programme for BEC but gave all funding of this programme to the group of the researcher who already had produced a BEC and to a junior research group leader in his department. These groups were the only two whose research was not hindered by insufficient funding. The other groups faced shortages. Two groups continued their BEC research but could not set up parallel experiments, which was common in BEC research. As a result, both groups' successes were considerably delayed. A third group had to give up BEC research entirely (see below).

The cases of delayed success in producing BECs confirm the necessary authority relations derived from the cases that were not delayed. Researchers that were successful in the end were delayed because they had to wait either for a position that gave them authority over the infrastructure and personnel provided by the university, or for grants that provided the necessary complementary funding. The following cases of unsuccessful experimental BEC demonstrate what happens if the two conditions are never simultaneously fulfilled.

Authority Relations Preventing BEC Research

A Dutch, a Swedish, and a Spanish group failed in their attempts to produce a BEC. Having tried for seven to eight years, these groups had not produced BECs and two abandoned experimental BEC research. While epistemic reasons may have contributed to these failures, the authority relations in which these researchers worked also deviated considerably from those characterising successful cases. The three cases have in common that at some point, the continuation of BEC research of all three groups depended on experimental success, that is on an externally enforced time horizon of their protected space that was too short.

A Dutch group was confronted by the termination of the BEC funding programme by FOM after three years (see the preceding section). The university did not compensate for the exclusion of the group from grant funding, and the group could not obtain enough grants to continue BEC research by bootlegging money.

A Swedish researcher on a 4-year fellowship had obtained knowledge about laser-cooling experiments in one of the leading US laboratories and managed to secure a grant from a major foundation for setting up a laser-cooling laboratory at his home university. The start-up process was slow because neither the fellowship nor the infrastructure grants allowed for any funding of additional research positions. The faculty did not allocate PhD positions, very likely because he was not an established researcher on a permanent position yet. BEC research also was new to the physics department's research agenda. The researcher could later secure two PhD positions for his laboratory, which both were jointly funded by his department and by external grants. Three years later, in 2001, the researcher was appointed as tenured associate professor at another Swedish university. The recruitment came with no start-up funding, and further funding for PhD students or equipment remained problematic for the group.

The group felt there was a lack of support from the university for the BEC research. Support further declined when a new dean of the department was appointed. There was a lack of understanding for the technical uncertainties of BEC research, and disappointment about insufficient publications. Eventually the group leader managed to secure funds from small, local Swedish funding agencies to fund doctoral students for his laboratory. Still, the group had only minimum resources in an environment where they could not collaboratively use the infrastructure of others. While funding for equipment did not seem to be a major problem, the grants left little room for the experimental failures that were unavoidable under conditions of high technical uncertainty. Technical support by workshops, which had been crucial for the German and Dutch BEC groups, was almost non-existent. The group could not recruit experienced postdocs from other laboratories. One PhD student travelled to one of the well-known laser-cooling labs in the United States to obtain additional knowledge. Comparing the conditions in the US lab with what was available in his home setting, he said that his group had to work 'with duct tape and home-made solutions' to make the experiment work. BEC was never achieved. In 2009, the group leader moved abroad to take up a professorship, and the only attempt of establishing experimental BEC research in Sweden ended.

In Spain, a theoretician who was internationally recognised for his contributions to theoretical BEC research became interested in experimental BEC, which he started when he obtained a professorial position in 2006. Although the Spanish physics community did not support his idea of producing a standard BEC, he managed to obtain some resources for the experimental work. A PhD student on a 4-year scholarship provided by the ministry was awarded through a general PhD programme and not specifically dedicated to BEC research but could be oriented this way. The researcher also received two small 2-year grants from the national government and regional government (together around €60,000). The researcher further bootlegged funding from grants for his theoretical research to buy equipment. This enabled the beginning of building the experimental setup, albeit on a shoestring budget. He got some ad-hoc assistance from his colleagues-experimentalists in the department. There was no technical support from the university at all. Through visits of leading European laboratories he and his PhD student obtained the necessary knowledge about the cooling techniques of BEC experiments. The visits were made possible by his reputation for theoretical BEC work.

The reputational risk of this attempt at experimental BEC was reduced since the researcher continued his theoretical BEC research, and was thus able to continually publish. However, the time horizon of protected space was limited to two years because the Ministry made funding conditional on proving experimental success:

> Yes, we finished the MOT [magneto-optical trap] and just on time. In the Ministry, they said okay if you don't have the MOT by this date you will not have more money. So we were really desperate and I remember the day when I was with this experiment – you know in these experiments you have lots of things to tune - and I was there and I was very impassioned with a detector we had there quite slow, 100 times more and we saw a flash there and okay, and I said to [the PhD student] have you seen that and she

> said yes and we were very delicately moving and then that was when we got it. And yes it was a really happy day! One week before the deadline! (Spanish researcher)

The group succeeded only with the first experimental steps but not with producing a BEC. Subsequent evaluations by members of the national physics community questioned the scientific significance of the standard BEC. Finally, the national funding agency rejected further grant applications for two successive years.

If we look at the authority relations in the three cases of failed attempts, the contingencies of BEC research become apparent. Researchers simultaneously need access to infrastructure and grant money for a sufficiently long time horizon, which means that they depend on the university having these resources and granting them, and on the approval of their research by their scientific community. In the Netherlands, the funding agency decided not to provide grants for BEC research to particular groups anymore because the time horizons were at odds with common expectations. In Sweden, the limitations of grants were not overcome by support from the university, partly because university funding was limited and partly because the researcher's colleagues also expected quick results. In the Spanish case, BEC research appeared somewhat like a suicide mission: a scientific community with strong misgivings, funding agencies controlled by the government with little understanding for the protected space needed. Only the flexible use of funding made it possible to start the experimental BEC work at all.

MACRO-MICRO LINKS IN THE DEVELOPMENT OF SCIENTIFIC INNOVATIONS

Having identified the processes by which international and national scientific communities developed the innovation and the role of authority relations in the building of protected space for changing research practices at the individual level, we can now return to our question about the link between macro-level authority relations and individual changes of research practices. We focus our discussion on the exercise of authority by the actors involved.

Absorptive Capacity of Scientific Communities and Exercise of Authority

Scientific communities exercise authority through their scientific elite, which control the grant funding that has become a necessary source of protected space in experimental research. In the case of basic research, the state and (in Sweden) private foundations supplied these resources but transferred their authority over them almost completely to the scientific elites. Their decisions in funding agencies, which are macro-level actors, bypassed all other actors including universities and their sub-units, and directly shaped researchers' opportunities to build protected space. This is why the communities' attitudes towards BEC research and to the use of grants for it were crucial for micro-level changes of research practices (Table 3).

Our reconstruction of the emergence and growth of BEC research in the international scientific community and in five national scientific communities shows that the idea of prior research creating absorptive capacity, which has been introduced by Cohen and Levinthal (1990) to organisational sociology, is also applicable to scientific communities and their research traditions. We found four distinct situations, each of which created specific responses to the innovations. Germany and the Netherlands had strong research traditions in the field in which the innovation was created, and featured research groups that contributed to the groundwork for the experimental success. This could be expected from the large German science system, which is likely to host most research traditions

Table 3. Absorptive Capacity and Attitudes towards the Use of Grants for BEC in Five Communities.

	Germany	Netherlands	Switzerland	Sweden	Spain
Absorptive capacity	High	High	Low (high in condensed matter physics)	Low	Low
Acceptance of proposals that contradict majority opinion	Yes, with some reluctance	Only for one member of international elite	Not observed	Not observed	No
Acceptance of time horizons exceeding terms of grants	Yes	Only for one member of international elite	Yes	Not observed	No
Transfer of authority over use of grants to researchers	Yes	Yes	Not observed	Limited	Yes

in some form. The absorptive capacity of the Dutch community was historically contingent. The Netherlands had a strong research tradition in low temperature physics that dates back to the 19th Century, which produced many important contributions to cooling techniques.

The example of Sweden highlights the contingent nature of such traditions. Sweden featured a strong AMO physics tradition which, however, was narrowly focused on the legacy of two Swedish Nobel laureates, to the exclusion of those subfields of AMO physics that provided the absorptive capacity for BEC research. Switzerland and Spain did not even have AMO physics communities.

Consequently, the German and Dutch research groups were best positioned to develop the innovation and responded first by producing BECs. The Swiss response is yet another illustration of the importance of absorptive capacity. Apart from the recruitment of two researchers who produced BECs of cold atoms, several initiatives to produce BECs were developed in the condensed matter physics community, which is a strong Swiss research tradition. Having no absorptive capacity, Swedish and Spanish physics had to rely on individual activists, who both can be said to have failed due to the wider physics community's lack of understanding for the intricacies of BEC research, particularly the technical uncertainties and the resulting unpredictable time horizons.

The degree to which the community's majority opinion actually mattered depended on the decision style of grant funding processes (Gläser et al., 2014). Of the three communities for which this could be observed because proposals that were at odds with the majority opinion were submitted, the German community exhibited a pluralistic attitude and (albeit reluctantly) funded proposals the majority did not consider worth funding. The Dutch and the Spanish community did not, with the Dutch community not believing in the possibility of BEC in alkalis (first phase) and in the scientific merits of continuing with BEC after the first experimental success (second phase). The Spanish community did not believe in the merits of a leading theoretician venturing into experimental BECs.

The community's response to the unpredictable and often long time horizons of BEC research is a third aspect of the exercise of authority that significantly affected researchers' opportunities to build protected space with grant funding. The German and Swiss communities accepted this problem and responded by approving new grants despite the previous ones not being successful. The response of the Dutch community is rather surprising because AMO physicists would know the problem (and have it experienced themselves). However, the decision was made at the level of funding programmes, with the wider physics community being included in a decision about fields to which the money should go. In Sweden, the attitude towards time horizons was not observed for the grant funding process, but was clearly visible in the critical attitude of the BEC researcher's faculty concerning delayed publications. In the Spanish case, the impatience manifested itself in intermediate 'milestones' for setting up the experiment that seem to have generated at the ministerial as well as the community side of funding.

The opportunities to build protected space were finally affected by the extent to which authority over the use of grants was transferred to researchers once the grants were approved. German, Dutch and Spanish researchers were able to overcome other obstacles set by their communities or by administrative delays in the grant funding process by 'bootlegging' money from grants they received for other purposes. This opportunity gave a clear advantage to 'wealthy' researchers, that is to those who were successful in acquiring many grants. In the Swiss case, the transfer of authority was not observed because bootlegging was not necessary. The same applies to the Swedish case, although some of the grants the BEC researcher received carried strong limitations (they could be used only for equipment).

Thus, although scientific communities used only one channel to exercise authority over BEC research, this channel turns out to be quite complex. The approval of grants and expectations concerning their use and outcomes carry the use of both specific authority concerning the content of research (in our case BEC research and its time horizons) and unspecific expectations that include the extent to which authority over grant use is transferred to grant holders.

The Translation of Authority Relations in Micro-Level Conditions for Changing Research Practices

The second essential source of protected space for researchers was the funding provided by their research organisations (mostly universities, for a comparison of universities and public research institutes see Gläser et al., this volume). The authority exercised through this channel also created a complex pattern that varied between countries. The state was the ultimate source of all resources for BEC research (a Swedish private foundation being the only exception) but transferred its authority over all these resources to other actors.

Authority over resources for research is transferred to research councils and universities in all five investigated countries. The degree to which authority is transferred varies, and has been greatly increased with recent higher education reforms in the Netherlands, Germany, Sweden and Switzerland. While the use of resources within universities was previously prescribed in great detail, universities now have more authority over the use of their resources.

In all five countries, control over the expensive infrastructure for experimental research was concentrated on professors. This situation occurred regardless of the progress of higher education reforms. Even in the Dutch system, whose career structure and university governance was reformed in order to reduce authority of professors, the latter's control over infrastructure and PhD students remains. This is partly due to scarcity. Universities do not have enough resources to provide all their academics with infrastructure, and if a selective approach is necessary anywhere, concentration on the most highly reputed academics suggests itself.

In university systems that are further reformed, professors share their authority with their parent faculty, which has the authority to allocate additional resources or positions for PhD students. We observed this split authority in the Netherlands and Sweden. In Germany the authority over infrastructure is still transferred exclusively to professors, while the authority of the faculty was not relevant to the Swiss and Spanish cases.

This made professors the gatekeepers of the BEC innovation in all four countries. While the grant allocation process was more diverse and also provided researchers below the professorial level with resources for BEC research, the second essential source for protected space, the university's infrastructure, could only be utilised by professors or those whose research projects professors approved of. This is why fellowship positions rarely provided enough protected space for a change of research practices towards BEC. Even generously funded fellowships depend on pre-existing infrastructure, which made fellows dependent on those who control it. The very few exceptions from this pattern we observed confirm rather than challenge it. They include one decision of a Dutch faculty to provide a non-professorial researcher with resources for infrastructure and a German researcher who had accumulated grants that might have sufficed for a change of research practices (which was not tested because he was appointed professor soon thereafter).

CONCLUSIONS

The experimental manufacture of BEC constituted an extreme case because it required protected space that is large both in the resource and the time dimension from the beginning of the 1990s at least until the beginning of the 2000s. This made it a very good test case for the observation and analysis of authority relations. Our analysis enables some general conclusions about the impact of authority relations on researchers' opportunities to change their research practices for following or generating scientific innovations.

A first important conclusion concerns the role of epistemic traditions for creating absorptive capacity in scientific communities. For scientific innovations to be taken up and developed in a country, this country not only needs interested researchers but also a basis in the form of prior knowledge and techniques. While larger countries can be expected to have this basis for most innovations, its existence in smaller countries depends on historical developments and path dependencies. This is why for many countries the opportunity to immediately respond to a scientific innovation is contingent on its research traditions.

A second conclusion concerns the impact of authority relations on researchers' opportunities to build protected space. If we start from the assumption that any researcher in any position might want to change their research practices in order to either create an innovation or to develop an innovation that has been created elsewhere, we can assess how authority relations reduce this space.

If building the necessary protected space depends on access to the infrastructure provided by universities, the opportunity to create or develop an innovation is limited to those who control it, that is to professors and those whose research is approved by professors. This dependence is undermined where faculties have the right to allocate infrastructure. However, this moves a researcher's dependence from individual professors to local organisational elites.

If building protected space additionally depends on external grants, the opportunity to create or develop an innovation is thematically limited to innovations that are considered worth pursuing by a scientific community. Only if a scientific community transfers the authority over this particular decision to the researchers by not making the majority opinion a binding foundation for the approval of grants, researchers can work against the mainstream. It was interesting to notice that all investigated communities mitigate some of the consequences of their decisions by transferring far-reaching autonomy over the use of grants once they have been awarded.

These dependencies prevented some researchers from changing their research practices, while others experienced considerable delays. It is now possible to assess the impact of some of the larger longer-term trends of changing authority relations in the public sciences (see Whitley, this volume). The transition from predominantly recurrent funding to a split system in which recurrent funding must be supplemented by competitive grant funding has ambivalent effects. It increases the number of researchers who can build protected space by including staff below the professorial level. At the same time, it makes all researchers dependent on the authority of their national and international scientific elites, which can cause considerable delays, and may prevent some innovations altogether. Higher education reforms and the transfers of authority it involves do not affect the limitation of innovation opportunities to those who control the infrastructure (i.e. professors) but may create additional opportunities for non-professorial staff by transferring authority over resources to faculties. The funding of fellowships and temporary research groups is not sufficient for innovations requiring large protected space but may be beneficial for less demanding innovations.

Finally, the increasing state interest in research serving societal goals did not play a direct role for the purely basic BEC research. However, as Laudel and Weyer (this volume) suggest, the total protected space for basic research might shrink due to funding problems and the increasing incorporation of state priorities in science policies.

NOTES

1. Telephone interviews were conducted with three of the researchers in the Swedish case.
2. The research of Swiss condensed matter physicists who work on BEC cannot be compared to the other cases in terms of authority relations and protected space, which is why we didn't include them in Fig. 1 and Table 2.

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