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Summary:
In this paper we develop and apply a comparative framework for the epistemic regimes of scientific fields, which we hope may contribute to strengthening field-comparative research in the sociology of science. We start from the comparative framework developed by Richard Whitley (1984) but modified it radically in order to develop an approach that includes more characteristics of research practices and social structure, and uses characteristics that can be empirically operationalised for a fine-grained comparative analysis of epistemic regimes. We use data from several empirical studies for a comparative description of the epistemic regimes of experimental atomic and molecular optics (AMO physics), plant biology, early modern history, and automotive engineering. This comparison serves as proof of concept. The usefulness of our framework is demonstrated by applying it to an explanation of the emergence of individual research programmes in the four fields. Further possible applications that are briefly discussed include field-specific effects of evaluation regimes, field-specific career patterns, and field-specific practices of data sharing.

Keywords:
Regimes of knowledge production – Epistemic cultures – Scientific specialties – Epistemic conditions of action

Contents

1. Introduction

In this paper we develop and apply a comparative framework for the epistemic regimes of scientific fields. Given that most processes and situations analysed by social studies of science turn out to be field-specific, surprisingly little attention has been paid to systematic comparisons of fields of research. Two common forms of avoiding the issue are investigating just one field (with the implicit hope that relevant properties do not vary within the chosen field or discipline) and the use of names of fields as symbols for differences that are not explicated.[1] Both approaches have left the sociology of science with a wealth of empirical studies which are able to state in great detail that things are this way in one field and that way in another but without any explanation as to why this is the case. However, if the sociology of science were to develop a theory of knowledge production, it would need to account for the ways in which specific types of conditions, by triggering and maintaining social mechanisms, lead to particular kinds of knowledge being produced.

Neither the idea of the sociology of science developing a theory nor the idea of comparative research into practices of knowledge production have attracted much of a following. When Richard Whitley proposed his comparative framework for scientific fields, he pointed out that the potential for comparison inherent to the Kuhnian (1962) pairing of paradigma and scientific community had not been exploited (Whitley 2000 [1984]: p. 3-5). This applies to both major strands of post-Kuhnian sociology of science. The research that built directly on Kuhn investigated social properties of fields with varying degrees of paradigmatic maturity and searched for patterns in the emergence of new paradigms and fields. This research implicitly assumed that there is one model of collective knowledge production to which all fields converge. The constructivist sociology of science followed the same pattern of combining commonality at the highest level of abstraction ('all scientific knowledge is socially constructed') with idiosyncratic descriptions of individual cases. Apart from Knorr-Cetina's (1999) attempt to draw case studies together in a comparison of high-energy physics and molecular biology, laboratory studies have not led to comparative research.

The idea of epistemic regimes – stable arrangements of practices of knowledge production and social structures in which these practices are carried out – provides the opportunity to renew the argument for comparative studies of fields of research. The concept 'epistemic regime' can be

[1] 'Single-field' studies include the 'laboratory studies' and constructivist historical reconstructions of research processes (e.g. Knorr-Cetina 1981; Pinch 1985; Latour and Woolgar 1986 [1979]; Traweek 1988; Collins 2004). Other lines of research also include many single-field studies (e.g. Morris and Rip 2006; Müller and de Rijcke 2017). Studies using names of disciplines or fields without explicitly stating comparative dimensions can be found in many areas of science studies (Guetzkow et al. 2004; Hammarfelt and de Rijcke 2015; Rushforth and de Rijcke 2015).

applied across a wide scale of phenomena ranging from disciplinary (Heilbron 2004) or interdisciplinary (Marcovich and Shinn 2014) regimes of knowledge production to small scientific fields featuring specific practices of knowledge production (Shinn and Marcovich 2009). It thus includes scientific specialties or fields as potential units of analysis whose epistemic regimes can be comparatively analysed.[2]

The aim of our paper is to develop and apply a comparative framework for the epistemic regimes of fields of research. We start from Whitley's framework and modify it in order to develop an approach that includes more characteristics of research practices and social structure, and uses characteristics that can be empirically operationalised for a fine-grained comparative analysis of epistemic regimes (2). We use data from several empirical studies for a comparative description of the epistemic regimes of experimental atomic and molecular optics (AMO physics), plant biology, early modern history, and automotive engineering (3). We discuss the comparison as proof of concept, apply it in an explanation of the emergence of individual research programmes in the four fields, and briefly discuss further applications (4). Conclusions focus on avenues for further research (5).

2. Towards a comparative description of epistemic regimes

The idea of comparing processes and structures of knowledge production has an ambiguous history in the sociology of science. Its investigation started when Kuhn (1962) took up Fleck's (1935) idea of 'thought collectives' featuring 'thought styles' and developed it into his model of particular paradigms being used by, and thus orienting, scientific communities in their 'normal-science' activities of 'puzzle solving'. This idea of specific bodies of knowledge ordering the research activities of particular collectives of researchers enabled the question as to how these bodies of knowledge and corresponding collectives differ, and how such differences could be explained.

As we noted in the introduction, this opportunity was not exploited by subsequent studies. The only comparative framework for collective-level knowledge production processes so far has been offered by Whitley (2000 [1984]). Whitley uses two main dimensions for the comparative description of scientific fields, namely the degree of mutual dependence between scientists and the degree of

[2] The concepts of scientific field, scientific specialty and scientific community have all been used to denote a group of researchers in the sciences, social sciences or humanities who work with, and contribute to, a shared body of knowledge. The shared body of knowledge is advanced by community members interpreting it, deriving tasks from this interpretation, and offering new knowledge as contributions to this shared body. Contributions are integrated through their use by other community members (Polanyi 1962; Whitley 2000 [1984]: p. 11-13; Gläser 2006).

task uncertainty. The degree of mutual dependence "refers to scientists' dependence upon particular groups of colleagues to make competent contributions to collective intellectual goals and acquire prestigious reputations which lead to material rewards" (ibid: p. 87). This dimension has two aspects. Functional dependence is "the extent to which researchers have to use the specific results, ideas and procedures of fellow specialists in order to construct knowledge claims which are regarded as competent and useful contributions" (ibid: 88). Strategic dependence is "the extent to which researchers have to persuade colleagues of the significance and importance of their problem and approach to obtain a high reputation from them" (ibid).

The second dimension, task uncertainty, also has a technical and a strategic aspect. Technical task uncertainty is the extent to which "results will be ambiguous and subject to a variety of interpretations and the use of technical procedures [is] … tacit, personal, and fluid" (ibid: p. 121). Strategic task uncertainty is the "uncertainty about intellectual priorities, the significance of research topics and preferred ways of tackling them, the likely reputational pay-off of different research strategies, and the relevance of task outcomes for collective intellectual goals" (ibid: p. 123).

According to Whitley, the two dimensions and the two aspects within each dimension vary independently of one another, presenting 16 possible combinations of these properties. Of those, Whitley considers only seven as "likely to be stable and distinct reputational systems of knowledge production and control" (ibid: p. 157), and discusses them as "fragmented adhocracy", "polycentric oligarchy", "partitioned bureaucracy", "professional adhocracy", "polycentric profession", "technologically integrated bureaucracy" and "conceptually integrated bureaucracy" (ibid: p. 158-205, see Appendix 1). These seven types mainly differ in the way their knowledge production is structured and, in current terms, in the ways authority is distributed within fields.

Whitley discusses three sets of contextual factors that affect mutual dependence (ibid: p. 104) and task uncertainty (ibid: p. 141). These include reputational autonomy, i.e. a field's ability to control skill and competence standards, the concentration of control over the means of intellectual production and distribution, and audience plurality and diversity. These factors describe internal authority structures of fields and the ways in which authority is shared with external actors.

Whitley's account is paradigmatic for the sociology of science in that it demonstrates how a comparative theoretical approach to the collective production of scientific knowledge should be structured. However, we feel it necessary to deviate from his proposal because we see a conceptual and a methodological problem. The conceptual problem concerns the level of detail at which epistemic practices are described. With the exception of technical task uncertainty, Whitley's framework focuses on variables describing the social structure of fields. This is obvious for strategic dependence and strategic uncertainty but also applies to functional dependence, which describes the mutual dependence of actors and thus an aspect of a field's social structure. This leaves technical task uncertainty as the only epistemic variable. In addition, all four variables are formulated at a high level of abstraction, which enables the construction of a manageable number of types of fields but limits the resolution of comparisons. For many research problems, it might be advantageous to start with a higher resolution, i.e. a larger number of comparative dimensions that depict more variance. Depending on the purpose of the comparison, more general categories might be built later. While this approach does not lend itself to exhaustive theoretical accounts like the one provided by Whitley, including more variance enables more fine-grained causal analyses.

The methodological problem posed by Whitley's framework is that both mutual dependence and task uncertainty appear to be difficult to use in empirical investigations. Mutual dependence is defined as the necessity for researchers to use each other's findings. This necessity can occur for a variety of reasons. Its strength is not easily established empirically, let alone compared between fields. The sociology of science can use only few empirical methods, and much of its empirical research comes down to asking researchers. However, asking researchers how strongly they depend on others is unlikely to lead to usable information because they do not have a scale, and the question is somewhat removed from their everyday concerns.

In the case of technical task uncertainty the measurement problem is confounded by the fact that this property refers to single research processes, and the technical uncertainty of a field is some average of all technical uncertainties of its research processes. This makes technical uncertainty difficult to use whenever it varies strongly between research processes within a field.[3] At the same time, it is difficult to see how field-level technical task uncertainty could be measured at all. While researchers are able to describe the levels of uncertainty involved in their work (this is an everyday concern, after all), they can do so only for their past and current research processes. For accounts of a field's uncertainty in relation to others, they again lack both a scale and the means to average observations.

These considerations lead us to the following approach. We take from Whitley mutual dependence as the central variable describing the social structure of a scientific community but disaggregate it according to the phenomena that mediate interdependence between researchers. We start from

[3] In previous empirical studies, a strong variation of technical task uncertainty was observed both within AMO physics (Laudel and Gläser 2014; Laudel et al. 2014b) and within evolutionary developmental biology (Laudel et al. 2014a).

Whitley's definition of functional dependence as the necessity to use other researchers' findings. This necessity occurs at the field level when other researchers produce contributions that change the knowledge with which a researcher works, i.e. the theories they use, knowledge about the methods they apply, and knowledge about the empirical objects they investigate. Field-level interdependence contributes to shaping the control exercised through peer review, which is another aspect of interdependence. Furthermore, collaboration patterns can be considered as a specific case of interdependence. Since interdependence may not be restricted to community members, we include the mutual dependence with external actors as external sharing of authority over research goals and approaches.

In a second step, we inductively derive from our empirical data and from the literature social phenomena that produce the various forms of mutual dependence (Figure 1).[4] The first of these phenomena are the methods used by researchers, which we define as generalised prescriptions for practices of producing new knowledge. Methodological interdependence is created by uniformity of the methods with which community members work and the frequency at which community members change these methods. The uniformity of methods depends on their genericity, i.e. the range of objects and problems to which methods can be applied (Hentschel 2015), and on the degree to which methodological knowledge is codified. The degree of codification of knowledge "refers to the consolidation of empirical knowledge into succinct and interdependent theoretical formulations" (Zuckerman and Merton 1973 [1972]: p. 507). This variable captures two aspects, namely the extent to which a field's theories have clear structures and the degree of standardization of the field's language. Applied to methodological knowledge, codification means the extent to which the knowledge is formulated explicitly and unambiguously. A field's methodological interdependence is strongest when community members work with the same methods and frequently alter them or develop new methods. When researchers work with different methods, their methodological interdependence is low. Methodological interdependence is also low when researchers work with the same methods and the rate of change of methods is low.

[4] See Gläser et al. (2010), Laudel and Gläser (2014), Whitley (2014), Gläser and Laudel (2015), Franssen et al. (2018).

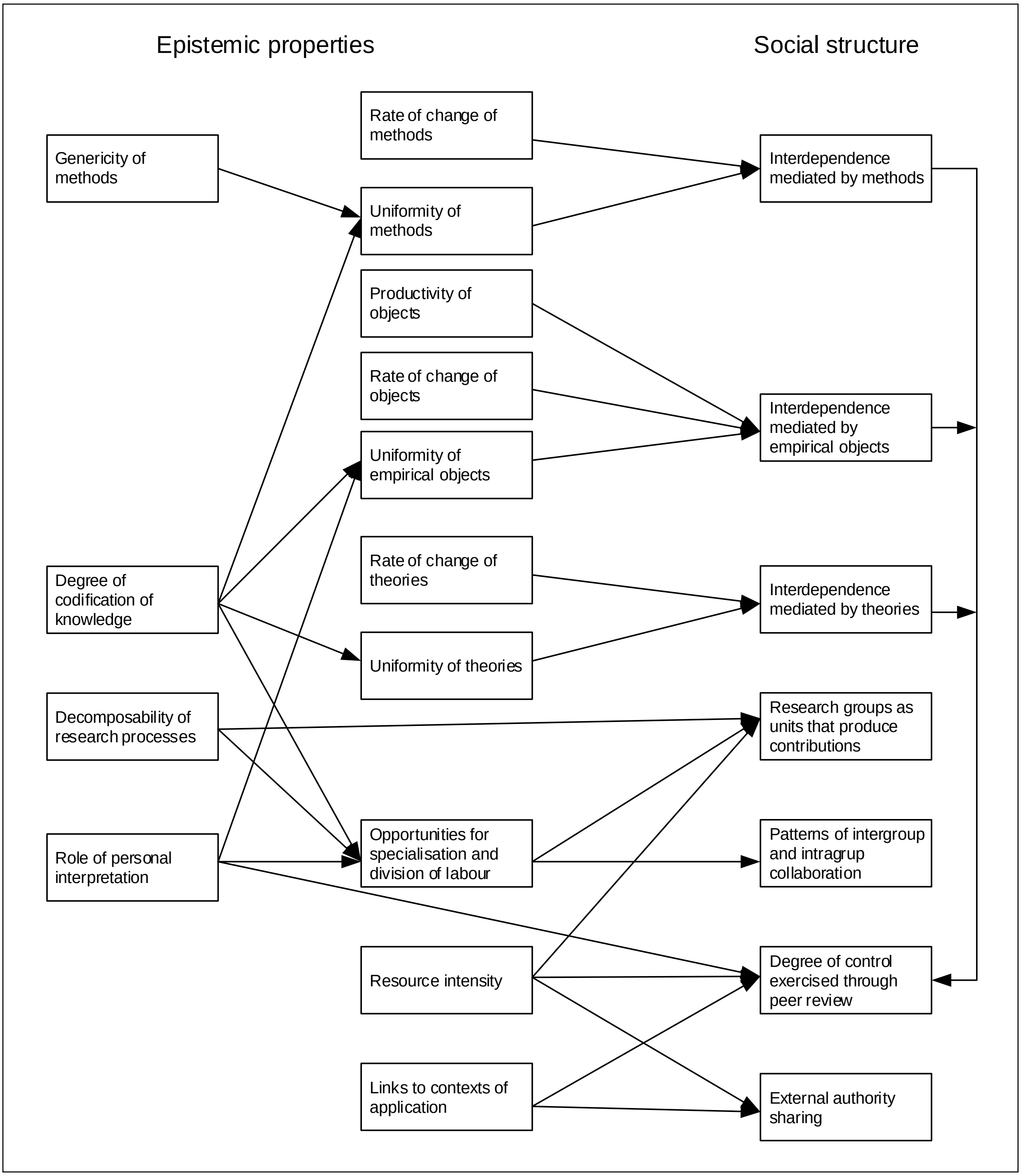

Figure 1: Links between epistemic properties and the social structure of fields

A second phenomenon that mediates interdependence is the research object. We define empirical objects as the entities that are prepared, observed, manipulated or measured in research processes in order to produce new knowledge about their morphology or behaviour. Object-based interdependence is created by the uniformity, yield, and dynamics of research objects. The yield of an object is the number of different research processes it enables. It is high when an object enables a large number of different research processes. If an object supports only a small number of research processes, its yield is low, creating strong interdependence between all researchers working with this object because anything one researcher finds out about an object limits its use for the production of new knowledge by others. The uniformity of objects describes the extent to which members of a community work with objects that are constructed as being the same. This variable is influenced by how unambiguously objects are defined. Therefore, uniformity depends on the degree of codification of knowledge. The uniformity of objects additionally depends on the role of personal interpretation in problem formulation and construction of empirical evidence, i.e. how much the formulation of problems and the construction of empirical evidence are guided by the community's knowledge and standards versus the researcher's ideas. Applied to research objects, this epistemic property describes the extent to which researchers construct their own objects rather than deriving them from the state of the art. Finally, object-based interdependence depends on the frequency of changes in objects with which researchers work, i.e. on the frequency at which definitions of objects change and the rate at which new objects are used by the field. High uniformity and high frequency of change lead to strong interdependence, as do high uniformity and low yield.

Theories constitute a third phenomenon that mediates interdependence. We define theories as explicated generalised systems of knowledge.[5] Theoretical interdependence is created by uniformity of the theories used by community members and the frequency at which community members produce contributions that change these theories. The uniformity of theories depends on the degree of codification of knowledge because the extent to which researchers work with the same theory depends on their unambiguousness. Theoretical interdependence is strongest when uniformity is high, i.e. all community members work with the same theory. This is the case if their research problems fall within the scope of this theory, if their empirical objects are instances of classes of objects defined by this theory, and if their findings are formulated as contributions to that theory. When groups of community members share different or even contradicting theories, uniformity is medium. Low uniformity means that no explicit generalised systems of knowledge are used (which does not exclude the use of isolated abstract concepts). Depending on the degree of uniformity of a field's theories, new theoretical knowledge contributed by a researcher modifies the theoretical knowledge used by all their colleagues, some of them, or none. Uniformity and the frequency at which new theoretical knowledge is offered create theoretical interdependence.

[5] This implies that phenomena which might not be considered theories by researchers in some fields are included and phenomena researchers in some fields consider theories are excluded. Otherwise, comparisons would be impossible.

Theoretical, methodological and object-based interdependence affect how widely and how strongly community members exercise control over each other's research trough peer review. The three major forms of peer review that enable the exercise of control include the allocation of resources through peer reviews of project proposals, the allocation of communication channels through peer review of manuscripts, and the allocation of positions through peer review in and for appointment committees. The strength of the first form depends on a field's resource intensity and links to contexts of application. Resource intensity describes the kinds and amounts of resources (research time, infrastructure, equipment and consumables, and materials) that are necessary to carry out a typical research process in a field. Links to contexts of application (which may provide access to resources without peer review) are shaped by the degree of uniformity between a field's problems, methods and objects and the problems, methods, and objects in society outside science (Gläser 2000).

The strength of the second form depends on the importance of publications in the field's knowledge production. The strength of the third form depends on the proportion of organisational positions that enable contributions to the field's knowledge and are controlled by peer review. It might be lower in fields were industrial researchers are members of scientific fields. The actual practices of peer review are further influenced by the role of personal interpretation in problem formulation and construction of empirical evidence. In fields with a strong role of personal interpretations, peer review might be absent or 'weak' in the sense that reviewers do not exercise much control. Low theoretical, methodological and object-based interdependencies may have similar effects where there is no competition for resources.

In addition to these field-level interdependencies, interdependencies at lower levels of aggregation vary between fields. The most important of these are local interdependencies in research groups and local or trans-local interdependencies in collaboration networks. The emergence of both forms of interdependence can be linked to the internal differentiation and specialisation of research, which requires division of labour and collaboration as a specific form of mutual dependence. Thus, opportunities for specialisation and division of labour affect the likelihood of the emergence of research groups as basic units of knowledge production in many fields.[6] Opportunities for specialisation and division of labour depend on the degree of codification of knowledge, the role of personal interpretation and the decomposability of research processes. The latter describes the extent to which research processes can be disaggregated into discrete operations which are performed

[6] Research groups can also be artificially created by allocating resources, a process that we cannot consider in this paper.

sequentially or in parallel. Together with the standardised objective description of such operations, the decomposability of research processes determines if and how different researchers can contribute to the same research process. When the necessary expertise cannot be combined within one group, researchers form trans-local collaboration networks. This is why we consider patterns of intra-group and inter-group collaboration as another dimension of mutual dependence.

The last variable describing interdependence refers to external authority sharing. It describes how external actors can exercise authority over research content (goals and approaches to solving them). This interdependence with external actors depends primarily on links to contexts of application, which make research relevant to exercise influence, and on a field's resource intensity, which affects the opportunities to exercise influence through resources.

3. Comparing the epistemic regimes of four fields

3.1 Empirical basis

We demonstrate that our comparative framework reveals important variation in epistemic properties and social structures of fields by applying it to the description of four fields we previously investigated. The data are drawn from a number of empirical studies for which epistemic properties and social structures had to be analysed in depth. Experimental atomic and molecular optics in physics (AMO physics) has been studied in a comparative project on the emergence and diffusion of scientific innovations (Laudel et al. 2014b) and in a comparative study of the emergence of individual research programmes in the early career phase (Laudel and Bielick 2018). Plant biology and early modern history have been studied in two projects on the early career phase (Laudel 2017; Laudel and Bielick 2018). Some plant biologists and AMO physicists were also included in a study on planned innovations funded by the European Research Council (Laudel and Gläser 2014). Automotive engineering was studied in a project on industry influence on scientific communities (Grieser 2018). Additional information on engineering was used from a study on the wider field of mechanical engineering (Meyer 2013), of which automotive engineering is a sub-discipline and which we deemed sufficiently similar in epistemic practices and social structures to include.

All projects were based on semi-structured interviews with professors and early career researchers, and included descriptions of what we can retrospectively consider the epistemic regimes of the fields in question. In the following description, we use interview quotes to illustrate how we drew conclusions about the variables of our framework from the interviews. This illustration is not always possible because in some cases the decision on a particular 'value' of a variable is based on a synthesis of several interviews.

3.2. AMO physics

Experimental AMO physics aims at contributing to theory by manipulating micro objects (atoms, molecules, photons) and measuring their behaviour. Research questions are derived from theory, i.e. low-energy quantum mechanics. This unified theory consists of unambiguous terms whose interrelationships are expressed by mathematical formulae and thus is highly codified, which leads to a very high uniformity – all researchers work with the same theoretical knowledge. The highly codified knowledge corresponds to a very low role of personal interpretation in the research process. By integrating their results into this theory, researchers frequently change it, which also means that AMO physicists need to constantly observe theory developments in their scientific community (e.g. by reading the newest theoretical concepts and empirical results in the pre-print server arXiv) and adjust their research accordingly. Consequently, the interdependence mediated by theory between its community members is very high. Research problems derive from the highly codified and hierarchical theory. There is usually consensus about which problems should be solved next.

Many different research questions can be addressed investigating the same object (e.g. ultracold rubidium atoms). Objects can be manipulated in many different ways (e.g. by putting them into an optical lattice or in a resonator), and can be studied in different interactions (e.g. atoms with atoms, atoms with light). Hence, the yield of objects is high. Empirical objects are selected for their suitability for specific manipulations but especially for their theoretically relevant properties (e.g. being bosonic or fermionic), which further increases the interdependence mediated by theory. The uniformity of objects is also high because atoms and elementary particles are assumed to be the same in all scientifically relevant aspects in all laboratories. The kinds of empirical objects used change only slowly (low rate of change), usually when new objects become experimentally accessible. However, due to the high yield of objects, the object-based interdependence of AMO physicists is low. Researchers observe each other's choice of objects but rarely adapt to others' choices.

Experiments are designed specifically to answer theoretical research questions. In order to answer a small set of interrelated research questions, researchers realise new conceptual approaches by combining methods for manipulating objects and measuring their behaviour in one integrated new experimental setup. Building such a complex experiment usually takes several years, and the whole research process takes at least five years.

> Well, in general it works like this. You first build an experiment, which in our case is quite a large setup where several people construct different aspects. Thus, the experiments in our lab are extremely technology-heavy, are very complex experiments, probably the most complex experiments that still take place in a single laboratory.

The micro objects and their properties are produced by applying sophisticated technologies such as laser cooling, magneto-optical traps, vacuum technologies, and electronics. The individual methods or technologies combined in the experiment are generic, i.e. they can be (and are) used in many different experiments. The uniformity of these methods is high. At the same time, the generic technologies are combined in the experimental setup in a way that is specific to a set of research questions, and are further adapted to each specific research question. Thus, while the genericity of methods is high, the genericity of the experimental setups that integrate them is low. These contradicting features also apply to the rate of change of methods, which is high for each individual method but lower for the experimental setups in which they are integrated. Overall, the methodological interdependence of AMO physicists must be considered medium because the frequent improvements of single technologies influence a large number of community members but the influence is moderated by the slower pace of change of experimental setups.

All technologies that constitute the experimental setup have to be controlled at the same time and at the same place. Therefore, the degree of decomposability of research processes is low. Decomposability is also low because the micro objects to be studied are an integral part of the experimental setup and all measurements are made there.[7] The only steps that can be singled out and performed by other researchers are theoretical calculations for building experiments and interpreting results. Thus, there is little specialisation and division of labour among experimentalists but a strong specialisation and division of labour between theorists and experimentalists.

The simultaneous control of many properties/technologies and the complexity of the experiment require a collaborative effort. Research processes in AMO physics are socially structured around a small group of researchers, consisting of the group leader, two or three PhD students and (preferably) a postdoc who work closely together. The group leader makes dominantly conceptual contributions, while the other group members build and run experiments. However, due to the importance of theory, group members are involved in developing conceptual ideas as well. External collaborations only occur when theoreticians directly contribute to the experiment.

Research processes in AMO physics are very resource intensive. They require equipment (e.g. laser, vacuum chambers, optical and electronical devices) of about half a million to one million Euros and usually at least two researchers to run the experiment, additionally to the group leader.

[7] Neither can the objects be carried around to other groups for measurement (as in biology) nor can additional methods be added to the apparatus (as in high energy physics).

There is a high degree of control through peers in decisions on publications, research positions, and funding. The elite seems to play a crucial role in defining research problems that should be tackled next. However, there is no evidence that it controls the community through peer review. Other authorities play hardly any role because AMO physics is not linked to contexts of applications, thus external authority sharing does not exist.

This epistemic regime is reproduced by the selection of research programmes and researchers who conduct them, in which the community is strongly involved at several stages. An individual research programme consists of a design for an experimental system that can answer a set of theoretical questions. Its originality is secured by the researcher through close monitoring of the literature, monitoring of other groups, and through the discussion of ideas with peers. Realising the design requires substantial investments, which the community decides upon in peer review processes on group leader positions and academic positions that control substantial resources. This creates a tight link between the quality of the first research programme and the continuation of the researcher's career. The approval of the first research programme of an early career researcher by the community is necessary for the continuation of their career. With the selection of a research programme that differs in content but is similar in its epistemic practices, the main epistemic features and interdependencies are reproduced.

3.3. Plant biology

Plant biologists focus on answering research questions about cellular and molecular processes in plant cells by studying 'interesting objects'. 'Interesting objects' are genes, proteins, cell types or plants whose properties enable the empirical investigation of a particular process. They are produced by breeding plants, creating mutants of plants or plant cells in trial-and-error searches and screening them for properties that enable the study of particular processes. A single research process usually takes at least three years. Owing to the high uncertainty of experimental outcomes, research processes may take longer.

The set of research questions that can be answered by investigating such objects is limited and largely standardised. Questions commonly address the functions of genes and mechanisms at work at different levels of the plant. These questions are currently answered by plant biologists for a large variety of objects. In contrast to AMO physics, plant biology does not feature a unitary theory but works with a collection of usually disconnected models of cellular processes. These models inform the selection of research questions and the interpretation of results to some extent. However, research is also guided by empirical hypotheses and by empirical information on homologs (structurally similar genes, proteins, etc.) with known functions, which can be obtained from databases.

Plant biologists formulate their knowledge in unambiguous terms. The degree of codification and the uniformity of theories in plant biology can thus be described as medium. The rate of change of theoretical development is low. New knowledge is either accumulated in form of claims about single molecular mechanisms, or it is purely descriptive.

We can mechanistically explain cell behaviour, in a few cases, in specific cases under certain conditions, but we can explain cellular behaviour from the dynamic interaction of proteins. We do not need other things for that. This is extremely difficult and technically very demanding. It does not work in all cases. Some things still are just too complicated for us.

For these reasons, interdependence mediated by theories in plant biology is medium. Personal interpretation plays no role in formulating questions and very little in the interpretation of data.

Model organisms (such as Arabidopsis thaliana) play a crucial role in plant biology; they seem to provide the framework for the accumulation of mechanistic knowledge. Despite the important role of model organisms, many other organisms are studied. Furthermore, each organism provides a large number of micro objects for empirical investigations. Overall, the uniformity of objects is medium. Each object enables the investigation of only a very small number of questions (yield is low). They find themselves in a "winner takes all"-competition for objects. Once a function or mechanism has been found for a certain object and is published, all other research groups are forced to abandon their research on this object because its yield has been exhausted. The rate of change of objects is medium due to the overlay of two dynamics: on the lowest level of micro-objects the rate of change is high because researchers must constantly create new objects (mostly by mutating genes) in order to replace those whose yield has been exhausted. On higher levels of classes of genes or organisms, the rate of change is much lower. Researchers develop expertise and tools for these higher-level objects and investigate them over longer periods. Despite a medium uniformity and varying rates of change of objects, the low yield of empirical micro objects makes the object-based interdependence high. Researchers monitor their peers' research very carefully when they choose objects. Negative coordination – the avoidance of objects known to be investigated by colleagues – is very common.

> Q: Do you feel that someone could anticipate you?
>
> A: Well, that's a feeling you always have. Although I have to say that it was never as weak as it is now.
>
> Q: Oh, nice.

> A: At the moment, I have the feeling that we are quite visible by now. People know what we are doing and would not try to scoop us. Not least because we have already demonstrated that we have a big lead as far as this particular field is concerned.

Biologists utilize a large variety of methods to find new objects and answer questions about them. Most are generic methods that can be applied to many objects and for many questions. In order to manipulate these natural and quasi-natural objects, new methods are constantly emerging, and existing methods improved. Thus, the rate of change of methods is remarkably high. Research groups constantly have to observe methods developments and integrate them into their labs, hence plant biologists are highly methodologically interdependent. Plant biologists' research objects (genes, proteins etc.) are embedded in natural environments (cells, plants) which cannot be completely controlled by the researcher. This is why methods need to be adapted to these natural environments. As a consequence, the standardization of methods is limited (medium uniformity). Since methodological knowledge cannot be formally communicated through publications, this further contributes to the high degree of methodological interdependence.

A research process is highly decomposable. The manipulation and measurement of objects can be disaggregated in separate operations that can be conducted sequentially and partly simultaneously. Research objects can be moved around and be manipulated by other researchers who specialise in certain methods. This is why there are many opportunities for specialization and division of labour. Research is conducted in relatively large groups. Since it is essential to use as many methods as possible for the characterisation of an object, and because there is a large variety of methods which evolve rapidly, plant biologists have a tight intra-group collaboration structure as well as numerous external collaborations.

Plant biology is resource intensive. Researchers need access to plant breeding facilities, equipment and consumables. Authority over personnel for the daily experimental work is especially important because experiments are time-consuming, often risky, and depend on tacit knowledge.

Some of plant biology's research objects carry links to contexts of applications, particularly to agricultural industry. The degree of control through peers in terms of publishing and the distribution of research opportunities in form of positions as well as research funding is high. It is partially shared externally with industry in terms of research funding and positions for PhD students and postdocs.

Similar to AMO physics, the epistemic regime of plant biology is reproduced through the selection of research programmes that carry the major epistemic and social-structural properties of the field's epistemic regimes. Again, the scientific community is strongly involved in the selection process. The high degree of interdependence mediated by empirical objects and relatively low interdependence mediated by theory shapes the way in which early career researchers develop their first individual research programmes. The core of programme development is the search for a suitable object that can be used to answer the field's standard questions. The programme's originality is secured by monitoring other research groups and by explicit negotiations. The latter are necessary because early career researchers find the objects on which they build their research programmes while they are working as postdocs in somebody else's group. When they leave the group, they need to negotiate with the group leader the right to make this object "theirs", which literally means taking it with them. The community decides (via peer review) on the research programme and the group leader position which is necessary to realise the programme. In contrast to AMO physics, the decision is not based on assessment of plans alone. The object must be there and some preliminary work must be shown.

3.4. Early modern history

Research in early modern history aims at answering questions about societies in a specific region and in a time period within or coextensive with early modernity. The research process from the first idea to writing a monograph takes usually at least five years. Research in early modern history is primarily an empirical endeavour and theory (i.e. explicated generalised knowledge) has no guiding role in this process. Early modern historians sometimes borrow theories from other fields, such as sociology, as methodological tools (e.g. to structure their subject matter) without contributing to these theories. Single, weakly codified theoretical concepts play some role. Interdependence mediated by theory is very low. Instead, the individual perspective and personal interpretation is crucial during the whole research process. In contrast to the other fields we studied, research in early modern history is an individualised and personal activity. Owing to the crucial role of the researcher's individual perspective, early modern historians have to construct their own topic. They do not feel comfortable with topics developed by others, as the following quote from a historian who quit a position on somebody else's project indicates.

> When my boss said, this is my project, I want to do that, I would like to have someone for it, then I did that. And I think I've had a relatively convincing proposal for the job application, had been to the archive a couple of times, and so on. But that was not something I felt comfortable with. [...] ... I think that's also the approach of most historians, that you need your own topic. And thus it was not so difficult to say, I do not do that anymore. (Postdoc)

Early modern historians begin the research after their PhD by searching for a new object. For this they utilise their personal repositories of literature and archival material previously collected or newly gathered. They construct their object by delineating it thematically, regionally and in terms of a certain time period. It is rather unlikely that other historians would delineate their objects in exactly the same way; hence the uniformity of objects is very low.

> Of course, there are people who are specifically interested in this Pacific context. There are not many in Germany, a few more in Britain and France [...]. But in the precise combination that interests me – that is with a focus on media and this figure – I do not know anyone.

The historians must formulate questions about the selected object and visit libraries and archives to ascertain the availability of data. Usually a variety of questions can be addressed to that object (particularly if the sources are rich and have not been used by others), so the yield of objects is high. It is common that the research question(s) are developed during the process of collecting data and writing, which stresses again the low role of theory. Researchers may slightly change their object during the course of the research process (e.g. extending or reducing the time period) and every new research process requires a new object, hence the rate of change of objects is very high. Although we observed researchers who had to change their topic because the sources where exhausted and no new questions could be addressed, this rarely happened. Still, researchers check by reading the literature on the object to avoid such situations. Overall, the object-based interdependence of early modern historians is low. There is a certain interdependence in terms of general empirical foci, e.g. on media, law, emotions, or culture, which are more or less fashionable.

Similarly, there are certain methodological fashions, such as focusing on historical events, networks, practices, or norms. Researchers use archival sources in order to develop original arguments. Data collection is thus centred on archival work, while developing arguments consists of analysing and interpreting sources as well as developing arguments through writing. Methods in history centre on how to use different types of source material, such as letters, newspapers, court proceedings, ego documents (diaries, memoirs), images, and artefacts. The rate of change of methods is low, simply because the number of different types of sources is limited, and new types of sources are rarely added. The methods are not strongly standardised because interpretation and personal perspective play an important role in their application. The uniformity of methods must therefore be described as low. The genericity of single methods is high. All the evidence must be combined and simultaneously taken into account in the process of interpretation. Thus, it is impossible to decompose the research process, and opportunities for specialisation and division of labour are very limited. Research in early modern history is not conducted by groups, and there is no collaboration involving a division of labour. The difficulty to separate even the formulation of the research question from the subsequent research is illustrated by the following recollection of a researcher who received his PhD topic from his professor, who had secured grant funding for it:

> But I was able to shape the topic in a relatively independent way. My professor fully accepted that what I made of it differed from what he imagined. Because when you look into the [archival] sources, this just makes it clear that some stereotypes in the research literature are incorrect. And then it does not make sense to pursue these stereotypes as a guiding hypothesis.

Earl modern historians either create completely new interpretations if they describe an object that nobody had described before, or they offer a competing interpretation, which is then accepted or rejected by the scientific community.

The resource intensity is rather low: researchers only need access to existing infrastructure (archives and libraries). There are very few links to contexts of application, e.g. in the case of commissioned research on special occasions (anniversaries). Correspondingly, external authorities play hardly any role, particularly in the German context. In other countries, the control over publication opportunities (books) is shared with commercial publishers. The main publication output is the monograph and the peer review system of journal articles is rather weak, thus publishing is only weakly controlled through peer review. Due to the relatively small resource requirements for projects in early modern history, control over external research funding is marginal. Even the control over positions is limited because research in early modern history was also conducted on non-academic positions.

The epistemic regime of early modern history is reproduced by the selection of individual research programmes that construct a new empirical object which is thematically, regionally and temporally delineated and that are feasible because there are sufficient sources. The originality of the programme can be secured by checking the literature. In contrast to AMO physics and plant biology, the community does not approve the individual research programme because it accepts the relevance of the researcher's individual perspective. However, the community decides about the further career of a researcher based on the programme's success, i.e. the results of the planned research.

3.5. Automotive engineering

Automotive engineering (AE) aims at improving contemporary vehicles and automotive components. Research questions are derived from industry needs and concern the overall performance of vehicles, the improvement of individual components or certain processes in those components. The research of the AE community is thus doubly fragmented. A first fragmentation is produced by the different automotive components: those researching windshields have little in common with those researching the engine. The second fragmentation is produced by the close connection to producers of cars: researchers who work with one company's cars are separated from their colleagues by non-disclosure agreements.

The latter fragmentation is more significant because it concerns a body of knowledge that could be integrated but is not. German AE researchers depend on close connections with industry for two reasons. First, they cannot access their research objects without industry support. While they could buy a car and study its components, they actually need the developer's access to it in order to do research. With only a customer's access, they would need to reverse engineer their object before being able to study it scientifically, which is difficult, time-consuming and for some research questions even impossible. This is why AE researchers who do not collaborate with industry are rather disconnected from the state of the art of research.

Second, much automotive research (e.g. the research on engines) is extremely resource intensive, so automotive engineers are highly dependent on industry partners for financial support.

Consequently, most AE research is conducted in industry-academic partnerships. In these partnerships, automotive companies tightly control and partly suppress the public communication of research results. They want to keep performance data secret in order to prevent benchmarking by competitors. Publishing findings is not considered important by most AE researchers. If research results are published at all, details that are considered relevant for competition by the industry partners are left out.

> Hardly anyone is interested in publications in our field. That's mostly only the professors themselves. [...] The research assistants are barely interested in it, because most of them go to the industry anyway.

*

> Sometimes there are conferences where they show graphs with a curve progression and some labelled axes […], but otherwise there is no unit or size anymore. You actually cannot do anything with that.

Research results are hardly open to personal interpretation. As an engineering science, the field's language is highly standardised, and is heavily based on models and tools from other engineering branches. However, due to the lack of communication, the community's knowledge is not integrated into structured theories. This is why the overall degree of codification of knowledge must be considered medium. AE researchers use various standardised models but different models are used by different groups of researchers, and models are not changed. Consequently, theoretical interdependence is quite low, although the ongoing improvement of vehicles certainly indicates high dynamics concerning automotive knowledge. This knowledge, however, does not constitute a shared, publicly accessible body of knowledge of a community.

In AE research, the rate of change of methods is high but their genericity is low. The methods applied in AE research depend on the specific set of research equipment used in the AE laboratory, which is usually donated by the firms whose engines are being studied. Not surprisingly, new methodological knowledge is mainly exchanged in collaborations with firms.

> There are methods, well working methods. […] How do I operate an engine test stand efficiently? How do I use emission measuring techniques in an exact and reproducible way? […] Some industry partners have 50 or even 100 engine test stands and operate them 24 hours a day. […] They develop working methods for those test stands, certain evaluation methods, that we can also use to our benefit. […] In many publications you have basic descriptions, but the actually important details are not included.

The research heavily relies on highly standardised models and tools from other engineering fields. These methods are sometimes shared in pre-competitive research consortia, in which several firms and AE researchers collaborate. However, the uniformity of methods is low for industry collaborations because methods are firm-specific, or are believed to be firm-specific because little methodological knowledge is published. Despite the indirect proliferation of new methods through firms, a low degree of methodological interdependence is assumed.

The object-based interdependence is also rather low, despite the high rate of change of objects through constant development by automotive companies. A variety of questions can be answered with one research object depending on the equipment that is used, so the yield of research objects is high. However, the uniformity of concrete research objects is low as research possibilities depend on access granted by a certain firm to their specific vehicles and components. Therefore, even AE researchers who collaborate with the same firm on the same component may still work on different research objects, and there is no link between researchers based on studying similar research objects.

AE research is organised in groups that differ enormously in size, ranging from large groups of 60 and more researchers that are hierarchically structured like companies (with ‘thematic groups’ as subgroups) to smaller groups of three researchers. Opportunities for specialisation and division of labour are limited. Overseeing and maintaining specific research infrastructure like engine test facilities is a specialised role. Otherwise, projects are mostly small and conducted independently of each other.

Inter-group collaboration is rare. The collaboration structure in AE is mostly characterised by industry-AE-pairs which tend to form long-term research partnerships. This makes AE groups self-sufficient, and the required secrecy prevents most inter-group collaborations. Furthermore, funding for collaborative endeavours between two AE groups would require a budget for two groups but industry usually only funds one:

> When I want to do a project with a colleague, then he must secure some funding as well. I would need a doubled budget, [doing collaborative projects] frequently fails because of this. […] We are so reliant on external funding, […] if we had a higher budget from the university, then we could collaborate more.

The high reliance on the industry is also clearly visible in the distribution of authority in AE. The fact that the interdependence in AE is low in almost all respects leads to a low to non-existing control over each other’s research through peer review. There are few publications, and with the exception of two German AE journals, there is no peer review of publications. Publications are primarily conference papers without peer review. Since industry partners provide most resources for research, they also review the project proposals. Peer review in AE seems to be restricted to the appointment process. Hence, control exercised by peer review is very low.

External authority sharing is strong and occurs through several channels. As any academic automotive engineer depends on the industry for funding as well as access to a research object, research opportunities are effectively distributed by firms. Because industry careers are a de facto standard in AE, automotive companies have some influence on positions in AE research and strong influence on (future) AE professors concerning their collective identity, their research directions, and their general socialisation as automotive engineers.

> We primarily do what the industry wants. We see ourselves as research service providers for industry. It is important that the service we offer meets the needs of the industry. The money from the state we get anyway. For funding from producers we must apply.

Because of AE groups' dependency on industry partners, the latter can enforce different stipulations like the withholding of publications or strict instructions on how to anonymise the results. Even with publically funded consortium research projects, firms exercise some authority. Industry representatives are board members of public grant agencies, and firms often initiate consortia. This effectively makes automotive companies coordinators of publicly funded consortium research, with the opportunity to select members of research consortia. Furthermore, many firms organise relevant conferences and influence which AE researchers are admitted and to whom conference papers are made available.

The epistemic regime of AE is reproduced through interaction with industry. There are two mechanisms at work. The first is 'deployment'. As practical experience in the industry is an important factor in the appointment of new engineering professors, there are no pure academic careers for AE researchers. A career phase in industry is the de facto standard for an academic career in AE. This means that firms effectively send researchers to universities, who then become their collaborators. Because of industry careers, (future) AE professors import the relevance structure of the industry and hence reproduce the links to application and the external authority sharing of AE. As professors, the automotive engineers also bring along their industry contacts from their former employer, which they use to initiate research collaborations with the industry, thus reproducing the collaboration structure of AE. The second mechanism is equipment. Since universities are unable to fund the expensive test stands used for research on engines, these are financed or sometimes even donated by industry, and are usually 'inherited' by new professors from their predecessors. This means that automotive companies exercise control over research programmes through providing or withholding research opportunities.

4. Applications

The purpose of a comparative framework is to support the answer of research questions by systematically capturing relevant variance. At the beginning of its life, demonstrating this function is always difficult because it has not been applied in empirical investigations. While several variables we use in our comparative framework have played an important role in previous studies (Laudel and Gläser 2014; Whitley 2014), the framework for the comparison of epistemic regimes did not. In this section, we consider three applications of our comparative framework. First, we interpret its application to the four fields in the previous section as 'proof of concept', i.e. as a demonstration that it can be used in empirical research and produces detailed comparative information. Second, we discuss the variation between processes by which individual research programmes emerge and show that differences between the four epistemic regimes explain why the individual research programmes have field-specific forms and emerge in field-specific ways. Third, we look at published research questions of science studies and discuss possible contributions of our empirical framework.

Proof of concept

Our application of the comparative framework to four fields of research demonstrated that a) the characteristics can be empirically determined, i.e. derived from interviews with researchers about their research, and b) that the fields do vary in the dimensions of the framework. Although the independent variation in some epistemic dimensions still requires complex decisions like 'this field features low object-based interdependence', the bases of these decisions can be located in the empirical material. The table in Appendix 2 compares the four fields in all dimensions. It demonstrates that there are differences between fields in all dimensions, which means that at least for now, none can be considered redundant. The selection of dimensions for concrete comparisons depends on the research question for which the comparison is conducted.

A closer look at the social structure of the four fields – the variables concerned with interdependence – illustrates advantages of a more fine-grained comparison (Table 1).

	Experimental AMO Physics	*Plant Biology*	*Early Modern History*	*Automotive Engineering*
Interdependence				
mediated by methods	medium	high	low	medium
mediated by empirical objects	low	high	low	low
mediated by theories	high	medium	low	low
Research groups	small groups	larger groups	no group structure	groups of varying size
Patterns of collaboration				
intra-group	strong	strong	none	limited
inter-group	only with theoreticians	strong	none	only with firms
Degree of control exercised through peer review				
Publishing	high	high	low	low
Positions	high	high	medium	high
Funding	high	high	low	none
External authority sharing	none	marginal	marginal	high authority of firms

Table 1: Patterns of interdependence in the four fields

The table illustrates that although we observe a similar degree of interdependence in all three dimensions in three of the four fields, merging the three dimensions into one would obscure interesting variance and force decisions we are not comfortable to make. The decision would be particularly difficult in the case of experimental AMO physics, where the interdependence of researchers is different in all three dimensions.

However, the use of this many variables confronts us with the problem that it makes impossible the construction of exhaustive theoretical typologies. One could argue for a reduction of complexity by pointing out that in most dimensions of social structure, we see the basic difference between the sciences and the humanities. However, automotive engineering complicates the picture. Automotive engineering seems similar to early modern history, largely because its fragmentation by external influences creates a similar pattern of interdependence as the low degree of codification of knowledge and the importance of personal perspectives create in early modern history. This functional equivalence of different constellations of variables would be obscured by a less detailed framework.

In any case, we believe to have demonstrated that our comparative framework ‘works’ because it can be applied to empirical information about research fields and because it captures important differences between the fields we studied. The price for the higher resolution is equally obvious. A high-resolution framework does not lend itself to the building of exhaustive general typologies, and is difficult to use in empirical investigations because it demands extensive data collection. Both difficulties can be partially overcome by specifying the framework for each research question and by selectively using dimensions to build typologies for specific purposes.

Emergence of individual research programmes

In section 3 we identified the selection of individual research programmes as a process through which fields of research reproduce their epistemic regimes. The brief description of processes through which early career researchers develop their first individual research programmes (or through which companies implement their individual research programmes at universities) already showed these processes to vary systematically between fields. In this section, we use selected dimensions of our comparative framework to explain these processes of emergence (Table 2).

Individual research programmes in experimental AMO physics are designs of complex integrated experimental setups that are dedicated to answering specific theoretical questions. The combination of high resource intensity, limited opportunities for specialisation and division of labour and low decomposability of research processes makes it impossible for researchers to experimentally try out ideas for individual research programmes. Accordingly, the community must select them on the basis of plans without preliminary work showing that the researcher is able to realise the plans. Early career researchers prepare for developing their first individual research programmes by working on existing experiments and monitoring the literature in order to develop theoretical ideas. The high theoretical interdependence requires an adjustment of plans that avoids addressing the same theoretical questions. Since interdependence mediated by empirical objects is low and interdependence mediated by methods is medium, observation of the community through the literature as well as conference and personal communication is sufficient. Since everything depends on the selection of the research programme by the community, researchers discuss their ideas with peers to make sure their plans are appealing.

	Experimental AMO Physics	*Plant Biology*	*Early Modern History*	*Automotive Engineering*
General epistemic properties				
Role of personal interpretation	low	low	high	low
Decomposability of research processes	low	high	low	high
Opportunities for specialisation and division of labour	limited	many	very limited	limited
Resource intensity	high	medium	low	high
Links to contexts of application	weak	medium	weak	strong
Interdependence				
mediated by methods	medium	high	low	medium
mediated by empirical objects	low	high	low	low
mediated by theories	high	medium	low	low
Degree of control exercised through peer review				
Publishing	high	high	low	low
Positions	high	high	medium	high
Funding	high	high	low	none
External authority sharing	none	marginal	marginal	high authority of firms

Table 2: Impact of epistemic regimes on the emergence and selection of individual research programmes (Variables affecting the content, emergence and selection of individual research programmes are shaded.)

Individual research programmes in plant biology are plans for a series of experiments that answer standard questions about a new empirical object. The combination of many opportunities for specialisation and division of labour with the high decomposability of research processes enables the search for these objects during the work on other topics in research groups. However, the high interdependence mediated by objects makes the use of objects constructed in other researchers' groups for one's research programme a matter of negotiations about 'ownership' of the object. The combination of many opportunities for specialisation and division of labour, a high decomposability of research processes, and high interdependence mediated by methods and objects makes the community expect preliminary work that demonstrates the feasibility of the programme with the application for funding.

Individual research programmes in early modern history are plans for answering questions about an individually defined object. The important role of personal interpretation, the low resource intensity and the relative unimportance of peer review make the process of developing an individual research programme an individual activity of historians that is largely decoupled from everything else. Consequently, individual research programmes are developed on positions that have no connection to the content of the programme, sometimes even on non-academic positions. Peer review does not play a role in the selection of individual research programmes.

Research programmes in automotive engineering concern research on objects that are developed and given to researchers by industry with methods that are based on technologies also given to researchers by industry. They are effectively established by the industry partners in university-industry collaborations. The high resource dependency of the field, the low interdependence between AE researchers, the strong links to contexts of application and the high authority of industry let the latter implement the field's research programmes.

To conclude, a major process of field development – the institutionalisation of research programmes – can be at least partly explained by the differences between epistemic regimes in the selected comparative dimensions. This explanation has already been used for the first three fields, albeit without explicit reference to epistemic regimes (Laudel and Bielick 2018). The exercise also suggests why the framework needs to be rather complex. Some variables may play a role only in some fields but must be included in order to keep the comparison systematic.

Further possibilities

Although we have not conducted further investigations using this comparative framework, we can point to some lines of research in which a comparative framework for scientific fields may support causal analysis.

First, although much research has been conducted on the impact of evaluations on research practices (Gläser and Laudel 2016: p. 129-134; De Rijcke et al. 2016), there are only few studies that take field differences into account (Leišytė 2007; Gläser et al. 2010). In these attempts to comparatively assess the impact of evaluations on research, epistemic dimensions for comparisons were derived from the empirical material ad hoc by categorizing epistemic properties that co-varied with responses to evaluations. We would like to point out several variables in our comparative framework that are likely to contribute to field-specific responses.

- Performance-based funding is likely to affect researchers differently depending on the resource intensity of their fields and the amount of university funding for research distributed according to performance criteria. Empirical studies in Australia and Germany found researchers in resource-intensive fields to largely ignore performance-based funding schemes because they did not make a difference. The resource requirements of these fields were at least one order of magnitude higher than the amounts paid through performance-based funding schemes (Gläser et al. 2008; 2010)

- Resource intensity, the degree of codification of knowledge, opportunities for specialisation and division of labour and interdependencies affect the opportunities for researchers to adapt to expectations inscribed in evaluation schemes. For example, low codification of knowledge is associated with book-length publications which are usually undervalued in performance evaluation schemes. At the same time, a non-normalised use of external funding as a performance indicator rewards scholars for the resource intensity of their field. At the Technical University Berlin the combination of both features creates a situation where humanities scholars could counterbalance their disadvantage in resource intensity by writing 15 monographs each year. Epistemic regimes also determine the extent to which researchers can adapt their publication practices to performance evaluation schemes. In fields with high interdependence, access to publication channels strongly depends on the potential influence of findings on other researchers, which means that publishing the same results elsewhere (e.g. in journals with higher impact factors) is often impossible.

Second, the comparison of epistemic regimes may contribute to explaining particularities of career paths in some fields. For example, phases of unemployment or non-academic employment may be integrated in researchers' careers in some fields. The possible duration of such phases and consequences for the subsequent career are likely to depend on resource intensity and the decomposability of research processes, which determine the opportunity of separating research activities that do not require access to infrastructure or equipment.

Third, the variation of data sharing practices across fields is likely to depend on resource intensity, degree of codification of knowledge, and researchers' interdependence. The relationship is not entirely clear, and empirical research is urgently needed in light of ubiquitous political demands for more data sharing. The degree of codification of knowledge is likely to affect the possibility to decontextualise data, which is a prerequisite for sharing them. Resource intensity might further data sharing when access to large data producing facilities is scarce (e.g. in Astronomy and High Energy Physics). The interdependence of researchers might further data sharing if it creates a need for replication but might hinder it if it increases competition.

These examples illustrate the importance of field-comparative research for answering causal questions in the sciences, many of which have some relevance for science policy because the latter tends to apply one policy uniformly across all fields. They also illustrate the potential of the comparative framework we propose because selected dimensions of this framework appear to contribute to explanations of the observed variance.

5. Conclusions

Our experiment with a framework for field-comparative empirical research leads to three conclusions. First, a link between empirical studies and theory building in the sociology of science is still difficult to create and maintain. While this can be said for all of sociology to some extent, the sociology of science faces a specific difficulty because its theory building needs to reduce the complexity of causal factors that are not under its theoretical control, namely properties of knowledge and the material world researchers deal with in their work. Our focus on empirical operationalisation led to a complex array of factors, which do not easily lend themselves to reduction by abstraction because they vary independently of each other. We need more empirical studies that are theoretically guided and focus on contributions to theory to build foundations for a systematic reduction of complexity.

Second, we demonstrated the importance of including epistemic regimes in explanations of field-level processes. The variance of epistemic properties and interdependencies between researchers makes it extremely unlikely that processes studied by the sociology of science are the same in any two fields. Fields might not be the unit of analysis in all cases. It is likely that epistemic regimes can be grouped into types, and that purpose-built typologies operate with fewer types depending on the aspects of epistemic regimes that are relevant. However, it is difficult to imagine explanations in the sociology of science to be accomplished without systematically including the content of researchers' work and the social structures in which it is conducted.

Finally, we would like to suggest that the notion of epistemic regimes can be extended beyond research. The notion of epistemic regimes is based on the idea that there is a correspondence between some aspects of the content of work and some aspects of the social structure in which it is conducted. This notion might be an interesting tool for comparisons with non-organisational production regimes, i.e. for comparing research with open source software production or with the arts.

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Appendix 1 Seven stable arrangements of knowledge production identified by Whitley

<table>
<tr><td colspan="4" rowspan="4"></td><td colspan="4">Degree of functional dependence</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">High</td></tr>
<tr><td colspan="2">Degree of strategic dependence</td><td colspan="2">Degree of strategic dependence</td></tr>
<tr><td>Low</td><td>High</td><td>Low</td><td>High</td></tr>
<tr><td rowspan="4">Degree of technical task uncertainty</td><td rowspan="2">Low</td><td rowspan="2">Degree of strategic task uncertainty</td><td>Low</td><td></td><td></td><td>Technologically integrated bureaucracy</td><td>Conceptually. integrated bureaucracy</td></tr>
<tr><td>High</td><td></td><td></td><td>Professional adhocracy</td><td>Polycentric profession</td></tr>
<tr><td rowspan="2">High</td><td rowspan="2">Degree of strategic task uncertainty</td><td>Low</td><td></td><td>Partitioned bureaucracy</td><td></td><td></td></tr>
<tr><td>High</td><td>Fragmented adhocracy</td><td>Polycentric oligarchy</td><td></td><td></td></tr>
</table>

Source: Combination of Tables 5.1 and 5.2 from Whitley (2000 [1984]: 155, 158)

Appendix 2 Comparison of epistemic regimes of four fields

	Experimental AMO Physics	*Plant Biology*	*Early Modern History*	*Automotive Engineering*
General epistemic properties				
Degree of codification	high	medium	low	medium
Role of personal interpretation	low	low	high	low
Decomposability of research processes	low	high	low	high
Opportunities for specialisation and division of labour	limited	many	very limited	limited
Resource intensity	high	medium	low	high
Links to contexts of application (degree)	low	medium	low	high
Methods				
Genericity	methods: high experimental setup: low	high	high	low
Rate of change	medium	high	very low	medium
Uniformity	methods: high experimental setup: low	medium	low	low
Objects				
Yield	high	low	high	high
Rate of change	low	medium	high	high
Uniformity	high	medium	low	low
Theories				
Rate of change	high	low	low	low
Uniformity	high	medium	low	low
Interdependence				
mediated by methods	medium	high	low	medium
mediated by empirical objects	low	high	low	low
mediated by theories	high	medium	low	low
Research groups	small groups	larger groups	no group structure	groups of varying size
Patterns of collaboration				
intra-group	strong	strong	none	limited
inter-group	only with theoreticians	strong	none	only with firms
Degree of control exercised through peer review				
Publishing	high	high	low	low
Positions	high	high	medium	high
Funding	high	high	low	none
External authority sharing	none	marginal	marginal	high authority of firms

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