

The third mission in eight cases: How Triple Helix dynamics vary across scientific fields

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Abstract

This paper investigates the consequences of institutional changes on academic research practices in eight fields of natural science. We analyze the similarities and differences among the dynamics of these different fields and reflect on possible explanations for the changes observed. This study shows that the increasing pressure for productivity, as measured in bibliometric terms, can counteract the pressure for practical utility. Moreover our work indicates that the dynamics of science vary much more across scientific fields than most literature suggests.

1. Introduction

This paper aims to contribute to the understanding of transformations in the knowledge infrastructure, as discussed in a large and expanding literature (Gibbons et al. 1994, Etzkowitz & Leydesdorff 2000, Ziman 2000). One of the central claims in this literature is that research practices are changing in the sense that research agendas are increasingly oriented at producing societal benefits, or, in other words, that the relevance of science is increasingly defined in terms of specific products or policy solutions. In other words, universities are increasingly engaged in a ‘third mission’, next to teaching and fundamental research (Etzkowitz et al. 2000).

However, the understanding of these dynamics is still limited, due to two problems: first, the empirical evidence supporting these claims is not fully convincing, and second, one of the most influential concepts used in this debate (‘Mode 2 knowledge production’) suffers from conceptual weaknesses that inhibit a proper operationalization (Hessels & van Lente 2008).

Preliminary evidence suggests that the changes in the academic research system may involve conflicting forces: shifts in funding stimulate scientists to make direct contributions to economic growth or other societal goals, but the rise of systematic performance evaluations strengthens the pressure for scientific excellence as measured in bibliometric terms (Hessels et al. 2009). What are the consequences of these institutional changes for the nature of academic research activities? Will they be more strongly oriented at the third mission? Do university researchers in all fields of science interact increasingly with their stakeholders in society? In this paper we address the questions based on an analysis of the ‘credibility cycle’ in eight fields of natural science. Special attention is devoted to (explaining) the differences across fields.

2. Theoretical framework

The ‘credibility cycle’ (Latour & Woolgar 1986) explains how struggles for reputation influence the behavior of individual scientists. Its starting assumption is that a major motivation for a scientist’s actions is the quest for credibility. Conceived in this way, the research process can be depicted as a repetitive cycle in which conversions take place between money, staff, data, arguments, articles, recognition, and so on (see also (Hessels et al. 2009)).

But scientists do not work independently; their activities take place in the context of a ‘research system’. Following Rip and Van der Meulen (1996), we regard a research system as consisting of ‘research performers (individuals, groups, institutions), other organizations and institutions, interactions, processes and procedures’ (Rip & van der Meulen 1996). This system contains universities, related research institutes and funding agencies, but also governmental organizations, firms and intermediary organizations to the extent that they are part of the institutional environment. This institutional environment provides research organizations with incentives and constraints to conduct (particular kinds of) research. Our notion of a research system is discipline-specific and it is delimited by national boundaries.

In line with the structuration perspective (Giddens 1984), the research system can be seen as the structure influencing the agency of individual researchers (Grin 2010). Existing structures are the product of practices and of dominant visions, such as the need to enhance agricultural productivity. The institutions of this system give shape to certain conversions of credibility, e.g. the possibilities to turn recognition into money (Hessels et al. 2009, Packer & Webster 1996). Simultaneously, funding bodies presumably take into account the outcomes of research practices when formulating their future priorities. In this way, research practices can strengthen these institutions, but they can also neglect them and put them under pressure (Bos & Grin 2008). So the research system can be seen as a structure that shapes research practices, but that is at the same time (re)produced by these practices.

3. Methods

The general research strategy of this study is a case study approach (Yin 2003). This study focuses on eight scientific fields in the Netherlands. The fields were selected to represent the variety of possible societal stakeholders of natural science (see Table 1).

Table 1 Fields selected within each case study and their stakeholders in society

Discipline	Fields	Main stakeholders
Chemistry	Catalysis	Chemical industry
	Biochemistry	Biotech industry / Medicine
	Environmental chemistry	Environmental policy
Biology	Paleo-ecology	Oil industry
	Toxicology	Environmental policy
Agricultural science	Animal breeding and genetics (ABG)	Animal breeding firms
	Animal production systems (APS)	Farmers, agricultural policy
	Cell biology	(Veterinary) medicine

In each case, the discipline was studied over the period between 1975 and 2005. We chose 1975 as the starting point because this marks the beginning of governmental science policy in The Netherlands (Salomon 1980, Blume 1985), which is generally considered as a key-event in the changing relationship of academic science with its societal context, and because around this time civil society started penetrating the science system (Grin 2010, Rip & Boeker 1975).

Data for the case studies have been drawn from in-depth interviews and documentary analysis. For the credibility cycle analysis of changing struggles for relevance semi-structured in-depth interviews with 47 academic researchers were carried out. The respondents’ ranks ranged from PhD-student to full professor and they were employed at five different universities in the Netherlands (see Table 2). They were asked questions about their current and past research activities, their personal motivation, and their experiences and strategies concerning funding acquisition, publishing, scientific reputation, and performance evaluations. Using NVivo (qualitative analysis software), we coded the interview transcripts in accordance with the different steps of the credibility cycle.

Table 2 Distribution of 47 respondents over fields, universities and academic ranks

Catalysis (9)	Utrecht University (18)	Retired full professor (6)
Paleo-ecology (8)	Wageningen University (12)	Full professor (13)
Toxicology (7)	University of Amsterdam (11)	Associate professor (10)
Biochemistry (6)	VU University Amsterdam (3)	Assistant professor (6)
Environmental chemistry (5)	Radboud University Nijmegen (1)	Post-doc researcher (5)
Animal breeding and genetics (4)	Eindhoven University of	PhD-student (7)
Animal production systems (4)	Technology (1)	
Cell biology (4)	Leiden University (1)	

Our analysis of the changing structural conditions of academic research is based on documents¹ in combination with interviews with scholarly experts, and representatives of firms, professional organizations, research councils and the government. The documents were collected based on prior knowledge of the authors, tips from interviewees, and the 'snowball method'. The selection includes governmental policy documents, reports and strategic plans of research councils, foresight studies, evaluations and other important publications about the disciplines addressed. The findings from these documents were triangulated in interviews with the experts and stakeholders mentioned above.

4. Results

4.1 Structural changes in the research system

In the period studied we have observed two major structural changes: shifts in the available funding and the rise of performance evaluations.

Diversification of funding

The first general structural change is a trend of funding diversification. In all fields studied the relative share of public funding for basic research has decreased. Moreover, over the years the relative share of unconditional funding (first money stream) has decreased. With the general expansion of the public science systems, budgets have become under pressure and the need to account for public investments in academic research has grown (Ziman 1994). In line with the ideologies of Neo-liberalism and 'New Public Management', the Dutch government has loosened state control and introduced market mechanisms to enhance efficiency and effectiveness (De Boer et al. 2007, Schmoch & Schubert forthcoming). Since 1975, the starting point of our analysis, the government has transferred an increasing share of public funding to competitive arrangements, organized by research councils or other intermediary organizations. Between 1975 and 2005 the total amount of block grant support for universities has grown almost twofold in real terms (Versleijen 2007), but its relative share in relation to more competitive funding sources has decreased (Jongbloed & Salerno 2003). Around 1975, this money stream was still sufficient for research groups to buy the necessary equipment and hire some temporary staff, but nowadays even some of the permanent academic staff needs to be paid from project funding. Even the funding that has remained in this category has become less secure, as it has become subject to university policy, and it is often needed to 'match' externally acquired funding (Jongbloed & Salerno 2003, AWT 2004).

The 'second money stream' has also changed dramatically. Research councils were initially organized in sub-disciplinary Working Committees, but they have been merged and reorganized into a general matrix organization supplying most funding in the form of multidisciplinary research programs. While Dutch research councils originally exclusively funded basic research, they have expanded their territories to application-oriented activities, too. Moreover the Dutch Organization for Scientific Research (NWO, the new umbrella organization of all research councils) has developed a variety of hybrid funding configurations in collaboration with ministries, firms or other knowledge users.

In addition, the third money stream (all contract funding except from NWO), which is more strongly oriented to practical applications, shows a spectacular increase in the 1980s and 1990s at all Dutch universities (see Figure 3). Between 1983 and 2000 the total size of this 'stream' has increased from about 125 to about 638 Million Euros. This amounts to an increase of a factor 3.85 in real terms (Jongbloed & Salerno 2003).

¹ A list of documents is available on request.

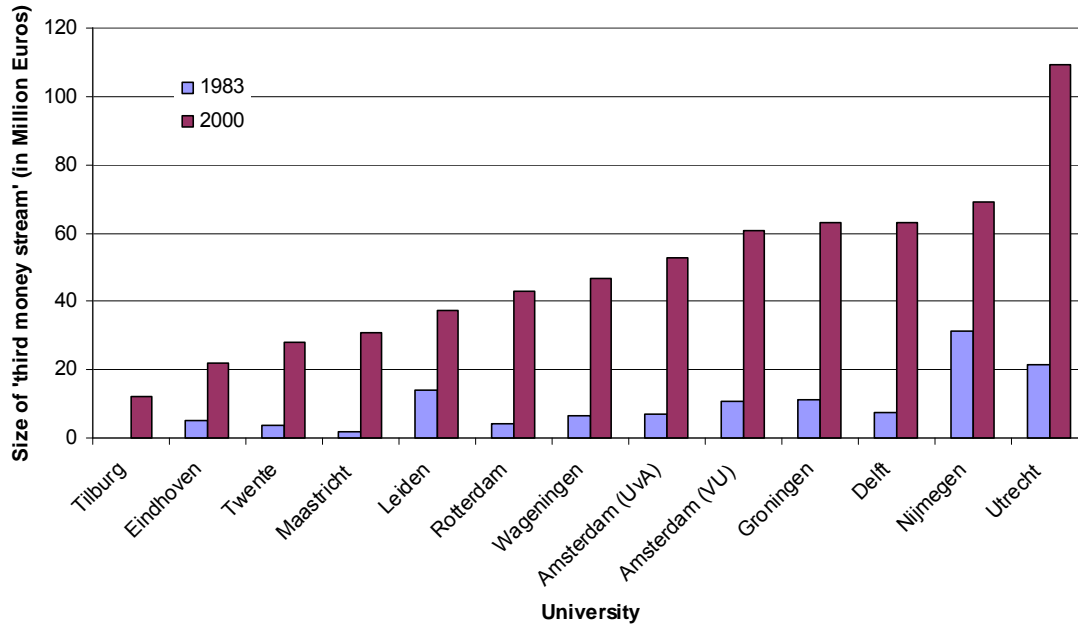


Figure 3 The size of the ‘third money stream’ in 1983 and 2000 (in current prices) at Dutch universities. Source: Jongbloed & Salerno, 2003.

Simultaneous to this major shift towards application-oriented funding, however, a smaller trend took place in the opposite direction. Over the last decade, the research council’s policy to nurture and stimulate excellent researchers has created a small but significant subset of funding arrangements lacking any consideration of practical utility. In 2000 NWO introduced the highly competitive ‘Vernieuwingsimpuls’ grants, as a policy-instrument for supporting talented researchers. In the selection of proposals for these grants, the most determining factor is the individual quality of the requesting applicant, assessed mainly using bibliometric criteria. With its emphasis on bibliometric quality indicators, this type of funding has probably contributed to the decreasing value of practical applications as a source of recognition. At the moment the grants under this scheme together consume about 20% of NWO’s total budget². However, the relative impact of this funding instrument is probably larger than its financial share, thanks to its prestige and popularity³.

Rise of performance evaluations

The second structural change is the rise of performance evaluations. After a number of pilot evaluations and foresight studies in the 1980s, a more or less standard approach has been developed for systematic evaluations of academic research groups (van der Meulen 2008). Nowadays, every research group in the Netherlands is subject to regular evaluations. Research quality assessments officially use a variety of criteria⁴, but in practice they tend to be ruled by bibliometric quality indicators. Even if other dimensions such as viability or relevance are measured as well, in the interpretation of the evaluation scores, numbers of publications and citation rates dominate⁵. The availability of digital bibliometric databases, and the relative generic validity and cross-comparability of these indicators made these into

² NWO, 2010, ‘Begroting 2010 en meerjarencijfers 2011 tot en met 2014’, NWO, Den Haag

³ Between 2000 and 2006 the success rate of this funding instrument was only 20% (Technopolis & Dialogic 2007), while the overall average success rate at NWO was about 50% (NWO, 2005, ‘Jaarboek 2004’, NWO, Den Haag).

⁴ VSNU, NWO & KNAW 2003, *Standard Evaluation Protocol 2003-2009 for Public Research Organisations*

⁵ The newest protocol for Dutch research evaluations more explicitly demands the assessment of ‘societal relevance’ (VSNU, KNAW & NWO 2009, *Standard Evaluation Protocol 2009-2015: Protocol for Research Assessment in the Netherlands*), and a recent set of pilot-studies has shown the potential of indicators for this criterion (ERiC 2010, *Handreiking Evaluatie van maatschappelijke relevantie van wetenschappelijk onderzoek*, ERiC publicatie 1001.), but the effects of this development on academic research practices were not yet visible in our case studies.

a success that is not equalled (yet) by any other indicators (Gläser & Laudel 2007). Although the results of Dutch research evaluations do not have direct financial consequences, their outcomes do influence strategic decisions by deans and university boards, and high scores can also contribute to successful acquisition of external funding.

4.2 Common trends in the credibility cycle

What are the consequences of these institutional changes on the credibility cycle of individual academic researchers? We have observed common trends at three steps in the credibility cycle at the acquisition of data, recognition and money, respectively (see Figure 1).

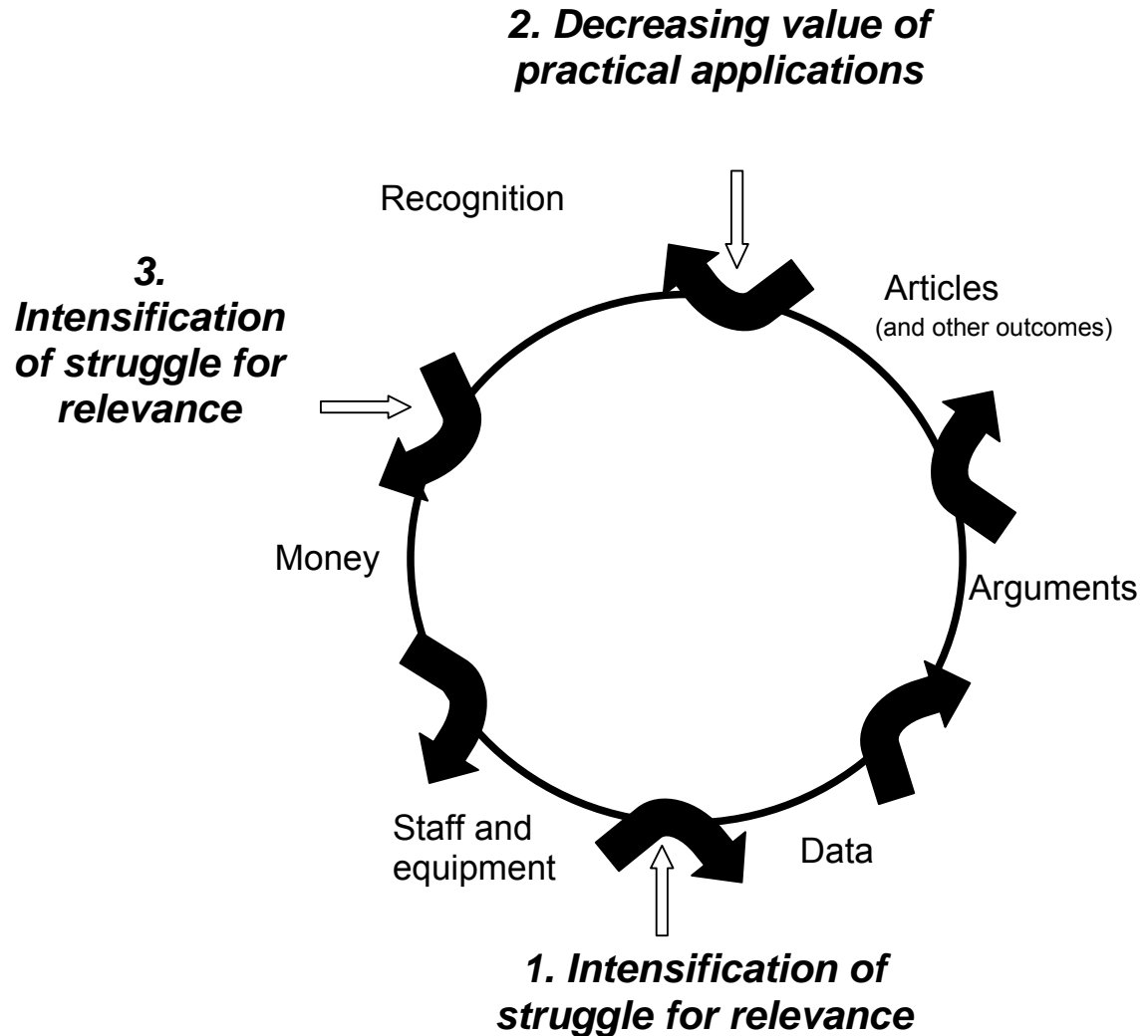


Figure 1 The three common trends in the struggles for relevance of eight fields of natural science, depicted in the credibility cycle (adapted from Latour and Woolgar (1986)).

Intensification of struggle for relevance during data collection

First, in most fields the struggle for relevance during the collection of data (the actual research process) has intensified. Over the past few decades, the role of societal stakeholders in this process has grown. Nowadays, some researchers even collaborate so intensively with knowledge users that they conceive them as ‘partners’:

‘We are free and they are free to go where they want. But you simply feel that they care about a long-lasting relationship. So we don’t have a collaboration that is project-oriented. Then you would talk about customers. We talk about partners, [when we talk about] the firms.’ (researcher A7).

In agreement with the claims about the rise of 'Mode 2 knowledge production', an increasing share of all Dutch academic research is conducted in 'the context of application'. In several fields interactions with possible users of research outcomes were already common practice, but in general their frequency and salience have grown. In fields like catalysis, ABG, and toxicology most projects are supervised by an industrial sponsor or by a 'users committee'. These receive a regular update about the progress and provide feedback for future directions. In other fields, like APS and environmental chemistry, it has become common to conduct academic research projects in collaboration with applied researchers employed by public research institutes or private R&D labs. These types of interactions with stakeholders have increased the awareness of scientists of potential applications of their work and – to some extent - this awareness influences their choices on the lab floor. There are also fields in which researchers still hardly interact directly with societal stakeholders, in particular biochemistry and cell biology.

Decreasing value of practical applications as a source of recognition

The second major development that was visible in all fields we have studied relates to the way scientists earn recognition: on average, the value of practical applications as a source of academic recognition has decreased. Asked whether practical applications can help to get peer recognition, a biologist replied:

'Maybe it would count a bit, but also here the scientific content comes first and if it is applicable by accident, then that is so much to the good. I mean, it is like the cream on the pudding, but... It makes it more fun, yes. But it is not...' (researcher B20).

Since the 1970s recognition has become more and more linked to the production of scientific papers. Scientists are increasingly under pressure to be productive, both in quantitative and qualitative terms. In the credibility cycle, recognition has become so strongly based on numerical indicators of scientific productivity, that academic researchers simply face the choice 'publish or perish'. A strong publication list has become a crucial condition in order to qualify for particular kinds of funding, in particular grants from national research councils and from EU Framework Programmes. Moreover, scientific productivity is the main topic discussed during individual performance interviews, and it is also the main criterion for selecting candidates for academic positions.

Our interview data shows that scientists anticipate on the importance of scientific publications during the whole credibility cycle. Data collection is organized in such a way to optimize publication prospects. Some scientists choose particular strategies because they either need to publish in a high-impact journal (researcher B20) or because they perceive the need for a larger number of papers (researcher A10), depending on the current status of their publication list. In addition, several 'cheating' strategies are pursued, like the formation of writing 'task-forces' whose members grant each other co-authorships without any actual collaboration (researcher C5), submitting several papers each highlighting different aspects of the same research project, or dividing a particular contribution into its 'smallest publishable units' (researcher A10).

Over the years, publication achievements have (further) pushed away social or economic impact as a source of academic recognition. As we will specify below, practical applications are not always in competition with scientific papers, but in most fields they are. In the selection of manuscripts for publication in scientific journals, the societal relevance of the reported research does not play a significant role. Obviously, editors and peers decide about to publish papers based on purely scientific considerations, like consistency, novelty value and methodological quality. In many fields there is even a trade-off between research projects that are of high societal relevance and projects that are likely to result in (many) high-impact scientific papers.

Intensification of struggle for relevance in context of funding acquisition

The third generic trend visible in the period 1975-2005 concerns the intensification of the struggle for relevance in the context of funding acquisition. Earning sufficient income for continuing one's research activities is not anymore self-evident, but it has become the result of active acquisition efforts. Our interview data raise the impression that it has become common for senior researchers to spend between 10 and 20 % of their time on networking, exploring funding options, writing proposals and negotiating contracts.

Promises about practical applications often play a central role in the selection of project proposals. In all fields the scientists we have interviewed report that aligning their work with the knowledge needs of societal stakeholders has become increasingly important for gathering sufficient funding. In the credibility cycle, expected societal benefits strongly catalyze the conversion of recognition into money. Based on a certain amount of recognition (for example, expressed in one's

publication list), the same researcher will more readily acquire funding if (s)he manages to convincingly specify the societal value of a proposed research project:

‘Yes. It is much easier to get money, there are much more possible sources to get money, if you have something that is relevant to society.’ (researcher C12)

Still there are some possibilities to get funding for research without promising societal benefits, most at the national research council NWO. But for only a few of the 47 researchers interviewed these provide a substantial share of their budget.

4.3 Changing struggles in different scientific fields

To a certain extent the three common trends just presented were visible in all eight fields (in the Netherlands). However, a closer look also reveals significant differences across scientific fields in the manifestation of these changes.

In our findings, four types differences can be discerned among the eight fields studied, regarding the changes in their struggles for relevance (see Tables 3 and 4). The first three are directly linked to the general trends just described. A fourth concerns the tension that has arisen in some fields due to the combination of these trends.

Table 3 Overview of the differences among struggles for relevance in eight scientific fields

Credibility conversion	Variable	Observed range
Acquiring data	Intensity of stakeholder interactions	Low – High
Acquiring recognition	The value of practical applications	Negligible – Considerable
Acquiring money	Influence of stakeholders on research agenda	Weak – Strong
(generic)	Relationship practical applications – scientific productivity	Strong tension - Synergy

First, although the role of stakeholders in the academic research process has generally grown, the *extent* to which stakeholders have become involved in data collection varies strongly across fields. Second, there is variation in the (limited) *degree* to which practical relevance is rewarded in terms of academic recognition. Third, in all fields promising societal benefits can help to acquire funding, but the *degree* of involvement of societal stakeholders in the actual agenda-setting differs. A fourth dimension that deserves to be addressed here is the relationship between practical applications and scientific publications; in some fields there is a synergy between scientific productivity and practical relevance; in other fields these are in contradiction. Table 4 presents a classification of the eight fields in our sample based on this dimension. In the following some the characteristics of the three categories of fields will be explored in terms of the other three ‘dimensions’ of the struggle for relevance.

Table 4 Classification of the eight fields based on the relationship between practical applications and scientific productivity

Relationship practical applications - scientific productivity	Fields	Intensity of stakeholder interactions during data collection	Value of practical applications for acquiring recognition	Influence of stakeholders on research agenda
Strong tension	Cell Biology	Slight increase	Negligible	Remains weak
	Biochemistry	Still low	Negligible	Remains weak
Weak tension	Environmental Chemistry	High but stable	Considerable	Strong but stable
	Animal Production Systems	High and growing	Considerable	Strong and increasing
	Toxicology	High but stable	Low	Strong, slight increase
Synergy	Catalysis	High and growing	Negligible	Strong and increasing
	Animal Breeding & Genetics	High and growing	Low	Strong and increasing

Paleo-ecology	Slight increase	Low	Increasing
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In the two fields with the least intensive stakeholder interactions, biochemistry and cell biology, we observed a trade-off between scientific productivity and practical relevance. In these fields scientists complain that engaging in application-oriented research projects and interacting with societal stakeholders ‘distracts’ them from the main focus of their field. Efforts or achievements of this kind do not significantly yield peer recognition here. In biochemistry and cell biology contributions to high-impact journals are usually based on projects paid by research councils granting considerable autonomy to the researchers to formulate their own research priorities and approaches. Enhancing the industrial, medical or agricultural relevance of one’s work implies a move away from the central debates of these fields. To this end, one would have to shift to other model systems (for example chicken rather than mouse) or to address other research questions (for example relating to specific treatments rather than general understanding) which are less suitable for publishing in prestigious journals.

In a second class of fields, containing APS, environmental chemistry and toxicology, such a tension exists as well, but it is of a weaker nature. In this set of fields interactions with stakeholders are quite common, both during the acquisition of funding and during data collection. Here, under certain conditions, application-oriented research can lead to impressive publications. The most important requirements for successfully combining practical applications with scientific productivity seem to be substantial project size and consistency across projects. If these conditions are fulfilled, the results of application-oriented projects can lead to improved understanding on a fundamental level. In this way, the outcomes of (one or more) relatively practical projects can lead to scientific papers. For researchers involved in relatively short and diverse application-oriented projects it is difficult to develop fundamental insights that can be published in prestigious scientific journals.

The situation is different in catalysis, paleo-ecology and ABG. In this class of fields, in which stakeholder interactions have significantly grown, we observed a synergy rather than a trade-off between scientific productivity and societal relevance. Interactions with stakeholders do not only help to acquire funding, but they are also helpful in other credibility conversions. We identified three mechanisms that are responsible for this synergy. First, applied research projects for stakeholders can provide access to data that are useful for more fundamental investigations, too. Second, the interactions with stakeholders often give inspiration for challenging research questions. Third, some stakeholders simply sponsor fundamental research activities, of which they expect benefits on the longer run.

As Table 4 indicates, the relative value of applications (when compared to publications) as a source of recognition does not show a clear trend across the three sets of fields, that is, it does not correlate with the degree of synergy between practical applications and scientific productivity. It is the lowest in biochemistry and cell biology, the fields with the least intensive stakeholder interactions. In these fields, recognition is almost exclusively based on academic achievements, in terms of scientific publications and citations. In the two other classes of fields the relative value of applications ranges from negligible to considerable. Practical applications are most rewarding in terms of recognition in APS and environmental chemistry, which occupy a middle position in Table 4. In these two fields a scientific reputation is not only based on contributions to scientific debate, but also to contributions to environmental policy or to the development of more sustainable agriculture. This may be related to the fact that in these two fields scientists seem most strongly motivated to ‘change the world’. More than in the other fields studied, they draw inspiration for their work from personal ambitions to contribute to external goals like sustainable development⁶. In the same vein, they also value their colleagues’ practical contributions to such goals, more than scientists in fields like catalysis or toxicology.

5. Discussion: explaining field differences

To recapitulate the previous sections, we have observed three general changes in the struggles for relevance of Dutch chemistry, biology and agricultural science, in the period 1975-2005:

1. The struggle for relevance during data collection has intensified.
2. The value of practical applications as a source of academic recognition has decreased.
3. The struggle for relevance in the context of funding acquisition has intensified.

Moreover we have discerned significant differences in the way these changes became manifest in different scientific fields, and in the interplay between them. In some fields a tension has developed

⁶ For example: ‘Yes, in the time that I started I had a strong passion. That there was a large problem which already received attention, but which was not known yet in its full proportions.’ (interview researcher C15).

between scientific productivity and practical applications, in others a synergy. How can we explain the differences among the changing struggles for relevance of scientific fields? This section will present a possible explanation based on socio-organizational, cognitive and cultural field-characteristics, combined with the characteristics of societal stakeholders.

Explaining variation in stakeholder interactions

In the previous section we have seen that the degree to which stakeholder interactions have increased (both during data collection and during funding acquisition) varies strongly across fields. This can be partly explained by cognitive and socio-organizational characteristics of scientific fields, in particular their search pattern (Bonaccorsi 2008) and strategic task uncertainty (Whitley 2000). We have found that some fields with ‘convergent’ search patterns, namely biochemistry and cell biology, have developed relatively few interactions with societal stakeholders (see Tables 4 and 5). This is understandable, because convergent fields have a relatively sharp focus in terms of research problems and approaches. In these fields the strategic task uncertainty is low. This implies that there is a strong overall consensus about the intellectual priorities and scientists can not easily develop a new, application-oriented research direction.

Table 5 Classification of fields based on the degree of convergence of their search pattern

Search pattern	Chemistry	Biology	Agricultural science
Convergent	Biochemistry Catalysis	Toxicology	Cell biology Animal breeding and genetics
Divergent	Environmental	Paleo-ecology	Animal production systems

In divergent fields, such as APS an environmental chemistry, it may be more likely that niches develop which fit the knowledge needs of societal stakeholders. Divergent fields typically have a high strategic task uncertainty. This means that a large diversity of research directions is accepted simultaneously because there is no overall consensus about the intellectual priorities. Researchers and employers are able to pursue distinct strategies and orientations without being penalized for theoretical deviance. In such fields it is easier to develop new research directions that fit the needs of societal stakeholders.

Explaining variation in the value of practical applications as a source of credibility

The extent to which practical applications count as a source of credibility can be understood when taking into account the traditional communication culture of a scientific field. Fields with a divergent search pattern generally have a ‘rural’ communication style (Becher & Trowler 2001), as they are not very competitive and have a low people-to-problems ratio. In rural fields, such as APS an environmental chemistry, relatively few researchers work on a large number of dispersed problems, and the mutual competition is limited. As there is no broad consensus about overall quality standards, it is also difficult to formulate general evaluation criteria. Due to the theoretical diversity knowledge accumulation is less efficient than in ‘urban’ fields and there is usually a lower citation density. We can assume that in these fields less high-impact journals are available, which makes it more difficult to score high on bibliometric evaluations. This implies that bibliometric quality indicators have limited validity, so that it is less likely that recognition will be based on publications only and more likely that practical outcomes such as policy advice, patents or spin-off firms count as well. In urban fields, with a high citation density, bibliometric quality indicators will be more abundantly used, not only in formal evaluations and management decisions, but also in informal processes of exchanging recognition.

Explaining variation in the relationship between practical applications and scientific productivity

The variation in the relationship between practical applications and scientific productivity, which seems crucial for the fate of scientific fields, can be explained by taking into account characteristics of other actors in the research system, in particular the end-users of academic research. Depending on its cognitive content, each field has different potential users outside university. Of particular importance are ‘upstream end-users’, stakeholders with formal channels to influence the strategies and programs of a scientific field through research funding, regulation, or policy (Lyall et al. 2004 p. 79). In our case studies, the fields that were most successful in combining stakeholder interactions with academic performance, were fields with wealthy and powerful upstream end-users that have a long-term vision on the utility scientific research (see Table 6). Chemical industry (in the case of catalysis) and animal breeding industry (ABG) both invest substantial sums in academic research, in the expectation that these will pay back on the longer run. These companies support academic researchers in fundamental research activities, which provide good opportunities for high-impact publications. In this way, they

support scientists along the complete cycle of credibility. The same goes for environmental policy makers and oil companies in the case of paleo-ecology.

Table 6 The upstream end-users of different scientific fields. The fields are ranked according to their degree of synergy between practical applications and scientific productivity

Relationship practical applications – scientific productivity	Field	Upstream end-users
Synergy	Catalysis	Industry
	ABG	Animal breeding firms
	Paleo-ecology	Policy makers
		Oil companies
	Environmental chemistry	Policy makers
↕		Industry
		NGOs
	APS	Farmers
		Policy makers
	Toxicology	Policy makers
Tension		Industry
		NGOs
	Cell biology	- (some agro-food companies)
	Biochemistry	-

Biochemistry and cell biology, in contrast, hardly have any upstream end-users. Of course, stakeholders can be identified that may eventually benefit from these research activities, such as patient groups, farmers or veterinary surgeons. These, however, rather function as ‘downstream’ users, as they are no active players in the academic research system; they do not directly commission research or influence its directions. The only actors generously supporting these fields and directly influencing their directions are research councils (on both national and European level), but these rather function as intermediaries providing channels to transfer knowledge to and from downstream end-users.

In the third class of fields, including environmental chemistry, toxicology, and APS, upstream end-users can be identified as part of the research system, but these mainly support application-oriented research. These stakeholders definitely care about the research in these areas, but they cannot afford investments with a long time-horizon. For instance, support from a governmental body for academic research in the area of toxicology or environmental chemistry is usually connected to a knowledge need on a specific problem. This explains why researchers in these fields often experience a tension between end-user relevance and scientific productivity. The short time-horizon of the projects commissioned by upstream end-users is incompatible with the fundamental nature of dominant debates in scientific literature. In such cases, interactions with stakeholders catalyze some conversions of credibility (funding acquisition), but it inhibits others (publishing).

Another significant variable is the homogeneity of the upstream end-users of a particular field. In the cases of catalysis and ABG, the set of upstream end-users is quite homogeneous, but in environmental chemistry, toxicology, and APS it is heterogeneous. It seems that a homogeneous set of end-users makes it easier to build a consistent project portfolio, which will help to find synergy between practical applications and scientific productivity.

Changing science systems?

Our findings have two major implications for the debate about changing science systems. First, this study shows that the increasing pressure for productivity, as measured in bibliometric terms, can counteract the pressure for practical utility. In other words, there is a potential tension between the second and the third university mission. In some fields, such as catalysis and ABG, we have observed a synergetic relationship between societal impacts and scientific excellence. In other fields, however, like biochemistry and toxicology, the pressure for academic productivity is at odds with the pressure of practical applications. In these fields scientists have increased their efforts to produce papers in high-impact journals at the expense of the practical utility of their work. In these areas research activities addressing knowledge needs of societal stakeholders are not easily published in scientific journals. Here the increased publication pressure inhibits the shift towards application-oriented research modes.

Second, our work indicates that a further differentiation is needed, as the dynamics of science vary much more across scientific fields than most literature suggests. This study adds to a number of other recent studies that have reported varying reactions to institutional changes across scientific

disciplines (Reale & Seeber forthcoming, Albert 2003, Gläser et al. 2010). This study confirms their call for disciplinary differentiation in science (policy) studies. Moreover, it reinforces it to a call for an even more fine-grained perspective that does not only distinguish among complete disciplines, but also among specific fields. Some of the diagnoses of changing science systems differentiate across scientific fields or disciplines, in particular literature about post-normal science, Finalization science, Triple Helix and innovation systems. However, none contains a satisfying framework to understand the varying dynamics of scientific fields. Our study has indicated some possible building blocks for such a framework, in particular the concepts of search patterns (Bonaccorsi 2008), strategic task uncertainty (Whitley 2000), communication culture (Becher & Trowler 2001), and upstream end-users (Lyll et al. 2004).

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