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Anticipatory Uncertainty: How Academic and Industry Researchers in the Life Sciences Experience and Manage the Uncertainties of the Research Process Differently

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ABSTRACT



The institutional contexts of research increasingly require researchers to anticipate their productivity and the uncertainties inherent in their research. This applies to both academic researchers and to researchers in start-up companies. This creates a specific kind of uncertainty, anticipatory uncertainty, that we define as the state of being uncertain as to whether research processes will be productive in a specific time frame and along situated definitions of good performance. In the life sciences, this anticipatory uncertainty is experienced and managed differently, depending on how research is organized and the cultural resources available in specific institutional contexts. In biotechnology companies, there is a readiness to embrace dynamic changes in both research strategies and the organization of work in response to new developments in the progress of the overall research agenda. In academia, the ability of research groups to react with similar flexibility seems significantly constrained by the individual attribution of research work and credit, and the correspondingly high level of individual anticipatory uncertainty. This raises questions about how far the current organization of academic research allows epistemic uncertainty to be embraced and corresponding risks to be taken, rather than safe questions to be pursued.

KEYWORDS

Uncertainty; life sciences; comparison; research management; anticipation; work organization; biotechnology (business)

Introduction

‘Pressure to publish in journals drives too much cookie-cutter research,’ *The Guardian* reported in 2017 (Anonymous, 2017). The article provocatively argued that universities are generating ‘banal and wasteful research’ by defining and measuring academic performance only by publication numbers.

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Echoing voices in the academic literature (e.g. Fochler *et al.*, 2016; Müller and de Rijcke, 2017), the author criticized the current conditions under which research is done and careers are developed, which encourage the rapid production of predictable results rather than aiming at findings that are innovative, useful to society, or both. In a similar vein, eminent life scientists in the USA have publicly expressed concerns regarding how the long-term intellectual health of their fields is being affected by competitive pressures that drive researchers to pursue safe questions rather than to think outside the box and take the corresponding epistemic risks (Alberts *et al.*, 2014).

The tightening of systems of measuring, evaluating and managing researchers' performance as well as the fostering of competitive dynamics are central aspects of the changes in the organization of research work along New Public Management (NPM) lines (Gill, 2014; Mirowski, 2011; Shore, 2008). These changes not only compel researchers to monitor and report their performance, but constant competition and regular evaluations of projects and positions require researchers to anticipate how their work will develop and, in particular, which accountable outputs it will deliver (Felt, 2017; Müller, 2014; Murphy, 2015; Ylijoki and Mäntylä, 2003).

Some authors have argued that the production of academic knowledge is increasingly converging with cultural patterns of the business world (Vallas and Kleinman, 2007). Indeed, the call to perform and to anticipate applies to researchers in a start-up company who need to plan the next milestone on their development trajectory (Birch, 2017; Fochler, 2016a; Shapin, 2008), as well as to academics who are often expected to anticipate the output of their work in specific timeframes by funders and administrators (Felt, 2017; Sigl, 2016).

Under these conditions, the anticipatory management of the productivity of their own research processes becomes a challenge for researchers at virtually all career levels (Fochler, 2016b; Müller, 2014; Sigl, 2016). This produces a specific kind of uncertainty that researchers need to manage – 'anticipatory uncertainty.' We define anticipatory uncertainty as the state of being uncertain of whether research processes will be productive in a specific timeframe and of how a specific institutional context defines performance and the quality of research work.

Anticipatory uncertainty thus refers to the epistemic processes in which knowledge is produced and to the anticipated productivity in a specific context of research organization. Rather than being concerned with uncertainties of the knowledge itself (Hollin, 2017; Knorr-Cetina, 1999; Star, 1985), it captures the entanglement of epistemic uncertainties and social uncertainties related to funding and careers.

Comparing the ways in which this entanglement is experienced and managed in academia and biotech start-ups, we analyse how the cultural resources available to actors to manage uncertainty are related to how research is organized in specific institutional contexts (Neff, 2012; Star, 1985). We ask the following questions: How do researchers in different institutional contexts in the life

sciences experience and manage uncertainty about the future productivity of their research in a specific time frame (i.e. anticipatory uncertainty)? How are uncertainties related to epistemic processes and uncertainties related to funding and careers entangled in these anticipatory practices?

The two institutional contexts we compare – academic life science laboratories and start-up biotechnology companies – share similar epistemic approaches but differ strongly in their institutional organization. Our comparative optics helps us to show not only the specific ways in which work is organized but also the corresponding cultural assumptions and values that guide the ways in which researchers experience and manage the uncertainty surrounding the future productivity of their research.

We proceed by discussing three relevant lines of literature: uncertainty in scientific practice and culture, recent changes in the governance and organization of research, and anticipation as a growing cultural practice. We then describe our comparative approach, material, and methods. The main part of the paper is a detailed empirical account of how researchers in the two contexts anticipate, experience and manage the uncertainty of future productivity of their research processes. Our analysis shows very different ways of experiencing and managing epistemic uncertainty and links this to different forms of organizing research work and attributing the responsibility to address uncertainty and its consequences. We conclude by discussing how the organization of research work, particularly in the academic life sciences, affects researchers' capacity to productively embrace epistemic uncertainties in their work.

Analytical Framework

Our argument builds on and links three areas of research. First, we survey the existing literature on uncertainty in research practices, which focuses on variants of epistemic and ontological uncertainty but only rarely links the perception and management of these uncertainties to current institutional changes. Second, we draw on work on contemporary cultures of knowledge production and how they are changed by organizational reforms. While much of the literature in this domain has explored the important role of evaluation and audit regimes for research work, few contributions have pointed to the role of anticipating and attempting to manage both epistemic and social uncertainties in the conduct of research. To address this, we draw on the literature examining how the anticipation of the future governs the conduct of social actors in the present and develop the notion of anticipatory uncertainty.

Uncertainty in Scientific Practice and Culture

Uncertainty is a key topic in many areas of research in Science and Technology Studies (STS). This work addresses how the inherent uncertainties of scientific

knowledge and technological solutions challenge contemporary societies and their governance (Beck, 1992; Callon *et al.*, 2009; Gross, 2010). Other lines of enquiry focus on specific sub-aspects of this larger question; that is, the role uncertainty plays in the public communication of science (Mellor, 2010), or the deliberate strategic production of uncertainty by specific, particularly corporate, actors (McGoey, 2009). Our argument engages with a line of literature in STS that focuses on the role of uncertainty in scientific practices and cultures.

The uncertainty, contingency and messiness of scientific practice has been the central topic of the first wave of laboratory studies in STS, as has been the question of how uncertainty is erased as knowledge travels from the lab to scientific or public communication platforms (Knorr-Cetina, 1981; Latour and Woolgar, 1979). This notwithstanding, there is very little explicit attention to the concept of uncertainty in this early literature. Star's (1985) paper is a major exception to this. Focusing on how scientists transform local uncertainties into global certainty, Star described a range of types of uncertainties researchers face; some, such as taxonomic uncertainty, rather relate to epistemic actions, while others, such as political uncertainty, relate to societal and organizational contexts. Star described the management of uncertainty as not only central to research organization but also as rooted in specific forms of work organization, including both the organization of local daily work as well as larger political and institutional contexts.

Studies on understanding differences between cultures of knowledge production in different scientific fields have also touched on the differing role of uncertainty in these cultures. Whitley (1984) argues that the degree of task uncertainty, i.e. the uniformity, stability, and integration of specific task outcomes and wider research strategies, varies between fields and is strongly correlated with their respective social organization. His central interest is in how far fields are capable of standardizing processes and strategies of research and how this affects patterns of cooperation, theory building, and research evaluation. In her comparative study of high-energy physics (HEP) and molecular biology, Knorr-Cetina (1999) draws particular attention to how different epistemic cultures develop distinct forms of living and working with epistemic uncertainties. She describes HEP as a field in which identifying, understanding and minimizing uncertainties is a high priority. In contrast, she argues that in molecular biology epistemic uncertainties can remain unexplored due to the field's emphasis on making things work. Uncertainties linked to anticipating research processes and their outputs only play a marginal role in both Knorr-Cetina's and Whitley's work.

While uncertainty in scientific practice has been a rare topic in more recent literature in general, a number of papers have addressed uncertainty work in the study and diagnosis of mental disorders (Hollin, 2017; Pickersgill, 2011). For example, Hollin (2017) analyses how researchers reflect and manage uncertainty in autism research and how they relate it to both epistemic uncertainty

(related to the incommensurability of different diagnostic techniques) and ontological uncertainty (related to the question of whether autism is a uniform condition). While these studies add nuance to understandings of researchers' perception of epistemic uncertainties, they do not address the relationship to forms of work organization, or address uncertainties related to the anticipation of research productivity.

Uncertain Lives in Research: Shifting Work Organization and Uncertainties in Funding and Careers

The social organization of research has been changing considerably over recent decades, with most of the changes related to the re-shaping of academic organizations according to the logics of NPM (Gill, 2014; Mirowski, 2011; Shore, 2008). This includes new systems of research performance evaluation and monitoring, an increasingly competitive allocation of resources, the projectification of work (Torka, 2018), as well as the related temporalization and precarization of employment for large segments of the research workforce. In addition to addressing the epistemic uncertainties of the research process, researchers must increasingly address uncertainties related to whether they can secure further funding, obtain new contracts, and remain in academic research (Fochler *et al.*, 2016; Sigl, 2016; Ylijoki, 2010).

A number of studies have documented the effects of these changes on researchers' identities and health (e.g. Gill, 2014; Knights and Clarke, 2014). Moreover, observers suggest that the proliferation of social uncertainty in academia has a negative impact on researchers' ability to manage epistemic uncertainty. For example, authors have warned that hyper-competition suppresses 'the original thinking required to make fundamental discoveries' (Alberts *et al.*, 2014, p. 5774), may result in a rise in the number of published false positive results (Szucs and Ioannidis, 2017), and could increase the likelihood of misconduct in research practices (van Wesel, 2016).

Sigl (2016) argues that the project as an organizational form links epistemic (What can be studied in x years?) and social uncertainty (How will my work be funded after x years?) in ways which tacitly govern the epistemic and career decisions of early-stage researchers. Fochler *et al.* (2016) show that a hyper-competitive environment fostered by processes of projectification and temporalization leads early-stage researchers to focus more strongly on their individual productivity (defined along metrics and indicators) at the expense of other values. Foster *et al.* (2015) analyse how the connection between epistemic success and employment prospects in current research leads to conservatism in choosing research questions rather than the pursuit of high-risk epistemic innovations. While these contributions show the complex entanglements of uncertainties related to epistemic processes and uncertainties related to funding and careers, they do not discuss the role of anticipation in shaping

these entanglements. They also devote less attention to how the management of these uncertainties is related to the respective form of work organization in the specific institutional context.

The organization of research in corporate contexts has received far less attention in the literature. Shapin (2008) traces the efforts of mid-twentieth century corporate research managers to protect their researchers' freedom to engage with uncertainty against the interests of upper management. Mirowski (2011) describes a general shift in corporate research in late twentieth century biotechnology: the disbanding of larger corporate research laboratories and the rise of the academic start-up company as a new form to organize the early phase of product development. From the perspective of Big Pharma, this re-organization is mainly related to the aim of outsourcing the uncertainty of early phase development. A number of studies engage with biotechnology start-up companies as new spaces of knowledge production (Fochler, 2016a; Smith-Doerr, 2005; Vallas and Kleinman, 2007). However, while the major uncertainties of both financing (Birch, 2017; Fochler, 2016b) and epistemic development are important topics contextualizing these contributions' arguments, they do not focus on how the uncertainty of research processes is actually managed and experienced.

Anticipatory Uncertainty

Shifts in the organization of academic work change academic scholars' relation to time, particularly to the future. Anticipation, in the sense of a moral obligation to both plan specific futures and attempt to influence the conditions that may lead to their fruition, becomes central both in epistemic practices as well as in how lives are planned and spent in research (Adams *et al.*, 2009; Felt, 2017; Müller, 2014; Ylijoki, 2010). Analysing how researchers plan their research in relation to anticipated external expectations (e.g. anticipating future evaluation) is thus an analytical opportunity for studying epistemic implications of the changing social organization of research (Borup *et al.*, 2006).

On a larger scale, the promise of future achievements and effects has been described as a crucial facet of contemporary research – to the extent that promises themselves have been critically analysed as a specific form of asset and commodity in the dynamics of publishing, research funding and governance (Felt *et al.*, 2007). In the biosciences, past efforts (e.g. Human Genome Project) have been held accountable for their failure to live up to the outcomes promised in a specific timeframe (Gisler *et al.*, 2011). Critical analysts have argued that large parts of the biotechnology industry are characterized by a financialized regime focused on managing the future of potential innovations (Birch, 2017; Mirowski, 2011).

In academia, anticipatory practices have become central for individual researchers as well as for research groups. Genres of proposal writing and project auditing demand the anticipation of epistemic processes, results and

output. In addition, career norms and individual institutional evaluations require researchers to plan and anticipate their own future performance (Fochler *et al.*, 2016; Müller and de Rijcke, 2017). Strathern (1997) has argued that researchers internalize the anticipated auditing of their work and the associated norms. Through this, the anticipation of the future in turn governs researchers' actions in the present in the sense that they act in ways they deem necessary to optimize their chances of attaining a specific outcome.

These dynamics also seem likely to produce new forms of uncertainty. As discussed above, most STS work on uncertainty in research thus far has focused on forms of epistemic or ontological uncertainty, that is, on the uncertainty of how well specific scientific practices will produce reliable results or correspond to the natural or social processes observed. The future mostly plays a marginal role in the described strategies, and if, such as in Star's (1985) strategy of 'temporal segmentation,' it is as a discursive resource to legitimate current uncertainty under the assumption that more certainty will be possible in the future, due to technological progress or other reasons.

We argue that the particular anticipatory practices required by researchers in the current organization of academic work produce a new form of uncertainty that has not yet been addressed. *Anticipatory uncertainty* is not concerned with the specific characteristics of the knowledge itself but rather with the processes in which knowledge is produced and whether these processes will be productive in specific time frames of the social organization of work and careers. In that sense, anticipatory uncertainty links epistemic uncertainties to social uncertainties (related to funding and careers).

The uncertainties of epistemic processes, such as experimentation, writing, and publishing, are central to anticipatory uncertainty in research. However, the notion of anticipatory uncertainty draws attention to how the perception and management of these epistemic uncertainties is linked to the anticipation of desirable or undesirable social futures: the renewal of funding for a research group, the attainment of tenure or the loss of a career in research.

Comparison, Material, Methods

We compare how researchers experience and manage uncertainty about the future productivity of their research in two different institutional settings – academic life science laboratories and biotechnology companies. We compare these settings following the comparative tradition in the study of cultures of knowledge production (Knorr-Cetina, 1999). The comparative optics helps to see the particular characteristics of each compared setting through the lens of the other, resulting in a clearer picture of its respective specificities. Additionally, comparison challenges the analysts to question their own implicit assumptions and what they assume to be self-evident. This is particularly important when one

of the settings compared – academia – is a setting in which the analysts themselves are embedded.

We choose to compare academic life science laboratories and biotechnology companies because in both settings, anticipatory practices play a crucial role. They share very similar epistemic approaches and methodologies but are very different in their ways of organizing epistemic work and in their value structures. This will allow us to focus on how the different ways of experiencing and managing anticipatory uncertainty in both domains relate to the way in which work in both settings is organized without having to consider strong differences in epistemic objects and approaches as a complicating factor.

We use a person-centred approach to study empirically how researchers experience and manage uncertainty. We base our arguments on the analysis of interviews that were designed to explore the ‘epistemic living spaces’ of researchers:

... the multi-dimensional structures – symbolic, social, intellectual, temporal and material – which mould, guide and delimit in more or less subtle ways researchers’ (inter)actions, what they aim to know, the degrees of agency they have and how they can produce knowledge. (Felt, 2009, p. 19)

The interviews were based on a biographical approach that included retrospective and prospective reflections of researchers’ epistemic and career development and were structured as reflexive conversations on the specificities of the researchers’ knowledge production practices and their relation to the specific institutional context. The interviews were between 60 and 120 minutes in length and were audio-recorded and fully transcribed.

We draw on 51 qualitative interviews that were conducted in 12 different academic life science research groups (between 2007 and 2009) and 20 qualitative interviews in four start-up biotechnology companies (in 2012 and 2013). In addition to these four companies, interviews with single entrepreneurs completed the sample. All interviews were conducted in Austria. On the company side, the interviews were conducted in smaller research-focused companies. Similar to typical academic research groups, they employed between 5 and 15 researchers. Researchers in different positions and career stages were interviewed in each group or company. The academic research groups were selected with the help of an expert advisory board and covered different orientations of life science research sharing a focus on molecular biology. A similar approach was used for the start-up companies. Only companies that performed active research were included in the sample.

The analysis followed an open coding process with a grounded theory approach (Charmaz, 2006). Our comparative analytical interest developed through conversations between the authors regarding how different the ways in which uncertainty in the two settings seemed to be perceived and managed.

Will This Work? Anticipating Epistemic Uncertainties in Academic Life Science Groups

The feeling that there is a need to anticipate and manage the future productivity of research was a central topic of virtually every interview we conducted in both academic life science and biotechnology laboratories and with both junior and senior scholars alike. To set the tone for exploring these uncertainties, it is useful to remember that epistemic uncertainties have a very different role in the research process in the life sciences than they do in other fields such as physics. The way Knorr-Cetina described this nearly 20 years ago still holds for the practices in most groups and companies we studied:

In a molecular biology laboratory, little is fully controlled. Lines of inquiry are continually set back because of unexplained problems; procedures that used to work in the past suddenly stop working, and approaches that looked promising lead nowhere. Most of these difficulties cannot easily be explained, and in participants' reckoning of how to use one's time, they are not worth trying to explain. (229)

Unlike physicists for example, academic researchers in the life sciences saw little purpose in exploring the reasons why their methods and experimental procedures succeed or fail, or in reflecting the epistemic uncertainty of their results. In a deeply pragmatic attitude that resonates with the often fast-paced and competitive character of many fields in the life sciences (Alberts *et al.*, 2014; Fochler *et al.*, 2016), researchers were concerned with what works and how to make things work. Why lines of experiment do not work is not a topic of interest in itself; it was only relevant if this information can become useful for making the experimental process work again. Consider how an academic postdoctoral researcher described this 'tinkering' that is at the heart of everyday work in molecular biology laboratories:

In the beginning, you think, 'OK, I'm doing an experiment and then I will know something about it.' And that's when you don't know yet, that you will eventually have to do the experiment ten times until it works, and that it is hard hands-on work, and that you have to repeat things, and that it is, in fact, a very slow process (Female, academic, postdoc)

Academic life science researchers talked about two main kinds of uncertainty related to their experimental work. The first was related to the research process itself, whether an experimental design can be successfully built to investigate their hypothesis and to produce data. For example, this could relate to whether it will be possible to establish a transgenic animal model for the correlation one tries to investigate or to crystallize the proteins to be studied. Consider how an early-stage researcher described this as follows:

There is a lot of luck involved ... we work on proteins; it's not exactly predictable whether or not it will work or not ... when you consider a few things beforehand,

you will be successful in approximately 10% of the cases – simply because there are a range of things that might not work out. (Male, academic, PhD student)

The second kind of uncertainty was related to the outputs of the experimental process; that is, the resulting data and the question of whether they will be clear and relevant enough for publication – for example, whether the effect in the project's hypothesis can be seen in the data with adequate strength. A social science analyst might call this ontological uncertainty (Hollin, 2017), meaning the uncertainty of how hypotheses turn out to be once they have been explored, as opposed to the experimental uncertainty of the research process. For our informants in the life sciences, this distinction was of little interest. In their view, both kinds of uncertainty were entangled and hard to separate. The question of whether the data were inconclusive because the experimenter's skill had not been sufficient to control all the intervening factors or because the effect they attempted to observe was simply much weaker than assumed – after sometimes months or years of tinkering with an experiment – was a question neither possible to answer nor worth answering to most of our academic informants (Knorr-Cetina, 1999).

Will This Work? Anticipating Epistemic Uncertainties in Biotechnology Companies

Our informants in biotechnology companies shared a focus on how to make things work with their academic counterparts. For example, they were concerned with whether they would be able to provide proof-of-concept that their candidate substance has promising antiviral effects in cell cultures and animal experiments; or whether these effects will also hold in initial clinical trials and not be overshadowed by unintended side effects and toxicities. It was particularly in early phases of research that process and output uncertainties were seen as similarly entangled as in academia. Maybe even more strongly than their academic counterparts, industry researchers stressed the difficulty of dealing with the uncertainty of not only whether but also when experimental work will yield productive data:

When I am at the very beginning of a project, and I don't know when I will have useful data, that's difficult. It might be that I get something done within a year; it might also be that, even in four years, I'm not in a position to proceed. (Female, industry, junior researcher)

This quote hints at the fact that, unlike in academia, in a biotechnology company even very good data are not necessarily an output in themselves. They are the basis for moving into later phases of product development, into animal experiments and later also clinical trials in which the candidate product is tested in the complex environment of the human body (Birch, 2017; Fochler, 2016a; Mirowski, 2011). While in earlier phases of this process the relation of process and

output uncertainty described by our informants resembles academia, in later phases, output uncertainty in the sense of ontological uncertainty (Hollin, 2017) is seen as more central. Even a highly effective antiviral agent can fail in clinical trials if it has unexpected unfavourable effects on humans that did not show in prior animal models – and these side effects can hardly be prevented by even the best experimental design. Consider how an experienced CEO (Chief Executive Officer) described a baseline expectation that most senior researchers in biotechnology companies shared, which is that regardless of their skills as researchers, most products (and indeed companies) would fail because their envisioned products would not work in humans:

So, in this business, everything takes a long time, and the likelihood that things are going to work in the end is very low. Basically, you burn a lot of money to show that things don't work. But if they do, then it's commercially so significant that it makes up for that. (Male, industry, senior researcher)

Can I Work? Funding and Career Uncertainties in Academic Life Science Groups

In addition to the uncertainties associated with the experimental process itself, the uncertainty of funding and employment was a central topic for our interview partners in both domains. In academic laboratories, there was a separation of who was concerned with which of these two topics. Group leaders were quite preoccupied with navigating the uncertainties of the funding process (Fochler, 2016b), while PhD students and postdocs spoke at length about career uncertainties (Fochler *et al.*, 2016; Sigl, 2016).

For all the academic group leaders we interviewed, success in acquiring project funding was seen as crucial to enable research that they considered interesting – and often to do research at all. In the Austrian university system, usually only the positions of the group leader and possibly of a few technicians are permanently funded by the university. Group leaders typically apply for project funds from Austrian and European basic research funders and, to a much more limited degree, from industry. In our dataset, the continued existence of a research group itself as an organizational unit was hardly perceived as uncertain. Cases in which entire groups and their leaders were made redundant because of a lack of success in funding and publications were perceived as the rare exception. This situation is partially explained by the fact that at the universities we observed, most groups were headed by professors or other tenured staff who legally cannot be made redundant. However, given that the funding situation had become more difficult over recent years, some group leaders worried that they would not be able to sustain a continuous operation of their group, as indicated in this quote by a tenured associate professor:

So, if I don't succeed at keeping my group above a certain critical level in terms of size, then it's over for me, then I think I'll move on to industry. (Male, academic, group leader)

Junior members of academic research groups hardly talked about the group's funding but talked at length about their own employment situation and prospects. This had two dimensions. First, all junior researchers were employed on temporal contracts, usually of two to three years at maximum. Due to legal constraints in Austria (i.e. temporary contracts can be prolonged, but, in most cases, only to a maximum of 6 years at one institution) and the perceived career norms in the academic life sciences, they assumed that staying at their current institution would be very difficult. Looking forward to their own professional futures, they had to anticipate that they would have to secure a next position in another institution and possibly another country. Competition for these positions was seen as high, particularly for those at more prestigious institutions considered to provide better conditions for an academic career.

Second, choosing an academic career trajectory was seen as highly uncertain, and as a choice that becomes riskier with every new temporary research appointment (Fochler *et al.*, 2016; Müller, 2014), as this quote illustrates:

I don't want to [be in the situation that] ... I decide on this [academic career] path and from 38, from 40 on, there is no funding, no outlook. What would I do then, right? Then, I am ... so specialized that no one can use me anymore. Really, what can I do then? (Female, academic, PhD student)

Junior academic researchers were aware of the fact that the number of faculty positions in their respective fields was much smaller than the number of researchers on temporary contracts competing for them (Alberts *et al.*, 2014). Accordingly, they assumed that their own prospects of having a longer-term academic career were highly uncertain. It strikes us as surprising that, being in this situation, only a few of our interviewees thought about career pathways outside academia or about the careers of people who had already left academia. Thus, they tacitly assumed that leaving academia resulted in difficult job and life situations:

So, I am slightly afraid of this. Me and my colleagues, we ask ourselves, where do all the postdocs go in the end? So, they obviously can't all become professors. But what happens to them? That's scary. (Female, academic, PhD student)

Funding and Career Uncertainties in Biotechnology Companies

The distribution of uncertainties in biotechnology companies was quite different; while the company itself was often perceived as at risk, individual researchers were much less concerned about their professional futures.

Biotechnology companies are high-risk projects. The chances of epistemic and commercial success are assessed as relatively small by founders and employees alike. The risky nature of commercial biotechnology poses challenges in funding company operations (Fochler, 2016a; Mirowski, 2011). In the Vienna biotechnology cluster, companies usually raise funds from different sources,

including public subsidies and loans, private investors, venture capital funds, cooperation agreements with large pharmaceutical companies, and sometimes revenue from their own products (e.g. research technologies). These different forms of funding all relate to the long-term development trajectory in the business plan, and financial contributions are tied to the milestones to be achieved. Depending on the temporal commitment of the investor, such funding agreements can be either relatively short (up to 3 years) or up to 10 years in length and may earn several tens or hundreds of million Euros in the case of success.

However, because of the milestone-logic, at any given moment, most companies will have liquidity for only a few months or perhaps a year, after which new funds must be generated or raised. Both founders and employees know that every round of re-funding carries the risk of the company's liquidation and, therefore, the possible end to both their employment and epistemic work. A senior industry researcher explained this by saying that 'in principle, if things don't work, then the firm will cease to exist ... and that makes it very different from university.' (female, industry, senior researcher).

One of the most surprising results in the fieldwork that led to this paper was the finding that despite the fact that industry researchers are usually very well aware of the uncertain funding situation of their companies, the individual experience of career uncertainty played a much less important role for them than for academic researchers. Consider the following quote:

So, yeah, risk. I mean, there's always risk. I have no idea how much money we have left here or how long we can hold out without fresh funding. And of course, I see critical points [in product development] ahead. But I wouldn't say that the risk is more or less than that in other lines of work. [...] I think the times when you worked in the same company from school to retirement are over anyway, right? (Female, industry, junior researcher)

As in this quote, most industry researchers were aware of the considerable uncertainties of their future career but saw them very differently than their academic counterparts; they did not perceive these uncertainties as an existential threat. Rather, they discursively normalized the experience of this uncertainty by stressing that, in the current economy, no one could expect lifetime employment with one company. This was often based on the observation of past failed companies in the cluster and of the founders and employees of these companies who had moved on to new opportunities. Partly, industry researchers' more relaxed way of talking about career opportunities may be related to this more nuanced picture of potential future career paths compared to their academic counterparts. Our thesis in this paper, however, is that another important factor is the different way the two types of uncertainty we have described thus far – epistemic and funding/career – are linked to anticipatory practices in the two institutional domains.

The Entanglement of Epistemic and Funding/Career Uncertainties in Academic Life Sciences Groups

In our informants' accounts, the two types of uncertainty (i.e. epistemic and funding/career uncertainties) were not as distinct as we have described in the previous sections. In contrast, how uncertainty is anticipated, experienced and handled in both domains leads to them becoming closely entangled with each other. The form of this entanglement however varied between academia and biotechnology companies.

In academia, competition was the central discursive reference point that links epistemic and funding/career uncertainties. For academic group leaders, sustaining a stable stream of funding was crucial to sustain their research work. In a dynamic akin to the one described by Latour and Woolgar (1979) in their 'cycle of credit' (see also Fochler (2016b), the results and publications of their group were seen as an important resource to secure future funding in an increasingly competitive environment. A central challenge that academic group leaders perceived was to plan their projects in a way that both gives them the flexibility to follow their epistemic interest and allows their group to produce results that build reviewers' trust in further applications:

The unpleasant thing in writing grants is that mostly you write them for three years, and you cannot predict the results of the first experiments and where the path will lead. So, you need to let the reviewer know that you can imagine the next three years but also that you have exit strategies ... In the end, it is important to have a certain output. That is decisive. But researchers should have the freedom to decide how to get there. (Male, academic, group leader)

Managing the epistemic uncertainties of the projects of their group hence was a central issue in managing the uncertainties of research funding – and vice versa, as specific funding instruments and their time horizons allow for engaging with more or less risky epistemic questions (Felt, 2017).

PhD students and postdocs employed in academic research groups faced a structurally similar entanglement of epistemic and funding/career uncertainties. Additionally, for them, the successful management of epistemic uncertainties was crucial for producing results that can serve as resources in competition. However, in their case, it was rather the competition for individual postdoctoral appointments, and particularly for independent group leader positions, that structured the way they relate epistemic and career uncertainties (Fochler *et al.*, 2016). Consider how a postdoc stated this:

Many postdocs have to fight for the best publications to get a group leader position in the future ... We fight for money ... , and of course we fight ... for being first, you know, because only if you are first to publish then it's cited a lot. (Male, academic, postdoc)

For individual researchers in the academic life sciences, managing the uncertainties of a research career necessitated managing the epistemic uncertainties of

their own individual projects (Sigl, 2016). Note that these individual projects were only partly linked to the group leader's overall management of epistemic and funding uncertainties. While the overall group was likely to benefit from the publication success of individual researchers, the individual researchers were in turn less likely to benefit from a successful strategy on the laboratory level – because they will most likely have moved on before the next funding cycle.

The Entanglement of Epistemic and Funding/Career Uncertainties in Biotechnology Companies

In biotechnology companies, epistemic and funding/career uncertainties were linked through the need to progress along the development trajectory in order to present the company as an attractive recipient of further investments. Milestones have to be met to assure further financing, and good data or successes in clinical development may serve as assets to receive further public and private funding (Birch, 2017; Fochler, 2016b). In talking about this, managers stressed that it is more crucial for the company to perform along its own projected development trajectory than to compete directly with other companies pursuing similar projects. Managing the relation of funding and the epistemic progress of a company was seen as the central task of a CEO by most of our respondents, as this quote illustrates:

So, what I like about the job is to link things that actually don't relate to each other. But they all need to work out, so this company can succeed. There's no relation in how you get a soda producer to invest in a cancer antibody with the question of what the affinity of the antibody should be. But you need both to make this [the company] work. (Male, industry, senior researcher)

A number of our interviewees also acknowledged that the long period of uncertainty about the viability of a company's potential product is also a central problem of the political economy of the entire biotechnology sector (Mirowski, 2011). Uncertainty about whether development will succeed also implies hope that it might, a hope that is more often in vain than not, with the consequence of public subsidies and private investments being lost. Consider how a manager commented on this, pointing to his own company's effort to bring their project to the market as soon as possible:

So, most biotech companies are actually just burning money, right? [...] Which means, they never actually get to the point where they actually sell anything. (Male, industry, senior researcher)

Other than for their academic counterparts, individual company researchers' future career prospects were not perceived as tied to the success or failure of the particular epistemic project they were working on in their daily routines. Rather, what was perceived as central was the overall success of the company as

a collective project. In our interviews, this aspect was often seen as one of the largest differences in the everyday organization of work between biotechnology companies and academia. Some researchers recounted stories of surprise concerning this difference when they discussed their first employment at a biotechnology company. One postdoctoral researcher at a company told us that she had expected to be fired after her first two assigned projects had failed. She was surprised that instead the work of the entire research department of the company was restructured to focus on more successful projects. She comments on this as follows:

[I]t happens that a project dies because it was not ... rewarding anymore ... and in the first five months or so, I thought, 'Oh god, now I will lose my job.' ... But the thing is, I was also working on other projects, and we work as a collective. So somehow, it's not that everyone has their own baby, but I feel equally responsible for other things. So, if something does not work out, it is not the end of the world. (Female, industry, junior researcher)

At the individual level in biotechnology companies, epistemic uncertainties were thus decoupled from career uncertainties. Most researchers experienced this situation as very positive. However, some researchers also identified negative consequences. In particular, some were critical about the fact that potentially excellent individual work could remain unaccounted for if the larger company development failed.

Managing Anticipatory Uncertainty in Academic Research Groups in the Life Sciences

As we have shown in the previous sections, epistemic and funding/career uncertainties were inextricably intertwined in researchers' anticipatory practices in the academic life sciences. Researchers and group leaders developed strategies that simultaneously address both forms of uncertainty. Group leaders employed three sets of interlinked strategies for their groups. First, they aimed at increasing their grant money and diversifying their epistemic projects. Having more projects allowed the employment of more researchers, facilitated more experiments and was likely more productive in terms of producing publications. Organizationally, having projects with different temporal horizons also permitted flexibility. For example, by drawing on another project with a different time horizon, contracts could be extended beyond the formal end of a project if the related epistemic work was not concluded:

So, if you have enough projects, then you can divert a couple of months to fund someone if a paper still needs to be finished. (Male, academic, group leader)

Second, group leaders decoupled the actual epistemic practice of their groups from the formal task structure of their grants, often by reorganizing the temporal sequence of epistemic work. For example, group leaders applied for projects that propose experiments that had already been completed to a significant extent

during previous work. This practice secured early project findings and positive project evaluations:

I write something in the project proposal that is already done. That is very common. [...] Then, you can say relatively early on: there is a publication. (Female, academic, postdoc)

In addition to increasing the likelihood of getting successor projects funded, this strategy also freed resources to engage in less predictable lines of research.

Third, dividing work into different individual projects, where some projects are riskier and some are safer, and assigning them to individual PhD students or postdocs was a strategy to manage both epistemic and social uncertainty. In the group's overall epistemic performance, less successful projects may be compensated for by more successful projects. Group leaders reported that managing the uncertainties of their overall grant portfolio required them to relatively strictly define the epistemic trajectory of PhD students' projects, which left students with relatively little freedom:

So, I can't say 'Try this and we'll see what happens.' Everything needs to be carefully planned. ... And the willingness to take risks goes down. (Male, academic, group leader)

In addition to being a strategy of securing output to obtain grants, this strategy also corresponded to the career logic in the academic life sciences, which demands clear individual attribution of experimental work results (Fochler, 2016b; Knorr-Cetina, 1999). Blurring the boundaries of individual projects was seen as running the risk of deep authorship conflicts.

From the perspective of a group leader, organizing work into individual projects of which some projects will be more successful than others was a rational strategy to cope with uncertainty. For an individual researcher who is assigned to an unsuccessful project, however, this strategy is less useful because it may damage that researcher's career opportunities. Accordingly, there was a strong moral expectation among junior researchers that group leaders will withdraw them from unsuccessful projects and assign them to work that produces the publications necessary for graduation (Fochler *et al.*, 2016). This expectation leads to social and epistemic turbulence that is often reported as quite unproductive. As one PhD student described:

We had a situation ... one of the girls was getting lots of negative results, so she kind of took the back-up project from the other girl. And this back-up project worked out really nicely, but then the first girl's work also didn't work very well, and the back-up project was already taken, so that was difficult. (Female, academic, PhD student)

Therefore, one of the central fears of young researchers was to be 'caught in a bad project' that yields no good results but that the group leader is not ready to terminate. For group leaders, in turn, the individual attribution of epistemic projects and the strong link to career logic could hamper the flexibility of epistemic

work, since terminating a line of experiments always has implications for the career prospects of the researcher who is assigned to it.

Postdoc researchers developed their own strategies for managing anticipatory uncertainty. They already had more freedom to choose their epistemic projects but also experienced extreme competitive pressure to secure faculty positions (Alberts *et al.*, 2014; Müller, 2014). Postdocs timed their epistemic work in relation to their remaining contract length. In this way, they were inclined to balance more risky approaches with relatively safe questions and experimental approaches that allowed them to conclude their work in a way that benefits their next job application:

The pressure is there. A paper in Science helps, for sure, but I've seen many people working hard for five years on a postdoc without a Science paper as a result. So, there's quite a bit of risk. [...] I hope I can be somewhere in between. So, my main project is very risky. But I hope that I will be able to define some smaller aims that will still lead to a publication and that I will have a certain output without being here day and night or having to take the short way down here from the sixth floor one day (laughs). (Female, academic, postdoc)

As in this quote, most postdocs we interviewed developed complex strategies that balanced the uncertainties of their epistemic approaches with the uncertainties of their employment situation and prospects (Sigl, 2016). They stressed that developing strategies of their own was necessary because both career and institutional logics frame them as temporary members of their group who will be able to benefit from longer-term collective strategies only to a limited extent. As one postdoc indicated:

I am sorry; it is a kind of business. As a postdoc, you cannot stay too long in a place where you don't get any kind of profit, you know, in the form of publications or good scientific data because it's very bad for your future career. (Male, academic, postdoc)

Managing Anticipatory Uncertainty in Biotechnology Companies

As in the academic life sciences, senior company managers and junior researchers differed in how they managed anticipatory uncertainty. We will discuss both in turn.

Following the milestone-logic that was described in a previous section, the major uncertainties that biotechnology company managers faced were how to raise sufficient funds to continue their work and how to ensure that the research progress warranted new investments (Fochler, 2016b). At the company level, they employed two main strategies to address these uncertainties.

First, biotechnology company managers aimed to diversify their funding sources to allow them to negotiate different sets of milestones. To create resilience, milestones for different funders were defined in a way that allowed the company to remain operational even if the achievement of single milestones was delayed.

Rather than reorganizing the temporal sequence of their work to match the temporal structure of funding cycles or career steps (as academic group leaders do), biotechnology managers aimed to diversify the ways that the temporal logic of funding relates to the work at their company:

So, it's crucial to have at least a second source of funding not connected to the same milestones. It can be different milestones, or no milestones at all, but not the same. Because otherwise, you may have more money when you reach one [milestone], but if it is delayed, you are in deep trouble. (Male, industry, senior researcher)

Second, to manage epistemic risk, biotechnology companies also diversified the long-term goals of the company. Because any specific development trajectory could fail for many reasons at both the pre-clinical and particularly the clinical stages, companies usually started their operations with a number (usually two to four) of loosely related objectives. Each of these objectives was epistemically more specific than the business plan of the entire company but was planned along a similar long-term horizon. In this way, success in some of these epistemic objectives could to some extent compensate for epistemic delays or failures in others, and the objectives that are unsuccessful were typically terminated (by the management or through the pressure of external investors) to safeguard the long-term development of the company.

On the operational level, the different objectives and milestones were reduced to specific project-like time/task packages that were managed by individuals or teams of employees. Typically, these project-like structures reflected medium-term goals but were highly flexible in how these goals are approached both socially and epistemically. As one manager indicated:

You could see the entire company as a project. But that would make no sense; that is too long-term. You should define projects that you can plan and finish in an acceptable time – two years at most. (Female, industry, senior researcher)

Unlike academia, there was usually a clear relation between the organization of work and the aims and funding structure of the company, and it was important that employees knew and considered this relation. Another major difference from academia was that there was no individual attribution of the responsibility for projects and no individual credit that was associated with them (Fochler, 2016b). One CEO used an interesting metaphor to describe this difference:

It's like producing a car. Here, someone adds the tires, someone the doors. But no one is the first author of the car. In academia, people would rather build a shaky car, tires just made out of wire, but hey, that's what I've built alone, and it drove out of the garage once, and that's all that is needed. (Male, industry, senior researcher)

Other than their academic counterparts, industry researchers described collective and individual strategies to manage uncertainty as closely intertwined. As careers were not threatened by it, there was a flexibility to end unsuccessful lines of experimentation quickly, allowing bad projects 'to be put to a dignified

but definite end' (female, industry, junior researcher). This enabled the diversion of resources to other, more promising approaches. In our industry respondents' view, this flexibility tended to make the work more effective and less frustrating and provided an incentive to report failing lines of epistemic work to management sooner rather than later and to suggest a re-orientation of work:

[I]n a company, there is a high interest to terminate something that does not work rather quickly. At university, you might profit if you have one nice Western blot, and you let three others disappear. But in a company, you profit from saying, 'Hey, this does not work three times out of four,' because management also has an interest to stop this project as quickly as possible. [...] While at university, at least in my experience, nothing is ever really given up. Things are fiddled around with until they look at least somehow positive. (Female, industry, junior researcher)

Because work in a biotechnology company always progresses towards a specific aim, diligence in testing the reliability of empirical results was seen as paramount to prevent future problems. Similarly, openness and the sharing of experiences and data among colleagues was considered crucial (Fochler, 2016a; Vallas and Kleinman, 2007). Thus, consistent with the incentive to report negative results quickly, the biotechnology researchers repeatedly discussed a sense of responsibility for overall development of the company (and, therefore, their own future employment and the employment of their colleagues) and how this responsibility shaped their experimental practice and handling of data. In this and in many other instances, individual and collective ways of managing anticipatory uncertainty were described as mutually reinforcing.

Conclusion

How do researchers in different institutional contexts in the life sciences experience and manage uncertainty about the future productivity of their research? How are uncertainties related to epistemic processes and uncertainties related to funding and careers entangled in these anticipatory practices? These are the central questions we discuss in this paper.

Anticipating future uncertainties in epistemic processes, as well as in career and funding dynamics, is crucial in most institutional contexts in which research is conducted today (Felt, 2017; Müller, 2014; Ylijoki, 2010). We argue that this creates a specific kind of uncertainty, anticipatory uncertainty, that we define as the state of being uncertain whether research processes will be productive in a specific time frame and along situated definitions of performance and the quality of research.

Our analysis builds on and links concepts from three existing lines of literature. First, we situate our work within a larger body of work on how scientists perceive and manage uncertainties related to knowledge, most importantly ontological and epistemic uncertainty (Hollin, 2017; Pickersgill, 2011; Star, 1985). Second, we build on the literature on social uncertainties related to career and

funding organization under NPM principles (Felt, 2017; Knights and Clarke, 2014; Müller and de Rijcke, 2017; Sigl, 2016). In addition, third, we relate to work on anticipation as a cultural practice (Adams *et al.*, 2009; Borup *et al.*, 2006; Gill, 2014). Analysing anticipatory practices opens an analytical opportunity to understand how epistemic uncertainties and social uncertainties are entangled in the social organization of research.

Following Star's (1985) argument that the perception and management of uncertainty is strongly related to how work is organized in a specific context, we have studied how researchers experience and manage this uncertainty in the academic life sciences, whose organization has been fundamentally changing due to the complex dynamics of NPM reforms, and in biotechnology companies, for which the management of uncertainty is an inherent, if not the defining, part of their business strategy (Birch, 2017; Fochler, 2016b; Mirowski, 2011). The empirical analysis we present in this paper shows that in both contexts anticipating and managing uncertainty about the productivity of research work is a key issue in how both early-stage and senior researchers think and decide about their experimental work, about their careers, and about their research strategies. However, the way this uncertainty is experienced, related to funding and career logic, and managed differs significantly.

In the academic life sciences, the central dynamic generating anticipatory uncertainty to be identified in our work was the competition between researchers and research groups for scarce resources such as high-impact publications, funding and positions with a potential for tenure. This resonates with a number of recent contributions, which see the competition of academics on quasi-markets as one of the strongest governance dynamics of the current NPM regime (Fochler, 2016b; Fochler *et al.*, 2016; Taylor *et al.*, 2013). Interestingly, competition was much less relevant for the experience of researchers in biotechnology companies and their management of uncertainty. Here, rather epistemic uncertainties related to the highly unlikely chances of success of biotechnology innovations and to the long development time played a crucial role.

Perhaps the most surprising finding of our comparison is how individual researchers reported their experience of anticipatory uncertainty very differently in biotechnology companies and the academic life sciences. While academic researchers were highly anxious about anticipating their experimental work and its consequences for their funding and career, both biotechnology managers and employees saw this as a normal and only little distressing part of their practices. Our conclusion is that this is related to the very different organizational logic of anticipatory practices in both domains and to the resulting highly different management of uncertainty.

In the academic life sciences, competition takes place both at the level of research groups, mainly for funding and publication, and between individual junior researchers, mainly related to career prospects. The latter in particular

generates a very individualized and existential experience of anticipatory uncertainty (Müller, 2014; Sigl, 2016). Biotechnology companies, on the other hand, organize work in a way that attributes the risks associated with the uncertainty of their epistemic work to the company as a collective, not to individual researchers (Fochler, 2016b). This suggests that future studies addressing the management of uncertainty would benefit from asking the following: What subject is assigned the responsibility to manage uncertainty but also the risk that this management fails? How does this attribution change the relevant subjects and their propensities to act and decide?

These questions are related to a further important finding of our comparison: the management of epistemic uncertainty differed strongly between the two contexts studied. In biotechnology companies, we observed a readiness to change both research strategies and the organization of work relatively flexibly to react to new developments in the progress of the overall research agenda (including a propensity to shut down inconclusive areas of research relatively quickly). In academia, groups' ability to react similarly flexible seemed significantly constrained by the individual attribution of research work and credit, and the correspondingly high level of individual anticipatory uncertainty.

Caution in interpreting this finding is needed due to the different aims of research processes in each domain. Still, the lack of flexibility in the management of epistemic uncertainties in the academic context suggested by some of our findings opens up the question how strongly the epistemic flexibility of basic research is constrained by the organizational dynamics spawned by NPM reforms (Alberts *et al.*, 2014; Müller and de Rijcke, 2017). In particular, these reforms often generate multi-level dynamics of competition (such as competition at the group level as well as on the individual level), but do not address the frictions caused by the interplay of these different dynamics (Fochler, 2016b) that constrain the epistemic flexibility of research work. Additionally, competition is expected to take place in ever more standardized temporal frameworks (such as a three year project or a two to three year postdoctoral appointment) (Felt, 2017; Gibbs *et al.*, 2015). This also affects researchers' flexibility to engage with specific kinds of epistemic uncertainty.

Finally, we make a normative point related to the observation that the multi-level dynamics of competition (at the group and the individual level) are a key factor for both the increased individual anxiety in coping with uncertainty and the potential lack in epistemic flexibility in the academic life sciences. This resonates with critical voices from within the life science community which position hyper-competition as the root of many current problems of the field (Alberts *et al.*, 2014). To normatively address this, it seems that both within research organizations and professional academic communities, a deeper reflection on the dangers of competitive dynamics is needed, as are efforts to more productively relate individual and group level processes of competition.

We hope that the insights presented in this paper will help researchers and research managers to understand and address the structural problems of the current institutional organization of academic research work rather than just to criticize the symptoms of these deeper dynamics. Our results suggest that this would not only benefit junior researchers but also enhance the ability of academic research to productively embrace epistemic uncertainty and ask truly innovative questions, even if they are risky. In our fieldwork, we have encountered many academic scientists who value precisely this aspect of research work but find it increasingly hard to realize in the current structures of accountability with which their work must comply. Creating conditions that allow researchers to embrace uncertainty better may also contribute to counteracting the tendency to conduct the ‘cookie-cutter’ research criticized by our opening example.

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