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The Impact of Changing Funding and Authority Relationships on Scientific Innovations

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Abstract The past three decades have witnessed a sharp reduction in the rate of growth of public research funding, and sometimes an actual decline in its level. In many countries, this decline has been accompanied by substantial changes in the ways that such funding has been allocated and monitored. In addition, the institutions governing how research is directed and conducted underwent significant reforms. In this paper we examine how these changes have affected scientists' research goals and practices by comparing the development of three scientific innovations (one each in physics, biology, and educational research) in four European countries, namely Germany, the Netherlands, Switzerland, and Sweden. We find that the increased number of actors exercising authority over research goals does not necessarily lead to a greater diversity of interests funding research. A narrowing of goals and frameworks is especially probable when the increasing importance of external project funding is combined with reductions in state financing of universities and public research institutes. Finally, the growing standardisation of project cycle times and resource packages across funding agencies and scientific communities make it more difficult for researchers to pursue projects that deviate from these norms, especially, if they challenge mainstream beliefs and assessment criteria.

Keywords Science policy · Split funding mode · Higher education governance · Scientific innovations · Authority relations

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Introduction

After a considerable period of expansion of academic research in most OECD countries since 1945, the past three decades or so have witnessed a reduction in the rate of growth of public research funding.[1] In many countries, this decline has been accompanied by substantial changes in the ways that such funding has been allocated and monitored as well as significant reforms of the institutions governing how research is directed and conducted. These financing and governance changes can be summarised under four main headings.

First, much more academic research now depends greatly on scientists' ability to obtain funding from extra-mural sources, particularly state research councils but also private foundations, charities and other public and private organisations (Braun 1993; Rip 1994). While especially important for empirical research projects, these grants have also become increasingly significant for supporting non-empirical work as universities and other public research organisations (PROs) become less able to support such research on their own. Furthermore, the level of competition for external project funding has become much more intense, which is reflected in the significantly reduced success rates for project proposals in most OECD countries.[2]

Second, many public research councils and foundations have become more proactive in steering their allocation of grants towards particular priority areas and research problems. While these preferences have sometimes been determined and justified in terms of their intellectual promise and significance, they increasingly are linked to public policy priorities as formulated by governments (Drori et al. 2003; Guston 2000; Hessels et al. 2011).

Third, states are increasingly making their support of universities and other PROs dependent on their performance in achieving particular objectives or profiles as well as on the results of research quality assessments, based on peer reviews and/or quantitative indicators (Hicks 2012; Whitley and Gläser 2007). This contingent allocation of block grants has often been accompanied by governance and employment changes that transform public universities into formally independent organisations with their own governing boards and management structures directly employing academic and non-academic staff. University managers in many higher education systems are becoming more directly responsible for meeting the teaching and research targets set by state agencies and being granted greater formal authority over resource allocation and personnel decisions (De Boer et al. 2007; Paradeise et al. 2009; Musselin 2014; Schimank 2005).

[1] Since World War II, a phase of exponential growth until the end of the 1970s (Solla Price 1986 [1963]; Weingart 2003) has been followed by stagnation from the mid-1980s to the mid-1990s (Cozzens et al. 1990; Ziman 1994), renewed growth since the mid-1990s and an uneven development dominated by again-reduced growth and decline in some countries since the financial crisis (Makkonen 2013; Cruz-Castro and Sanz-Menéndez 2016).

[2] Evidence is scattered but consistent. The average success rates for all grants dropped for the US National Institute of Health from 33% in 1997 to 20% in 2015 (NIH 2015), for UK Research Councils from around 50% in 1980 to 28% in 2015 (Research Councils UK 2006: 52; Matthews 2015), for the Australian Research Council from 32.4% in 2002 to 17.8% in 2015 (ARC 2016), and for the German *Deutsche Forschungsgemeinschaft* from 84.5% in 1974 to 52.4% in 2009 (Aljets and Lettkemann 2011: 138).

Finally, many governments have initiated technology transfer and similar programmes to encourage greater commercialisation of research results and closer ties between private business and researchers in PROs. Often accompanied by changes to intellectual property rights' rules and incentives for universities to become more active managers of such rights, these initiatives have stimulated a growth in university applications for patents based on academic research and generated novel modes of private investment in academic work (Berman 2012; Kearnes and Wienroth 2011). This has been especially notable in areas where new knowledge has had relatively direct implications for commercial activities, such as the biomedical sciences.

While these changes have enjoyed considerable attention in science and higher education studies, they have been studied in isolation. Researchers in science studies have largely treated: a) competition for grant funding (Braun 1998; Langfeldt et al. 2015; Morris 2000), b) the increasing importance of public policy goals in science funding (Brunet and Dubois 2012; Furman et al. 2012; Leydesdorff and Gauthier 1996), c) higher education reforms (Hicks 2012; Musselin 2014; Paradeise et al. 2009) and, d) commercialisation trends (Baldini 2008; Owen-Smith and Powell 2001) as separate causal factors affecting research strategies and ignored their interconnections. Additionally, there have been few studies of how particular combinations of these changes in funding and governance have affected choices of research problems and approaches (Gläser and Laudel 2016).

This fragmentation of governance studies is unfortunate because these funding and governance changes interact in affecting research strategies. Their complex interactions have had a significant impact on the direction of research through changes in the organisation of authority relationships governing research priorities and practices. In particular, both the variety of authoritative agencies able to influence intellectual priorities and their willingness to steer knowledge development proactively have increased since the 1950s. Additionally, the specialisation and internationalisation of the epistemic communities evaluating the intellectual merits of contributions have expanded considerably.

As a result, many researchers in the public sciences are confronted by a contradictory situation. On the one hand, they have to share their authority over research goals with more varied sets of actors, many of which have developed strong expectations concerning research goals and are using their control of funding to exercise authority accordingly. On the other hand, the diversity of interests providing financial support may enable scientists to circumvent the priorities and judgements of established scientific elites and so pursue research strategies that deviate from mainstream intellectual goals as understood by those elites. Additionally, of course, authoritative actors may well pursue contradictory objectives, as when governments encourage universities to become "excellent" in terms of their intellectual reputations and rankings at the same time as urging them to contribute to policy goals that may conflict with current international scientific elites' priorities.

In this paper we examine how the changing organisation of authority relationships has affected scientists' research goals and practices by comparing the development of three scientific innovations in four European countries that differed in the extent to which they have implemented funding and governance changes. Innovations are here understood as research contributions that affect the research practices of a large number of researchers in one or more fields (Laudel and Gläser 2014: 1207). The empirical investigation on which this paper is based studied the impact of changing authority relations on the development of one innovation in physics, one in biology, and one in education in Germany, the Netherlands, Switzerland, and Sweden.[3] Funding and governance reforms following the new public management agenda from the early 1990s onwards were most significant in the Netherlands, less so in Sweden and Switzerland, and relatively limited in much of Germany (Meier and Schimank 2010; Paradeise et al. 2009; Schimank 2005).

In the next section we outline our conceptual approach, the key features of the three scientific innovations analysed in this study, the protected space required for their development, and the study's empirical methods. We then describe the different ways in which scientists in each country were able – to varying extents - to develop the necessary knowledge and skills and build protected space. These variations suggest some more general conclusions about how different authoritative actors were able to provide the necessary conditions for the development of these innovations, and the extent to which they did so in each country, which are discussed in the subsequent section.

Authority, Protected Space and Scientific Innovations

Changes in governance systems typically involve shifts in how, and by whom, particular activities and interests are coordinated and controlled through authority relationships. As Rosenau suggests (2004: 32): "To govern ….. is to exercise authority. To have authority is to be recognised as having the right to govern, to issue directives or requests that are heeded by those to whom they are addressed." Governance changes in the public sciences thus include shifts in both the nature of authoritative agencies that can legitimately influence the choice of research goals and approaches and in the means through which they ensure compliance (Crouch 2005: 108–124; Whitley 2011).

Authority changes can be expected to affect the development of innovations in the sciences in a number of ways but one of the most significant is through changes in the level of protected space afforded to researchers. Protected space is here understood as the period of time for which scientists have control over the use of particular amounts of human and material resources, including their own time, to pursue particular problems without suffering severe reputational and career consequences (Whitley and Gläser 2014a: 8). It has two dimensions: duration and

[3] The project "Restructuring Higher Education and Scientific Innovation" (RHESI) was funded under the EuroHESC programme of the European Science Foundation. The research has been supported by Deutsche Forschungsgemeinschaft (Grant Schi 553/7-1), by The Netherlands Organisation for Scientific Research (NWO Grant 461-09-710), by the Swedish Research Council (Grant 90671701) and the Swiss National Science Foundation (SNF grant 125814). The project was led by Richard Whitley, Uwe Schimank, Jochen Gläser, Dietmar Braun, Lars Engwall and Jürgen Enders.

access to resources, including the proportion of working time available for researchers to devote to particular problems.[4]

In their decisions to work on problems that are likely to result in significant innovations, it is important for researchers to consider the level of available protected space relative to the amount that they perceive to be necessary for the task (see Fujimura 1987 on the "do-ability" of research problems). Their ability to build the required level of protected space depends on the organisation of authority relations in a science system, particularly the ways that organisational positions and structures of the grant funding system are connected to the direction of research processes and access to resources (Gläser et al. 2014b; Whitley 2014). The impact of changing authority relations on opportunities to develop intellectual innovations can, then, be analysed by comparing situations in which researchers decide to begin, continue, or abandon the development of intellectual innovations. These situations are characterized by specific relationships between necessary protected space (which depends on the innovation), on the one hand, and opportunities to build protected space (which depend on authority relations). The comparative project analysed researchers' opportunities to develop three innovations: the experimental realisation of Bose-Einstein condensates (BEC) in physics, experimental evolutionary-developmental biology (evo-devo), and international comparative large-scale assessments of student performance (ILSA) in educational science (PISA being the best-known example).

Two of these innovations, BEC and the strand of evo-devo introducing novel model organisms, involved major commitments of time and other resources to technically uncertain projects that were unlikely to contribute directly to socio-economic objectives.[5] In contrast, the third, the International Comparative Large-scale Assessments of Student Performance (ILSA), represented a costly intervention by governments to develop specific research projects for policy purposes that could affect the development of education research in each country. These three scientific developments also varied in the extent to which they depended on access to different kinds of knowledge and skills and had high levels of scientific potential.

a) The Experimental Realisation of Bose-Einstein Condensates

Bose-Einstein condensates occur when gases of atoms are cooled to temperatures very close to absolute zero, particles lose their individual identities and coalesce into a single blob. Their existence was theoretically predicted in 1924 by Bose and Einstein. Although widely accepted as a theoretical phenomenon, the experimental

[4] The notion of 'protected space' has been used before to describe a social space in which researchers are shielded from interference (Krohn and Weyer 1994; Rip 1995, 2011; see also Hackett 2005 on 'protected sphere'; and Luukkonen and Thomas 2016 on 'negotiated space'). Our use of the concept emphasizes the shielding from interferences by all authoritative agencies including scientific communities (via reputational mechanisms), organisations (through hierarchical governance) and science policy and funding (through expectations tied to resources). The use of two measurable dimensions (time horizon and resources) turns 'protected space' from a metaphor into a variable that enables the comparative analysis of opportunities to build specific protected space under varying conditions.

[5] For the analysis of funding in the context of governance changes, we consider only the 'high-cost' strand of evo-devo innovations. For an account of the dynamics of evo-devo in its full breadth, see Laudel et al. (2014a).

realisation of BEC was regarded by many physicists as being very difficult, if not impossible, to achieve for both theoretical and technological reasons. In 1995 the first BEC was experimentally produced by two US groups, later rewarded with the Nobel Prize. However, the scientific community was initially undecided whether BEC would be the end of a long quest or whether it would open up new research opportunities. It soon, though, became apparent that BEC can be used for a wide range of fundamental research in several subfields of physics and BEC research grew rapidly to become an established field of research (Fallani and Kastberg 2015). There is, however, no immediate prospect of commercial applications.

In this case, scientists clearly required quite high levels of protected space. Without access to substantial human and material resources, the experiments simply could not be conducted. Constructing the necessary experimental system and understanding how it worked took several years. During this time scientists were unable to generate publishable experimental results and so ran considerable risks of being regarded as unproductive. In some cases, journals did publish details of their experiments, but the reputational dangers involved in pursuing such long term research projects that many physicists thought would result in failure remained considerable.

b) Evolutionary Developmental Biology

Evolutionary Developmental biology is a highly heterogeneous interdisciplinary field that explores links between the evolution of a species (the subject matter of evolutionary biology) and the embryonic development of its individuals (the subject matter of developmental biology). It can be traced back to the end of the 1970s, when it became more and more obvious that neo-Darwinian theory was unable to account for all empirical findings of evolutionary biology, particularly the rapid changes in the forms of organisms evident from the fossil record and the origins of traits that did not constitute an adaptation to the environment. The discovery of genes regulating embryonic development (HOX genes) in the 1980s and advances in molecular and genomic techniques made it possible to address specific questions by comparing the development of different organisms, which led to increased understanding of developmental mechanisms on the molecular level. Similar to BEC, this research has little commercial relevance.

As in the case of BEC research, obtaining the necessary resources for experimental evo-devo work has been a major concern for scientists conducting research with several non-standard organisms. While conceptual and less advanced experimental research were possible with average resources and in average time frames of developmental or evolutionary biology, advanced experiments required maintaining support for needed facilities over a number of years and had a duration that was difficult to predict. Equally, the possibility of publishing research results and gaining reputations from scientific audiences for significant contributions might conflict with traditional methodological standards for evaluating research on model organisms, which overwhelmingly dominated leading journals, conferences and academic positions.

c) International Large-Scale Student Assessments

The third innovation to be considered here dealt with the comparative analysis of the effectiveness of national school systems as revealed by international large-scale assessments of student performance. It stemmed from a more exogenous stimulus in that it arose from public policy interest in the relative performance of school students across OECD countries. Although attempts to conduct comparative analyses of student achievement have been made for a long time by various international groups, it was only at the beginning of the 1990s that their methodological quality and organisation significantly improved the comparability of national results. ILSA data could now be used for rigorous international comparative studies, which could not be done before.

Much of the impetus for comparative analyses of school performance using these large-scale surveys came from bureaucratic and political elites rather than established social scientists and many academics remained rather disdainful of their purposes and the techniques employed. The intellectual potential of such surveys and research based on them was commonly regarded as being rather limited given their highly standardised and decontextualised nature, except for posing many puzzles for more policy-oriented researchers.

The collection of ILSA data required considerable resources, particularly in large countries. Once the results of large-scale assessments of school student performance were made publicly available for researchers, social scientists used to analysing large data sets did not require long periods of time to generate publishable outputs. On the other hand, researchers who did not have such knowledge and skills needed more protected space to acquire such competencies, and in some cases to alter their intellectual goals and approaches quite radically.

Most of the groups working on the three innovations were identified from searches of publications in these scientific fields, websites, university staff lists in different faculties and asking interviewees to identify other contributors. Our main source of data consisted of semi-structured interviews with research group leaders and other researchers involved in selecting projects who intended to develop the three innovations.[6] Additional interviews were conducted with researchers in the three fields who observed but did not want to develop the innovation, officers of funding agencies, university managers, and policymakers. Their distribution between innovations and countries is summarised in Table 1. To contextualise data from interviews, we analysed publications that described the development of the innovations, annual reports of funding agencies, and other documents. The investigation covered the time period from interviewees' research prior to the decision to develop the innovation to the present (the interviews were conducted between 2011 and 2013). Prior research often went back to the early 1990s.

The interviews with researchers lasted between 60 and 120 minutes, and consisted of two main parts. In the first part, the interviewee's attempts to begin

[6] As part of the RHESI project, the empirical research was conducted by Enno Aljets, Martin Benninghoff, Adriana Gorga, Tina Hedmo, Elias Hakansson, Eric Lettkemann, Raphael Ramuz, and Linda Wedlin. For detailed results of case studies, see (Gläser et al. 2014a; Gläser et al. 2014b; Laudel et al. 2014a; Laudel et al. 2014b; Laudel and Weyer 2014).

Table 1 Number of interviews with researchers and other informants (numbers in brackets refer to researchers from the fields who did not develop the innovation)

	Researchers			Other Informants
	BEC	Evo-Devo	ILSA	
Germany	8	8	11 (2)	3
Netherlands	7 (2)	13 (1)	7	5
Sweden	2 (3)	5	5	2
Switzerland	13 (9)	13	6 (7)	9
	44	40	38	19

research on the innovation were discussed in the contexts of the interviewee's research since his or her PhD project, exploring the continuities and thematic changes and reasons for them. This part of the interview was supported by a bibliometric map of the interviewee's publications that showed thematic links between publications, an example of which is summarised in Fig. 1. The map was used to stimulate the recall and to prompt narratives about the content of research (see Gläser and Laudel 2015 on the methodology).

The second part of these interviews concerned the conditions of the research. Topics included the knowledge, personnel and equipment required to produce the innovation, sources of material support, and opportunities as well as constraints provided by the interviewee's organisational positions. Informants from funding agencies were asked about their decision-making procedures, while university managers and policymakers were asked about research priorities and the measures undertaken to support them.

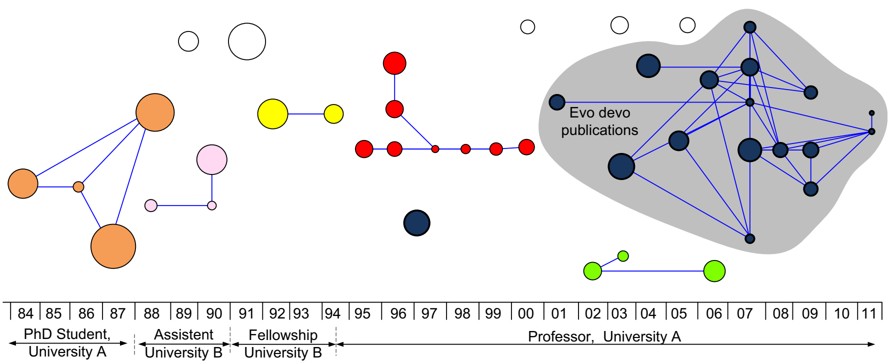

Fig. 1 Example of a research trail of an evo-devo researcher (the circles are publications, the size of the circles indicates the number of citations, the lines show thematic connections between publications)

Developing Three Scientific Innovations in Four European Countries

We now turn to describe how researchers in four European countries that differed in size, epistemic traditions and extent of funding and governance reforms dealt with these requirements. The uneven development of governance changes provided us with contrasting situations concerning: a) pre-existing epistemic foundations of the innovation, b) funding (substantial university recurrent funding in Switzerland but not in the other countries, substantial involvement of private foundations in Sweden but not in the other countries) c) the implementation of public policy goals in science policies (most widespread in the Netherlands), and d) higher education reforms (most advanced in the Netherlands, least advanced in Germany).

A) Bose-Einstein Condensates

Among the four countries under investigation, only Germany and the Netherlands had traditions in the experimental physics fields on which the production of BECs was based, namely atomic and molecular optics, low-temperature physics and laser physics. Not surprisingly, the earliest attempts to start BEC research were made in those two countries, followed a couple of years later by researchers in Sweden and Switzerland.

For a long time following the first experimental success, manufacturing a BEC remained a lengthy and risky process. Since BEC could be expected to occur only if a relatively dense atom gas was cooled to the lowest temperature possible at that time, researchers had to combine several recently developed advanced cooling methods. Among these, laser cooling was available only in few laboratories, and was 'spread' by postdoctoral researchers. The resources necessary for experimental success included a low temperature laboratory as basic infrastructure and between 100,000 to 500,000 Euros for additional equipment depending on the methodological difference between prior research and BEC. At least two researchers (postdocs or PhD students) were necessary to build and test the experimental set-up.

All researchers who were interested in manufacturing a BEC had to make a decision to change their research accordingly and build the necessary protected space. Several German researchers refrained because they feared not being able to compete with researchers from the US and especially with the two groups that announced their plans in 1993, succeeded in 1995, and whose results would not be replicated until 1997. Other researchers were less concerned about the competition but felt unable to build the necessary protected space. These included two Dutch researchers on tenured positions below the professorial level who wanted to start BEC research but did not have access to the infrastructure. The professors who controlled the infrastructure were not interested in BEC research and did not allow the use of 'their' laser equipment for it. A newly appointed professor at a German university also could not access the necessary infrastructure because the university delayed the promised investment for several years.

Researchers who did decide to focus on BEC research did so because they had access to the necessary infrastructure in four distinct ways. Established professors had their own laboratories while newly appointed professors received start-up or loyalty packages with which they could equip a laboratory. Several Dutch and German researchers below the professorial level were granted access to their professors' laboratories for BEC work. Finally, a Swedish professor built his infrastructure entirely from a large grant for equipment (a kind of grant that did not exist in the other countries). In addition to the equipment, university infrastructure for professors included discretion over positions for PhD students. Only the Swedish professor who built his infrastructure with a grant did not have discretion over personnel as part of the infrastructure funding.

Recurrent funding at universities was usually not sufficient to conduct BEC research. Only researchers at a German state research institute and two newly appointed professors in Switzerland were able to build the necessary protected space for their BEC research exclusively with recurrent funding. Since the latter two had already conducted BEC research in their previous positions abroad, they were able to rebuild their experimental systems with generous start-up packages from their new universities and continue their BEC research lines.

All the other researchers needed to obtain project grants.[7] However, even during the early years following the 1995 experimental success, these were not easily obtained because the scientific community was divided about the utility of further manufacture of BEC. Researchers could, though, partially compensate for the reluctance of funding agencies and slow decision-making processes by bootlegging funds from other external grants. Funding agencies typically did not closely monitor the use of approved grants, which gave many researchers considerable leeway if they wanted to take up new lines of research quickly. Only a Swedish researcher faced serious limitations because although his grant was approved for BEC research, it could only be used to fund equipment and he was allocated only one PhD position by his department.

All researchers had to cope with the mismatch between the time needed to develop their experimental systems and the three or four-year terms of project grants. Most researchers who successfully manufactured BECs did so after more than five years, some of them needed eight years and more. There was a remarkable difference in the attitudes of Dutch and German physics communities (and, consequently, grant funding agencies) towards these uncertain time horizons in the late 1990s and early 2000s. While German researchers received consecutive grants for BEC research regardless of their limited success with each single grant, the decision-making process in the Netherlands was different.

At the end of the 1990s Dutch researchers cooperated to submit a proposal for funding dedicated to BEC research. After reviews and revisions, which delayed the funding until 2000, this programme provided access to dedicated grants for researchers who wanted to produce BECs. However, when the programme was evaluated after three years, it was stopped because no further BECs were realised after the first success in 1999. The funding agency, FOM, then established a second funding programme for BEC but allocated all the funds of this programme to the

[7] Project funding was provided by external funding agencies: the Deutsche Forschungsgemeinschaft in Germany (DFG), *Stichting voor Fundamenteel Onderzoek der Materie* (FOM) in the Netherlands, Swiss National Science Foundation (SNF) in Switzerland, and private foundations in Sweden.

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 in the Netherlands whose research was not hindered by insufficient funding.

For some researchers, the long time required for successfully manufacturing BECs also came into conflict with evaluation cycles. For a Dutch researcher on a tenure-track position, this conflict was resolved by his faculty acknowledging the time frame of his research and suspending the mid-term evaluation. The Swedish researcher, however, found his department disappointed with his progress after the 'usual' time for projects to be completed.

Difficulties in gaining sufficient grants to deal with the uncertainties involved led two researchers to abandon their attempts to produce BECs. A Dutch researcher could not obtain grants for his BEC research anymore and had to give up. The Swedish researcher, who almost entirely depended on external grants, faced difficulties in securing sufficient resources to continue his research. In addition, he was criticised locally for his BEC research not producing enough publications, as the department did not allow for the long and unpredictable time horizon. As a consequence, he was not allocated any more PhD students from department funds and eventually he gave up BEC research and left Sweden.

This summary of the decisions of researchers enables us to identify the conditions necessary to realise BECs experimentally. For researchers to attempt developing BEC at all, it was necessary that they believed they would be able to build the necessary protected space. Those who felt unable to do this delayed the development of the innovation or permanently took up different topics. The same applies to those who did not feel they could successfully compete with the US groups because the fear of being too late was at least partly caused by insufficient access to resources.[8]

However, only in very few cases was such access sufficient for building the needed protected space. In most cases, repeated substantial grant funding was a second necessary condition because university support needed to be complemented by funding for project-specific equipment and (additional) personnel. This depended on scientific communities and funding agencies being prepared to tolerate and support projects that contradicted the majority opinion at the beginning of successful BEC research and exceeded the common grant funding cycles of three or four years throughout the development of BEC. Researchers also needed to have permanent positions, or at least to expect them on their tenure-track positions. An additional condition that helped to speed up BEC research was access to grant funding that could be 'bootlegged' before dedicated BEC funding could be acquired.

8 Still, the amount of grant and university funding obtained for BEC in the four countries was only half of what the US group leader producing the first BEC in the USA had at his disposal as a young assistant professor, at a time when BEC was a highly unpredictable endeavour (Ketterle 2002). When Ketterle became assistant professor, he received a start-up package. In addition, his former professor gave him full discretion over a lab that was newly equipped for BEC research and over two experienced PhD students. Ketterle could fund two more PhD students, one of them from an NSF grant that he received although the manufacturing BECs was considered impossible by most.

B) Evolutionary Developmental Biology

In developing this innovation, researchers in both Germany and Switzerland had a strong tradition in the relevant biological fields. Swiss scientists in particular contributed actively to the development of evo-devo. In the Netherlands and in Sweden both fields were well, but unevenly, established, with the Netherlands having a stronger tradition in developmental biology and Sweden in evolutionary biology.

In contrast to BEC research, evo-devo could be developed in a variety of ways that differed in the extent to which they broke with the epistemic traditions of the two 'home fields' and consequently the level of the required protected space (Laudel et al. 2014a). The simplest way of contributing to evo-devo is to extend research findings obtained in a traditional disciplinary context to an evo-devo one. This could be done within the protected space for their previous research, i.e. without additional resource or time requirements. At the other end of the spectrum, evo-devo research can be pursued as a high-risk and high cost strategy of comparative experiments with two species that are not traditional model organisms of biology but are best suited for evo-devo. This approach required substantial investments in infrastructure including animal breeding facilities and research personnel. It was characterised by long and unpredictable time-horizons and a high risk of experimental failure. Between these poles, medium-risk strategies struck a compromise, e.g. by comparing well established model organisms with one new species or by experimenting with a new species and comparing results to published data. Following such a medium-risk strategy could still lead to unpredictable time-horizons and to reputational risks when epistemic standards of a community were challenged.[9]

Owing to the variability of evo-devo research and its necessary protected space, researchers could adapt their decision to develop the innovation to their opportunities to build protected space. If they were interested, they could decide on a purely conceptual contribution or choose an experimental approach they could 'afford' in terms of protected space. As a consequence, we observed researchers at all career stages and with a wide range of opportunities to build protected space participating in evo-devo research. Many of the interviewed researchers started with a low-cost or medium-cost approach to evo-devo and gradually increased their commitment to the area as their opportunities to build protected space grew.

Nevertheless, some researchers faced similar problems as their colleagues developing BEC in that they did not believe they could build the protected space for the particular evo-devo research they intended. Medium- and high-cost evo-devo approaches require access to substantial infrastructure, i.e. a laboratory with basic equipment and technical staff. Two postdocs (one Dutch and one Swiss) could not develop these approaches because they did not have access to this infrastructure and postponed their evo-devo research. Another Dutch researcher intended to begin evo-devo research as a PhD student but no such post was available at the time.

[9] Evo-devo researchers working with non-model organisms sometimes faced publication difficulties because they could not provide the standard functional tests with these organisms because the methods were not developed yet.

Researchers who wanted to conduct dedicated evo-devo experiments needed access to both research infrastructure and grant funding. Access to infrastructure was restricted to professors, who could ‘lend’ it to members of their research groups for evo-devo research even when they were not interested in it themselves. In Sweden, a substantial part of the infrastructure was provided by unusually large grants from external funding agencies.

The infrastructure requirements of high-cost evo-devo research exceeded even those of BEC. If species that have not been used in biological experiments before were to be used for such research (which was often the case), these non-model organisms had to be bred and studied. New animal breeding facilities incurred costs that often exceeded the normal infrastructure, costs that could be covered by generous start-up or loyalty packages for professors. This is why high-cost evo-devo was found primarily in Swiss universities and German state-funded research institutes, which provided sufficient support without scientists having to apply for additional grants. In Sweden, these resources were provided by external research foundations.

All the other researchers needed to apply for additional grants. Since researchers were able to match their involvement in evo-devo research to funding opportunities, the failure to acquire grants did not necessarily lead to the immediate abandonment of the innovation. Instead, they adapted their approach to their access to resources in ways that worked well in Germany, Sweden and Switzerland. In contrast, an unfavourable situation for evo-devo research emerged in the Netherlands.

Here, in the late 1990s and 2000s the state developed strong political expectations concerning the utility of university research, which were adopted by funding agencies. The main Dutch funding council NWO shifted its funding into applied fields and to thematic programmes. Success rates for investigator-driven research in biology dropped to 20%. This led to a significant intensification of competition for grants between evo-devo and well-established fundamental biology groups. Evo-devo was ill equipped for this competition because as a new and interdisciplinary field, it did not feature the high citation rates and impact factors of the established areas. After initial support for evo-devo (NWO even co-funded a chair dedicated to it), the field faced increasing difficulties in grant funding.

Several researchers in the Netherlands abandoned evo-devo research because they felt they could not continue it under current political priorities in the Netherlands. Not only were grants increasingly difficult to obtain and promotion criteria increasingly difficult to meet, universities withdrew their support for the same reasons as the research council, namely evo-devo not being applied, not acquiring enough grant money, and not doing well in terms of evaluation indicators. As a consequence, evo-devo all but disappeared in the Netherlands (Laudel and Weyer 2014: 130–132).

The development of evo-devo in the four countries highlights two important conditions for developing these kinds of intellectual innovations. First, the research field must be sufficiently supported even if it does not match political priority areas. If a field does not contribute to public policy goals or university income, it might lose university support for infrastructure, grant funding, or both. Second, universities have to be supported sufficiently to provide access to dedicated infrastructure. As the examples of the exceptionally well supported Swiss universities and German state-funded institutes indicate, some innovations may require infrastructural support that exceeds the recent level of state support of universities in many European countries.

C) International Large-Scale Student Assessments

The innovative character of ILSA studies has two distinct aspects. First, the data generation itself (internationally comparative studies) constituted a major innovation in countries that did not have a strong tradition of quantitative educational research. While this was the case in Germany, where educational research was non-empirical or qualitative, it was much less so in the other three countries that had some previous experience of quantitative research, particularly in the Netherlands and Sweden. Second, the new kind of data provided by ILSA studies could trigger innovations by enabling new questions to be posed and new comparative studies to be undertaken. This applied to some extent in all countries, at least as far as internationally comparative studies were concerned. Such opportunities were more often taken up by social scientists who did not generate the data but had experience of these statistical techniques (Gläser et al. 2014a).

Participating in ILSA meant carrying out national surveys according to the standards set by the international organising associations, which required significant material costs of up to a million Euros. This necessary protected space exceeded by far the normal project size of educational research. While data collection was primarily a routine effort in the Netherlands, Sweden and Switzerland, to the extent that data could be collected by the state bureau of statistics in the last country, researchers in Germany became more involved in developing the ILSA methodology once policymakers decided to invest in these surveys.

Since the German national educational science community did not traditionally undertake or accept as valid quantitative educational research, no researcher at a German university was involved in ILSA at the beginning. Instead, German participation in ILSA studies was undertaken by staff at a state-funded research institute, which had a stronger quantitative orientation and was institutionally committed to conducting such studies as part of their mission. However, the young researchers who participated in ILSA studies ran a risk in the beginning because there were no career prospects for them at German universities. Continuous participation in ILSA studies since the late 1990s has, though, spurred the growth of a quantitative educational research community and a number of universities have established institutes for quantitative educational research (Aljets 2015).

The use of ILSA data for developing new educational research occurred with significant delay and at low speed. Decisions not to use the data for developing innovations were motivated more by epistemic considerations than by an inability to build protected space. Many researchers did not consider the data to be suitable for developing new research paths because they were cross-sectional rather than longitudinal. Dutch researchers, in particular, considered their own data as being better than ILSA data for their purposes.

In all four countries, data collection occurred at the request of the state, which also provided the necessary funding. Research groups in Germany and Sweden competed for this opportunity. Once a group was chosen, its financial needs were met by the state. More recently, research councils in Germany and Switzerland have also established thematic funding programmes supporting research using ILSA data.

Overall, the new ILSA studies represented a significant investment by national governments and international agencies, especially the OECD, in monitoring, comparing and improving the performance of school systems by means of highly standardised and centrally controlled surveys. By funding these directly and continuously over a considerable period of time, states created positions and career opportunities, albeit often on short term contracts, for education researchers that strengthened quantitative research traditions in Sweden and Switzerland, had little impact in the Netherlands, and facilitated the institutionalisation of an empirical research community in Germany.

These national variations reflected the different intellectual traditions at the time of the new ILSA surveys and researchers' assessments of these opportunities. While technical limitations and the centrally controlled structure restricted their scientific usefulness within each national education research field, the resources provided did create opportunities for changing the intellectual and organisational authority structure governing research strategies and practices in three countries, most significantly of course in Germany. While, then, this case illustrates the limited ability of political interest and funding to establish scientific innovations directly if they are not seen to provide significant intellectual advantages, they can stimulate shifts in the relative attractiveness of different goals and approaches that over time result in qualitative changes in scientific direction.

Varying Conditions for Innovation Development

A) The Roles of Authoritative Actors

The causal reconstruction of research processes in the previous section makes it possible to identify particular conditions as being necessary for developing these innovations. We consider conditions to be necessary if their presence triggered specific processes of successful innovation development, while their absence triggered different processes that did not lead to success.[10] Table 2 summarises these necessary conditions and the ways that different authoritative actors helped to fulfil them. First, researchers have to have the sufficient background expertise and competencies, or absorptive capacity (Laudel et al. 2014a), to develop the necessary knowledge and skills. This largely depends on a country's research landscape and epistemic traditions. However groundbreaking an intellectual innovation is, it nevertheless builds on prior research, and the speed at which a national scientific community can respond to innovation opportunities depends on pre-existing research.

[10] In this study we focus on one type of higher education system, which can loosely be described as 'Germanic', and its reformed versions. The inclusion of other types of systems (e.g. as categorised by Whitley and Gläser 2014b) could change the scope of our causal claims because other conditions of research would vary.

Table 2 Roles of authoritative actors in providing necessary conditions for three scientific innovations

<table>
<tr><th rowspan="2">Necessary conditions</th><th colspan="4">Authoritative Actors</th></tr>
<tr><th>Extra-scientific groups and organisations</th><th>Universities</th><th>State-funded research institutes</th><th>Funding agencies</th></tr>
<tr><td>Building Absorptive Capacity</td><td></td><td>Recruiting foreign scientists</td><td></td><td>Supporting international mobility</td></tr>
<tr><td rowspan="2">Maintaining Epistemic Pluralism</td><td></td><td colspan="3">Supporting basic research</td></tr>
<tr><td colspan="4">Supporting non-mainstream research</td></tr>
<tr><td rowspan="2">Long time horizons of protected space</td><td></td><td colspan="2">Providing tenured positions</td><td></td></tr>
<tr><td></td><td>Limiting/suspending evaluations</td><td></td><td>Extending/renewing grants before experimental success achieved</td></tr>
<tr><td rowspan="3">Large resource dimension of protected space</td><td></td><td colspan="2">Granting control of infrastructure</td><td></td></tr>
<tr><td colspan="3">Granting exceptional amounts of resources</td><td></td></tr>
<tr><td>Providing grants</td><td></td><td></td><td>Providing grants
Delegating use of resources</td></tr>
</table>

This was clearly illustrated by the varying positions national communities took in developing the innovations. The Dutch physics community had a strong tradition of research on cold atoms, which is why relatively many research groups were in a position to take up BEC research. Switzerland did not have such a tradition and had to 'import' BEC of atom gases. In contrast, it was at the forefront of evo-devo research due to its strong research in the two fields that formed its background. Germany had the relevant research traditions in the sciences but none at all supporting ILSA-related research. However, even in cases where relevant research traditions existed in countries, additional new knowledge required for developing the innovation often had to be imported. In the case of BEC, both recruitment of experienced researchers from abroad and international mobility of postdocs were important conditions for the diffusion of new methods, which were provided by universities and funding agencies (Laudel et al. 2014b).

A second condition is that epistemic pluralism – support for a variety of divergent theories and approaches is – maintained by authoritative agencies continuing to support basic research that is not widely thought to contribute to extra-scientific goals and tolerate non-mainstream approaches. As the Dutch case illustrates, this condition can become threatened if either universities or funding councils (or, in the case of the Netherlands, both) implement public policy goals to the detriment of investigator-driven 'blue sky' - research. The fate of evo-devo (and, to some extent, BEC) in the Netherlands illustrates that the incorporation of public policy goals in science policies may crowd out some fields of basic research.

More importantly, scientific elites can provide authoritative support for non-mainstream research by funding research that contradicts majority opinion. The comparison of German and Dutch research on BEC in the late 1990s shows that the active tolerance of non-majority opinions is an important necessary condition for at least some innovations in their early stages. Furthermore, the case of ILSA in Germany illustrates how external funding that is not controlled by the scientific community can enable non-mainstream research.

Turning to the third condition, the need for lengthy periods of protected space, high-cost evo-devo and, especially, BEC required long time horizons due to the technical uncertainty involved. Furthermore, it was very difficult to be sure about the length of time required to achieve success. In the case of ILSA, the considerable reputational risks involved in data collection activities resulting from their low epistemic status also required an extended time dimension of protected space. This aspect of the innovations was met in two ways.

First, researchers had to have long term, preferably tenured, positions in order to develop the innovation. While medium-cost and low-cost evo-devo provided 'entry points' for researchers on fixed-term positions, BEC, high-cost evo-devo and ILSA were developed by researchers on tenured or at least tenure-track positions only. Tenured positions were provided (and thus controlled) by universities and (in the case of Germany) state-funded research institutes.

Second, universities, funding agencies and scientific communities had to accommodate research processes whose duration was unpredictably long. The typical period for which research grants were available to BEC and evo-devo researchers was clearly shorter than the expected duration of successful research processes. The different approaches of universities and funding agencies in Germany, the Netherlands and Sweden indicate the importance of being flexible when applying formal accountability and evaluation requirements to these kinds of projects.

With regard to the fourth condition, the resource dimension of protected space, there were two necessary conditions. First, not only high-cost approaches but all experimental research depends on infrastructure, which in most cases is provided by universities or state-funded research institutes. This infrastructure includes the basic equipment of a laboratory, technical staff and university funding for positions of PhD students. It is typically controlled by senior professors, who can grant the use of 'their' infrastructure to other researchers in the university if they approve of the research. This did indeed happen, albeit not in all cases. The perception of not having access to infrastructure was the most important reason for young researchers to decide against developing an innovation.

Some cases of exceptional infrastructure requirements for high-cost evo-devo highlighted another factor affecting the development of some innovations. If universities or state-funded research institutes are supposed to fund such infrastructures, the split between recurrent funding and grant funding can be decisive for the opportunity to develop an innovation. In some cases of evo-devo research, the required infrastructure included new buildings, which were funded only by Swiss universities and German state-funded research institutes. Thus, the balance of funding streams and the resulting financial flexibility of universities is important.

Second, nearly all the researchers needed to acquire external grants, which were provided by governments for ILSA and by funding agencies for BEC and evo-devo. Funding agencies typically relied on decisions made by the elites of the relevant scientific communities and so the development of these kinds of innovations depended on scientific communities being willing to be flexible in their application of majority opinions, judgement of success, and handling of the institutionalised procedures governing grant funding. Finally, an important aspect of the exercise of authority is its delegation (Whitley and Gläser 2014b). Universities and research institutes delegate authority when they allow professors or heads of departments to control the use of infrastructure. Similarly, funding agencies delegate authority over the use of grants, which turned out to be a facilitating condition for developing BEC because researchers could 'bootleg' their existing grants for beginning BEC research, saving them time until BEC grants were approved.

B) The Provision of the Necessary Conditions in Four Countries

These conditions were met in different ways and to varying degrees in the four countries studied here.[11] In Table 3 we summarise the initial level of absorptive capacity for each of the three innovations in each scientific community and the major ways in which this was enhanced, as well as the primary means of supporting epistemic pluralism and their changing extent. Differences in the provision of protected space are also described.

If the development of BEC and evo-devo can serve as examples of how changing authority relations are affecting epistemic pluralism, such toleration of intellectual diversity is clearly declining in some countries (see also Lee 2009 on heterodox economics and Rafols et al. 2012 on a potential mechanism for reducing intellectual diversity built into the British research evaluation system). This decline can be ascribed to an increasing overlap and mutual reinforcement of major authoritative actors' priorities, as illustrated by the continuing implementation of public policy goals by universities and funding agencies, that leaves little room for non-mainstream research, particularly in the Netherlands. Here, higher education reforms have increased managerial control of research by universities without increasing the latter's autonomy from the state. Universities still closely follow all signals sent by the government because hierarchical subordination within the state has become partly replaced by increasing financial dependence. As a result, the institutional diversity of the science system has decreased, and research not contributing to public policy goals has come under pressure, which in the case of evo-devo overrode an initial attempt to establish the field.

[11] The following discussion is limited by the degree to which the relevant conditions actually made a difference. In the three smaller countries, the small number of attempts to develop BEC (two in Switzerland and one in Sweden) or evo-devo (two in Sweden) make it difficult to assess how conditions were provided.

Table 3 Provision of necessary conditions in four countries

	Germany	Netherlands	Sweden	Switzerland
Initial Absorptive Capacity	High for BEC and evo-devo, Very low for ILSA	High for BEC, evo-devo and ILSA	Limited for BEC and evo-devo, Considerable for ILSA	Limited for BEC and ILSA, High for evo-devo
Creating additional absorptive capacity	International mobility for BEC and evo-devo Direct state funding of ILSA studies	International mobility for BEC and evo-devo	International mobility for BEC, recruitment from abroad for evo-devo	International mobility for evo-devo, recruitment from abroad for BEC
Epistemic pluralism	University, research institute and funding agency support for basic, non-mainstream research, added to by state funding for ILSA	Declining university and funding agency support for basic, non-mainstream research	Diversity of funding agencies willing to support varied research areas	Generous funding agency and university support for internationally excellent research in the physical and biological sciences
Time horizon of protected space	Tenure for professors, rules for grant extensions suspended in physics	Tenure below professorial level, evaluation cycles suspended, rules for grants not suspended	Tenure below professorial level, evaluation cycles not suspended	Tenure below professorial level
Resource dimension of protected space	Control of infrastructure by professors, exceptional infrastructure in state-funded institutes, grant funding and government funding for non-mainstream research	Control of infrastructure by professors, university support and grant funding for non-mainstream research declining	Control of infrastructure by departments, emphasis on large grants rather than university funding	Control of infrastructure by professors, exceptional infrastructure funded by universities

Sweden and Switzerland compensated for their limited absorptive capacity for some innovations by importing researchers and supporting international mobility (Laudel et al. 2014a, b). In Sweden, large grants for investigator-driven research led to the start of both BEC and evo-devo research. While the attempt to establish BEC failed with the one researcher going abroad after not being supported anymore, the development of evo-devo research continues with several researchers being supported by a large long-term grant. In Switzerland, quality-driven and well-endowed appointments by universities led to the establishment of BEC with cold atom gases (BEC in condensed matter was already well established). Thus, actors in both countries made resources available that enabled the growth of additional fields.

The time horizon of protected spaces was strongly affected by the balance of funding between block grants to universities and project based grants. The governance changes described in the introduction had not yet affected the basic structure of national career systems in these public science systems. Tenured positions were available only for professors in Germany and, to a limited extent, below the professorial level in the other three countries. Swiss universities, German state-funded research institutes and Swedish large grants were able to meet exceptional infrastructure requirements and provided enough funding to build necessary protected space.

However, most researchers could not build protected space from recurrent funding alone and were forced to supplement protected space with grants whose duration did not match the required time horizons. The German physics community responded to this mismatch by applying grant rules flexibly, while its Dutch counterpart did not. Our observations also indicated the emergence of another short-term cycle, namely that of performance evaluations by universities (observed in the Netherlands and Sweden). Neither grant rules nor evaluation cycles fit the long and often unpredictable time horizons of innovations with high technical uncertainty.

The resource dimension of protected space was also affected by the split funding mode. Most researchers who wanted to develop BEC or experimental evo-devo needed control of infrastructure and accompanying grants, which limited the opportunity to develop these innovations to professors who still controlled the infrastructure at universities. In the Netherlands, they do so in spite of an explicit reform of the career system aimed at creating more equality at universities. It can be doubted that departmental control of university infrastructure in Sweden has made much of a difference because infrastructure is often funded by large grants, which are usually held by professors.

Grant funding contributed to an increase in epistemic diversity in Germany, where it was also provided for non-mainstream research, and in Sweden, where researchers were free to decide what field to develop with their grant. In addition, government funding in Germany contributed to epistemic diversity by supporting a non-mainstream development (ILSA) against the majority opinion of the national educational science community.

Thus, the changing authority relations brought about by changes in governance turn out to have ambivalent effects on the opportunities to build protected space for intellectual innovations. Basic research not thought to contribute to broader socio-economic purposes faces increasing difficulties because it competes for funding with research addressing public policy goals (see also Pavitt 2001: 768–771; Lepori et al. 2007). The split funding mode does not protect such research because recurrent funding is typically insufficient for conducting empirical research and because universities are also being pressured to contribute to public policy goals. On the other hand, when research contributes to extra-scientific interests, the increasing number of actors with the resources and commitment to fund it over some years can support some epistemic diversity.

Concluding Remarks

This analysis of how three scientific innovations have been developed in different ways in four European public science systems emphasises a number of points about how recent funding and governance changes are affecting research strategies and practices. First, increasing the variety of funding agencies and resource providers for academic research has different effects in different political contexts. If these organisations allocate their support in pursuit of a wide range of objectives with flexible evaluation criteria, this is likely to encourage greater diversity of research strategies and practices. In contrast, where varied authoritative actors focus on similar goals and apply similar standards in supporting research, the increasing variety of authoritative agencies supporting research might well lead to greater homogenisation of research goals and approaches. This may occur either as a collective focus on the investigation of mainstream problems with established approaches and techniques, or as hyper-innovation in the form of fashions.

This narrowing of goals and frameworks is especially probable when, second, the increasing importance of external project funding is combined with reductions in state financing of universities and public research institutes that restrict the availability of local research facilities and technical staff for academics and greater state steering of research council priorities towards public policy purposes. As seems to have happened in the Netherlands in the 2000s, in public science systems where both scientists and universities become more dependent on short term state funding, whether in the form of block grants or project support, and research councils suffer significant cuts in their budgets at the same time as state agencies guide them more proactively towards their objectives, researchers become increasingly pressured to work on problems that fit these priorities. Insofar as such choices and rationales become more generally institutionalised in a number of countries, this could result in the petering out of potentially productive research directions.

Third, the growing standardisation of project cycle times and resource packages across funding agencies and scientific communities (Laudel and Gläser 2014) make it more difficult for researchers to pursue projects that deviate from these norms, especially, if they challenge mainstream beliefs and assessment criteria. Some scientists undertaking experimental evo-devo research that extends over three years, requires extensive local infrastructure and continuing technical support, and studies non-model organisms have found it difficult to produce results to the expected standards of some journals and referees and to obtain continuing financial support.

Fourth, both experimental BEC and evo-devo research highlighted the importance of maintaining substantial locally controlled facilities and associated staff for scientists to be able to undertake long term, complex and multi-faceted research that involves high levels of technical uncertainty. If states reduce their block grants to PROs so much that they become unable to provide such infrastructure and/or researchers have to apply to external agencies when they experience difficulties with their equipment or run out of consumables, they are likely to discourage projects dependent on complex experimental systems and liable to produce such unforeseen problems.

It is important to note here, though, that the effects of high levels of dependence on standardised external project grants can be mitigated in some scientific fields by breaking projects down into distinct modules that can be undertaken by several researchers with only intermittent coordination, each of whom produces publishable results. If funding councils additionally delegate considerable discretion over project funds so that they can be switched between tasks and problems as well as facilitating extensions before technical success is achieved, as in the physical sciences in Germany and Switzerland, the constraints of short project cycles can be further reduced. Correlatively, they will have the greatest impact in sciences where high technical uncertainty and/or strong dependence on both personal formulation of problems and interpretation of evidence and long periods of uninterrupted research time hinder such a division of labour and make time horizons of research lengthy and unpredictable.

Such constraints are also mitigated in public science systems where the state continues to support academic research sufficiently for many scientists to be able to obtain funding for promising projects even if these challenge mainstream orthodoxies and/or appear to pose major technical difficulties. As the success of scientists in Switzerland pursuing BEC and experimental evo-devo research in the late 1990s and 2000s shows, providing enough support for universities for them to be able to attract leading researchers in these areas with substantial local infrastructure can prevent some of the homogenisation effects of hyper-competition and compensate for many of the problems arising from dependence on external short cycle grants.

Fifth, it is worth emphasising that the impact of direct funding of policy-focused research and commercialisation of results on the development of scientific fields depends greatly on researchers' assessments of the intellectual opportunities afforded by such support. As the effects of ILSA surveys suggest, policy driven initiatives can generate considerable outputs for political purposes but are unlikely to lead directly to new intellectual programmes and approaches becoming established unless they offer significant scientific advantages over current strategies and approaches. These advantages might emerge and be utilised with considerable delay not only in the social sciences but in other fields as well.

Finally, our study highlights two crucial issues in the examination of how financial and institutional changes affect the development of the sciences. Concerning progress in theory-building, it reinforces the point that explanations of such processes are inevitably multi-causal and must link the range of varying circumstances to particular effects through specific mechanisms. This means that assessing the impact of changing authority relations in research funding on the development of scientific innovations is simply impossible without simultaneously considering other changes in governance and other conditions of research. As other contributions to this special issue illustrate, funding may serve as a focus for the organisation of an explanatory argument but must not restrict the boundaries of empirical investigations if theoretically adequate explanations are to be achieved.

A second central issue concerns field-specific research practices and conditions of research, which stand out as critical factors that have to be included in any study of the impact of governance on research. Across all divisions in science studies, scholars agree that such field-specific factors impinge upon how funding and governance structures affect the direction of research. It follows from this that drawing general conclusions about these relationships depends on a systematic comparative approach to research content. Our study suggests one conceptual approach to these problems, which of course must be further developed to accommodate all fields of science and varieties of governance processes.

References

Aljets, Enno. 2015. *Der Aufstieg der Empirischen Bildungsforschung. Ein Beitrag zur institutionalistischen Wissenschaftssoziologie*. Wiesbaden: VS Verlag für Sozialwissenschaften.

Aljets, Enno, and Eric Lettkemann. 2011. Hochschulleitung und Forscher: Von wechselseitiger Nichtbeachtung zu wechselseitiger Abhängigkeit. In *Hochschule als Organisation*, eds. Uwe Wilkesmann and Christian Schmid, 131–153. Wiesbaden: VS Verlag für Sozialwissenschaften.

Australian Research Council (ARC). 2016. *ARC research funding trend data*. Retrieved 20 May 2016, from http://www.arc.gov.au/sites/default/files/filedepot/Public/ARC/NCGP_dataset/ARC_NCGP_Trends_web_update_Feb2015.xlsx.

Baldini, Nicola. 2008. Negative effects of university patenting: Myths and grounded evidence. *Scientometrics* 75(2): 289–311.

Berman, Elizabeth Popp. 2012. *Creating the market university: How academic science became an economic engine*. Princeton, NJ: Princeton University Press.

Braun, Dietmar. 1993. Who governs intermediary agencies? Principal-agent relations in research policy-making. *Journal of Public Policy* 13(2): 135–162.

Braun, Dietmar. 1998. The role of funding agencies in the cognitive development of science. *Research Policy* 27(8): 807–821.

Brunet, Philippe, and Michel Dubois. 2012. Stem cells and technoscience: Sociology of the emergence and regulation of a field of biomedical research in France. *Revue Française de Sociologie* 53(3): 251–286.

Cozzens, Susan E., Peter Healey, Arie Rip, and John Ziman (eds.). 1990. *The research system in transition*. Dordrecht: Kluwer.

Crouch, Colin. 2005. *Capitalist diversity and change*. Oxford: Oxford University Press.

Cruz-Castro, Laura, and Luis Sanz-Menéndez. 2016. The effects of the economic crisis on public research: Spanish budgetary policies and research organizations. *Technological Forecasting and Social Change* 113: 157–167.

De Boer, Harry, Jürgen Enders, and Liudvika Leišytė. 2007. Public sector reform in Dutch higher education: The organizational transformation of the university. *Public Administration* 85(1): 27–46.

Drori, Gili S., John W. Meyer, Francisco O. Ramirez, and Evan Schofer. 2003. *Science in the modern world polity: Institutionalization and globalization*. Stanford: Stanford University Press.

Fallani, Leonardo, and Anders Kastberg. 2015. Cold atoms: A field enabled by light. *EPL (Europhysics Letters)* 110(5): 53001.

Fujimura, Joan. 1987. Constructing 'Do-able' problems in cancer research: Articulating alignment. *Social Studies of Science* 17: 257–293.

Furman, Jeffrey L., Fiona Murray, and Scott Stern. 2012. Growing stem cells: The impact of federal funding policy on the US scientific frontier. *Journal of Policy Analysis and Management* 31(3): 661–705.

Gläser, Jochen, Enno Aljets, Adriana Gorga, Tina Hedmo, Elias Håkansson, and Grit Laudel. 2014a. Path dependence and policy steering in the social sciences: The varied impact of international large scale student assessment on the educational sciences in four European countries. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 267–295. Bingley: Emerald Group.

Gläser, Jochen, Enno Aljets, Eric Lettkemann, and Grit Laudel. 2014b. Where to go for a change: The impact of authority structures in universities and public research institutes on changes of research practices. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 297–329. Bingley: Emerald Group.

Gläser, Jochen, and Grit Laudel. 2015. A bibliometric reconstruction of research trails for qualitative investigations of scientific innovations. *Historical Social Research - Historische Sozialforschung* 40(3): 299–330.

Gläser, Jochen, and Grit Laudel. 2016. Governing science: How science policy shapes research content. *European Journal of Sociology / Archives Européennes de Sociologie* 57(01): 117–168.

Guston, David H. 2000. *The expanding role of peer review processes in the United States*. Proceedings from US-EU workshop “Learning from science and technology policy evaluation”, Bad Herrenalb, Germany, September.

Hackett, Edward J. 2005. Essential tensions: Identity, control, and risk in research. *Social Studies of Science* 35(5): 787–826.

Hessels, Laurens K., John Grin, and Ruud E.H.M. Smits. 2011. The effects of a changing institutional environment on academic research practices: Three cases from agricultural science. *Science and Public Policy* 38(7): 555–568.

Hicks, Diana. 2012. Performance-based university research funding systems. *Research Policy* 41: 251–261.

Kearnes, Matthew, and Matthias Wienroth. 2011. Tools of the trade: UK research intermediaries and the politics of impacts. *Minerva* 49(2): 153–174.

Krohn, Wolfgang, and Johannes Weyer. 1994. Society as laboratory: The social risks of experimental research. *Science and Public Policy* 21(3): 173–183.

Langfeldt, Liv, Mats Benner, Gunnar Sivertsen, Ernst H. Kristiansen, Dag W. Aksnes, Siri Brorstad Borlaug, Hanne Foss Hansen, Egil Kallerud, and Antti Pelkonen. 2015. Excellence and growth dynamics: A comparative study of the Matthew effect. *Science and Public Policy* 42(5): 661–675.

Laudel, Grit, Martin Benninghoff, Eric Lettkemann, and Elias Håkansson. 2014a. Highly adaptable but not invulnerable: Necessary and facilitating conditions for research in evolutionary developmental biology. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 235–265. Bingley: Emerald Group.

Laudel, Grit, Eric Lettkemann, Raphaël Ramuz, Linda Wedlin, and Richard Woolley. 2014b. Cold atoms—Hot research: High risks, high rewards in five different authority structures. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 203–234. Bingley: Emerald Group.

Laudel, Grit, and Elke Weyer. 2014. Where have all the scientists gone? Building research profiles at Dutch universities and its consequences for research. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 111–140. Bingley: Emerald Group.

Laudel, Grit, and Jochen Gläser. 2014. Beyond breakthrough research: Epistemic properties of research and their consequences for research funding. *Research Policy* 43(7): 1204–1216.

Lee, Frederic. 2009. *A history of heterodox economics*. London: Routledge.

Lepori, Benedetto, Peter van den Besselaar, Michael Dinges, Bianca Potì, Emanuela Reale, Stig Slipersæter, Jean Thèves, and Barend van der Meulen. 2007. Comparing the evolution of national research policies: What patterns of change? *Science and Public Policy* 34(6): 372–388.

Leydesdorff, Loet, and Élaine Gauthier. 1996. The evaluation of national performance in selected priority areas using scientometric methods. *Research Policy* 25(3): 431–450.

Luukkonen, Terttu, and Duncan A. Thomas. 2016. The 'negotiated space' of university researchers' pursuit of a research agenda. *Minerva* 54(1): 99–127.

Makkonen, Teemu. 2013. Government science and technology budgets in times of crisis. *Research Policy* 42(3): 817–822.

Matthews, David. 2015. *Success rates: Surge in applications to 'struggling' research councils*. Retrieved 20 May 2016, from https://www.timeshighereducation.com/news/success-rates-surge-applications-struggling-research-councils.

Meier, Frank, and Uwe Schimank. 2010. Mission now possible: Profile building and leadership in German universities. In *Reconfiguring knowledge production: Changing authority relationships in the sciences and their consequences for intellectual innovation*, eds. Richard Whitley, Jochen Gläser, and Lars Engwall, 211–236. Oxford: Oxford University Press.

Morris, Norma. 2000. Science policy in action: Policy and the researcher. *Minerva* 38(4): 425–451.

Musselin, Christine. 2014. Empowerment of French Universities by funding and evaluation agencies. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 51–76. Bingley: Emerald Group.

National Institutes of Health (NIH). 2015. *Research and training grants: Success rates by mechanism and selected activity codes*. Retrieved 20 May 2016, from http://report.nih.gov/NIHDatabook/Charts/Default.aspx?showm=Y&chartId=202&catId=2.

Owen-Smith, Jason, and Walter W. Powell. 2001. To patent or not: Faculty decisions and institutional success at technology transfer. *The Journal of Technology Transfer* 26(1–2): 99–114.

Paradeise, Catherine, Emanuela Reale, Ivar Bleiklie, and Ewan Ferlie (eds.). 2009. *University governance: Western European comparative perspectives*. Dordrecht: Springer.

Pavitt, Keith. 2001. Public policies to support basic research: What can the rest of the world learn from US theory and practice? (And what they should not learn). *Industrial and Corporate Change* 10(3): 761–779.

Rafols, Ismael, Loet Leydesdorff, Alice O'Hare, Paul Nightingale, and Andy Stirling. 2012. How journal rankings can suppress interdisciplinary research: A comparison between Innovation Studies and Business & Management. *Research Policy* 41(7): 1262–1282.

Research Councils UK. 2006. *Report of the Research Councils UK efficiency and effectiveness of peer review project*. Wiltshire: Research Councils UK.

Rip, Arie. 1994. The republic of science in the 1990s. *Higher Education* 28: 3–32.

Rip, Arie. 1995. New combinations. *European Review* 3: 83–92.

Rip, Arie. 2011. Protected spaces of science: Their emergence and further evolution in a changing world. In *Science in the context of application*, eds. Martin Carrier and Alfred Nordmann, 197–220. Dordrecht: Springer.

Rosenau, James. 2004. Strong demand, huge supply: Governance in an emerging epoch. In *Multi-level governance*, eds. I. Bache and M. Flinders, 31–48. Oxford: Oxford University Press.

Schimank, Uwe. 2005. 'New Public Management' and the academic profession: Reflections on the German situation. *Minerva* 43: 361–376.

Solla Price, Derek de. 1986 [1963]. *Little science, big science… and beyond*. New York: Columbia University Press.

Weingart, Peter. 2003. Growth, differentiation, expansion and change of identity—The future of science. In *Social studies of science and technology: Looking back, ahead*, eds. Bernward Joerges and Helga Nowotny, 183–200. Dordrecht: Kluwer.

Whitley, Richard. 2011. Changing governance and authority relations in the public sciences. *Minerva* 49(4): 359–385.

Whitley, Richard. 2014. How do institutional changes affect scientific innovations? The effects of shifts in authority relationships, protected space, and flexibility. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 367–406. Bingley: Emerald Group.

Whitley, Richard, and Jochen Gläser (eds.). 2007. *The changing governance of the sciences: The advent of research evaluation systems*. Dordrecht: Springer.

Whitley, Richard, and Jochen Gläser. 2014a. Editor's introduction. In *Organizational transformation and scientific change: The impact of institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 1–15. Bingley: Emerald Group.

Whitley, Richard, and Jochen Gläser. 2014b. The impact of institutional reforms on the nature of universities as organisations. In *Organizational transformation and scientific change: The impact of *institutional restructuring on universities and intellectual innovation*, eds. Richard Whitley and Jochen Gläser, 19–49. Bingley: Emerald Group.

Ziman, John. 1994. *Prometheus bound: Science in a dynamic steady state*. Cambridge: Cambridge University Press.