Changing struggles for relevance in eight fields of natural science

Laurens K. Hessels, Harro van Lente, John Grin and Ruud E.H.M. Smits

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

Keywords: *Mode 2; research funding; performance evaluation; credibility cycle*

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This paper sets out to contribute to the understanding of transformations in the knowledge infrastructure, as discussed in a large and expanding literature (see, for example, Etzkowitz and Leydesdorff, 2000; Gibbons *et al*, 1994; Ziman, 2000). One of the central claims in this literature is that research practices are changing as research agendas are increasingly being oriented towards producing societal benefits; or, in other words, that the relevance of science is increasingly defined in terms of specific products or policy solutions. The changing role of universities is also a prominent topic in the Triple Helix discourse. Although the Triple Helix can also be regarded, from a neo-evolutionary perspective, as three selection environments operating upon one another (Leydesdorff and Zawdie, 2010), it is often interpreted as an institutional model of increasingly networked relationships between universities, industries and governments (Etzkowitz *et al*, 2000). Universities claim to engage increasingly in a 'third mission', alongside teaching and fundamental research (Etzkowitz *et al*, 2000) and to be directing their activities more towards 'Mode 2 knowledge production' (Gibbons *et al*, 1994).

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 proper implementation (Hessels and van Lente, 2008). Preliminary evidence suggests that 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 evaluation increases the pressure to achieve scientific excellence as measured in bibliometric terms (Steele *et al*, 2006; Hessels and van Lente, 2011; Hessels *et al*, forthcoming).

What are the consequences of these institutional changes for the nature of academic research activities? Will such activities be more strongly oriented towards the third mission? Do university researchers in all fields of science interact increasingly with their stakeholders in society? In this paper we address these questions based on an analysis of changing *struggles for relevance* in eight fields of natural science. Special attention is given to explaining the differences that occur across these fields.

Theoretical framework

The opening assumption of this paper is that academic researchers struggle for relevance. Researchers will always encounter a certain pressure to position their work in a broader framework: to a greater or lesser extent, they need to make sure that their work is valuable to society, either directly or indirectly (Rip, 1988).[1] The struggle to achieve relevance can involve aligning one's research agenda to the needs of societal stakeholders. Another form of this struggle is the active transfer of knowledge to potential users. But, in principle, basic research that does not directly address external knowledge needs may also be relevant, depending on what counts as 'relevance'. In general, relevance refers to the possible (societal) benefits of science, but these benefits can come in many different forms, ranging from broad cultural values to the development of specific products or the creation of spin-off companies (Hessels *et al*, 2009).

Why would scientists strive for relevance? First, positioning one's activities in a broader context can deliver personal satisfaction[2] – for example, making a contribution to a larger goal can enhance one's work ethic. Second, considerations of potential societal benefits can also help to legitimize one's work to the outside world (van Lente, 1993). The third possible motivation is strongly related to the second: research of high relevance (in all its different forms) can provide access to funding and other valuable resources. Expected societal benefits have played a role in research funding since the emergence of modern science (Martin, 2003, Rip, 1997). Strong alignment of one's research agenda with the needs of external parties can help to secure funding, either directly or indirectly. Moreover, in some fields stakeholder interactions provide access to valuable knowledge, datasets or other research materials.

If relevance is so attractive, one may wonder why it would be an object of struggles. We would suggest that there are at least two reasons why striving for relevance is not a straightforward exercise. First, research issues that are considered highly 'relevant' by others do not always appear to be the most promising in terms of deriving personal satisfaction, producing high-impact scientific publications and obtaining peer recognition. This potential tension is particularly important because it appears that academic researchers are subject to increasing pressure to produce first-class performance, in terms of scientific productivity, as a result of the increasing number of performance evaluations over the past few decades (Steele *et al*, 2006). Second, struggles for relevance appear when the meaning of relevance is not clearly defined. The potential benefits of science are subject to speculation simply because there can be no certainty in advance about any beneficial outcomes. There is also an ongoing dispute about the degree to which research activities should be directed towards (short term) societal objectives (Gibbons, 1999, Ziman, 2003). In peer review panels responsible for evaluating research proposals there are often disputes about the relative importance of 'social significance' as a selection criterion (Lamont, 2009).

Based on these considerations we propose the following tentative definition: the *struggle for relevance* is the combination of the efforts of scientists to make their work correspond with ruling standards of relevance and their efforts to influence these standards. Depending on the dominant standards of relevance, the possibilities for scientists to optimize the relevance of their work may include aligning their research agenda with the needs of societal stakeholders and transferring the knowledge to potential users. However, they can also employ rhetorical strategies to present their research in such a way that, it can be argued, it will comply with dominant standards of relevance (van Lente and van Til, 2008).

To study struggles for relevance in the daily work of university researchers, we used the 'credibility cycle' model (Latour and Woolgar, 1986) which explains how the need for reputation influences the behaviour of individual scientists. Its starting assumption is that a major motivation for a scientist's actions is the quest for credibility. On this basis, 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'. In accordance with Rip and Van der Meulen (1996), we regard a research system as consisting of 'research performers (individuals, groups, institutions),

Table 1. Fields selected in 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

Table 2. Distribution of 47 respondents by field, university and academic rank.

Field
Catalysis (9)
Paleo-ecology (8)
Toxicology (7)
Biochemistry (6)
Environmental chemistry (5)
Animal breeding and genetics (4)
Animal production systems (4)
Cell biology (4)

University
Utrecht University (18)
Wageningen University (12)
University of Amsterdam (11)
VU University Amsterdam (3)
Radboud University Nijmegen (1)
Eindhoven University of Technology (1)
Leiden University (1)

Academic rank
Retired full professor (6)
Full professor (13)
Associate professor (10)
Assistant professor (6)
Postdoctoral researcher (5)
PhD student (7)

other organizations and institutions, interactions, processes and procedures' (*ibid*). Such a system contains not only universities, related research institutes and funding agencies but also governmental organizations, commercial businesses 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.

Adopting a structuration perspective (Giddens, 1984), the research system can be seen as the structure influencing the agency of individual researchers. Existing structures are the product of practices and of dominant visions on the potential value of research outcomes. The institutions within this system give rise to certain conversions of credibility – for example, the possibility to convert recognition into money (Packer and Webster, 1996, Hessels and van Lente, 2011).

Simultaneously, funding bodies – it is presumed – 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. So, the research system can be seen as a structure that shapes research practices but is, at the same time, (re)produced by these practices.

Methods

A case study approach (Yin, 2003) was used, focussing on eight scientific fields in the Netherlands selected to represent the variety of possible societal stakeholders of natural science (see Table 1). In each case, the discipline was studied for the period between 1975 and 2005. We chose 1975 as the starting point because this marks the beginning of a national government science policy in the Netherlands (Blume, 1985) that is generally considered to be a key event in the changing relationship of academic science with its societal context.

Data for the case studies have been drawn from in-depth interviews and analysis of the relevant literature. For the credibility cycle analysis of changing struggles for relevance, semi-structured in-depth interviews with 47 academic researchers were carried out. The respondents' academic status 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.[3]

Our analysis of the changing structural conditions of academic research is based on documents[4] combined with interviews with scholarly experts and representatives of firms, professional organizations, research councils and the government. The documents were selected on the basis of the prior knowledge of the authors, suggestions from interviewees, and the 'snowball method' (in which referrals from initial subjects generate additional subjects, and so on). The selection includes governmental policy documents, reports and strategic plans of research councils, foresight studies, evaluations and other important publications about the disciplines concerned. The findings from these documents were triangulated in interviews with the experts and stakeholders mentioned above.

Results

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

Diversification of funding

The first general structural change is a trend of funding diversification. In all the 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 public science systems (as opposed to those in the private sector), budgets have come 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 relaxed state control and introduced market mechanisms to enhance efficiency and effectiveness (de Boer *et al*, 2007). 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 and Salerno, 2003). Around 1975, this funding stream was still sufficient for research groups to purchase necessary equipment and hire some temporary staff: now, however, some of the permanent academic staff need to be paid from project funding – and even that funding which has remained in this category has become less secure, as it has become subject to university policy and it is often required to 'match' externally acquired funds (Jongbloed and 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 since been merged and reorganized into a general matrix organization supplying most funding in the form of multidisciplinary research programmes. While originally Dutch research councils exclusively funded basic research, they have expanded their territories to include application-oriented activities. Moreover, the Dutch Organization for Scientific Research (NWO, the new umbrella organization encompassing all research councils) has developed a variety of hybrid funding configurations in collaboration with ministries, firms or other knowledge users.

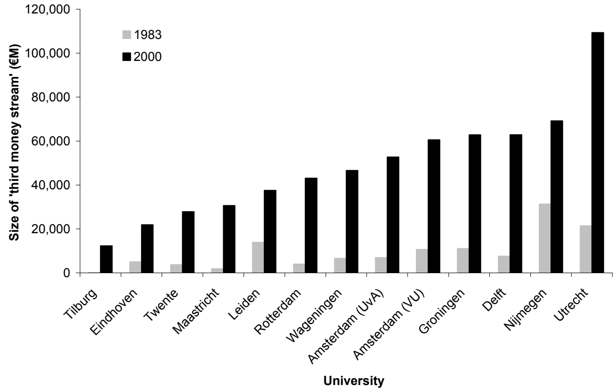

Figure 1. The size of the 'third money stream' in 1983 and 2000 (in current prices) at Dutch universities.
Source: Jongbloed and Salerno, 2003.

In addition, the third money stream (all contract funding except that from NWO), which is more strongly oriented to practical applications, shows a spectacular increase in the 1980s and 1990s in all Dutch universities (see Figure 1). Between 1983 and 2000 the total size of this stream has increased from about €125 M to about €638 M. This represents an increase by a factor of 3.85 in real terms (Jongbloed and Salerno, 2003).

Simultaneous with this major shift towards application-oriented funding, however, a less pronounced trend occurred in the opposite direction. Over the last decade, the research council's policy to nurture and stimulate first-class 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 important deciding factor is the quality of the individual 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 present the grants under this scheme consume about 20% of NWO's total budget.[5] However, the relative impact of this funding instrument is probably larger than its financial contribution, because of its prestige and popularity.[6]

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 evaluation of academic research groups (van der Meulen, 2008). Currently, every research group in the Netherlands is subject to regular evaluations. Research quality assessments officially use a variety of criteria, but in practice they tend to be dominated by bibliometric quality indicators: even if other dimensions such as viability or relevance are also measured, in the interpretation of the evaluation scores it is numbers of publications and citation rates that dominate.[8] The availability of digital bibliometric databases and the relative generic validity and cross-comparability of these indicators has resulted in their achieving recognition and success that is not equalled – yet – by any other indicators (Gläser and 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.

Common trends in the credibility cycle

What has been the effect 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 (see Figure 2).

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 increased. Some researchers now collaborate to such an extent with knowledge users that they regard 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 proportion 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 level of importance have grown. In fields such as catalysis, animal breeding genetics (ABG) and toxicology most

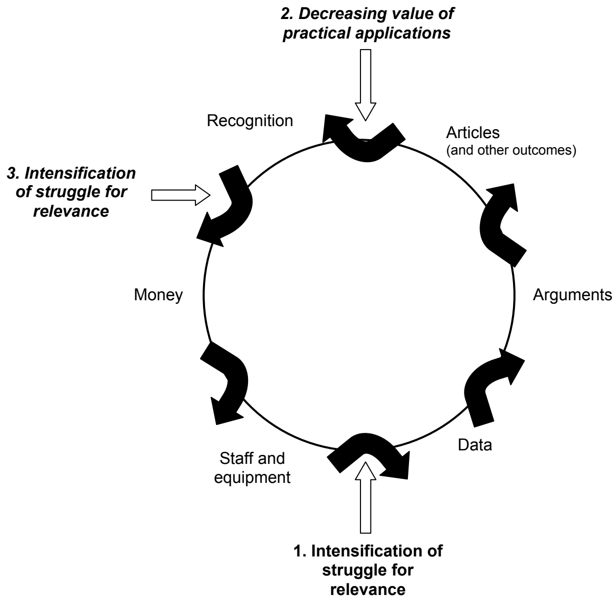

Figure 2. The three common trends in the struggles for relevance of eight fields of natural science, depicted in the credibility cycle.
Source: Adapted from Latour and Woolar (1986).

projects are supervised by an industrial sponsor or by a 'users committee'. These receive regular updates about progress and provide feedback for future directions. In other fields, such as animal production systems (APS) and environmental chemistry, it has become common practice to conduct academic research projects in collaboration with applied researchers employed by public research institutes or private R&D laboratories. 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 in the laboratory. It should also be noted that there are fields in which researchers still hardly interact directly with societal stakeholders – in particular, biochemistry and cell biology.

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 achieve 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 [sic], 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 face the simple choice: 'publish or perish'. A strong publication list has become a crucial condition in order to qualify for particular types 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 show that scientists are aware of the importance of scientific publications during the whole credibility cycle. Data collection is organized in such a way as to optimize the prospects for publication. 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 strategies which might be regarded as 'cheating' are pursued, such as 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 displaced – further – 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 material for publication in scientific journals, the societal relevance of the reported research does not play a significant role. Editors and peers largely decide whether or not to publish papers based on purely scientific considerations such as 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.

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 has now become the outcome of active acquisition efforts. Our interview data give 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 securing 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 they manage to specify convincingly 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)

There are possibilities for obtaining funding for research in the Netherlands without having to commit to producing societal benefits, mostly occurring at the national research council (NWO). However, such funds provided a substantial share of their budget for only a few of the 47 researchers interviewed.

Changing struggles in different scientific fields

To a certain extent the three common trends presented above 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 of 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: the fourth concerns the tension that has arisen in some fields due to the combination of these trends.

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 significantly 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. The fourth dimension that deserves to be addressed here is the relationship between practical applications and scientific publications: in some fields there is synergy between scientific productivity and practical relevance; in other

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

Credibility conversion	Variable	Observed range
Acquiring data	Intensity of stakeholder interactions	Low–High
Acquiring recognition	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

fields there is conflict. 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.

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 complained 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 affording 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 move to other model systems (for example, using chickens rather than mice for research projects), or 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 also exists, but it is weaker in 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 met, 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 grown significantly, we observed a synergy rather than a trade-off between scientific productivity and societal relevance. Interactions with stakeholders not only help to acquire funding but are also helpful in other credibility conversions. We identified three mechanisms that are responsible for this

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

Relationship practical applications and scientific productivity	Field	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

synergy. First, applied research projects for stakeholders can provide access to data that are also useful for more fundamental investigations. Second, the interactions with stakeholders often provide inspiration for challenging research questions. Third, some stakeholders simply sponsor fundamental research activities from which they expect benefits to be derived in the long term.

As Table 4 indicates, the relative value of applications – as 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 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 based not only on contributions to scientific debate but also on 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 such as sustainable development.[9] In the same vein, they also value their colleagues' practical contributions to such goals, more so than do scientists in fields such as catalysis or toxicology.

Discussion: explaining field differences

To recapitulate our empirical findings, 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 identified 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 between scientific productivity and practical applications, in others there was synergy. How can we explain the differences in the changing struggles for relevance of scientific fields? The remainder of this paper will present a possible explanation based on socio-organizational, cognitive and cultural field-characteristics, combined with the characteristics of societal stakeholders.

Table 5. Classification of fields based on 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

Variation in stakeholder interactions

Our empirical analysis has shown 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 cannot easily develop a new, application-oriented research direction.

In divergent fields, such as APS and environmental chemistry, it may be more likely that niches develop which meet the knowledge needs of societal stakeholders. Divergent fields typically have a high strategic task uncertainty: this means that a wide diversity of concurrent research directions is accepted 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 deviation. In such fields it is easier to develop new research directions that fit the needs of societal stakeholders.

Variation in the value of practical applications

The extent to which practical applications are valued 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 and Trowler, 2001) because they are not highly competitive and have a low people-to-problems ratio. In 'rural' fields, such as APS and environmental chemistry, relatively few researchers work on a large number of dispersed problems and mutual competition is limited. Because there is no broad consensus about overall quality standards, it is also difficult to formulate general evaluation criteria. Because of 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 fewer high-impact journals are available, which makes it more difficult to achieve high scores in bibliometric evaluations. This implies that bibliometric quality indicators have limited validity, so that it is less likely that recognition will be based on publications alone and more likely that practical outcomes such as policy advice, patents or spin-off firms are also valued. In urban fields, with a high citation density, bibliometric quality indicators will be used more abundantly, not only in formal evaluations and management decisions but also in informal processes of exchanging recognition.

Variation in 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 participants in the research system, in particular the end-users of academic research. Depending on its cognitive content, each field has different potential users outside academia. Of particular importance are 'upstream end-users', stakeholders with formal channels to influence the strategies and programmes of a scientific field through research funding, regulation, or policy (Lyall *et al*, 2004). In our case studies, the fields that were most successful in combining stakeholder interactions with academic performance were those with wealthy and powerful upstream end-users having a long-term vision of the utility of scientific research (see Table 6). The chemical industry (in the case of catalysis) and the animal breeding industry (ABG) both invest substantial sums in academic research, in the expectation that there will be payback in the long term. Such companies support academic researchers in fundamental research activities, which in turn provide good opportunities for high-impact publications. In this way, the companies support scientists through the complete cycle of credibility. The same is true for environmental policy makers and oil companies, in the case of paleo-ecology.

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

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

Biochemistry and cell biology, in contrast, have hardly any upstream end-users, although stakeholders – such as patient groups, farmers or veterinary surgeons – can of course be identified that may eventually benefit from these research activities. These stakeholders, however, function rather more as 'downstream' users, because they are not active players in the academic research system; they do not directly commission research or influence its directions. The only participants providing generous (that is, substantial) support for these fields and directly influencing their directions are research councils (at both national and European level); but they function more 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 related to 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 inhibit others (publishing).

Another significant variable is the homogeneity of the upstream end-users in 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 identify and develop 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 missions. In some fields, such as catalysis and ABG, we have observed a synergistic relationship between societal impacts and scientific excellence. In other fields, however, such as 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 implications and implementation of their work. In these areas, research activities addressing the knowledge needs of societal stakeholders are not easily published in scientific journals. The increased publication pressure here inhibits the shift towards application-oriented research modes.

Second, our work indicates that a further differentiation is needed, because the dynamics of science varies much more across scientific fields than most literature suggests. This study adds to a number of other recent investigations that have reported varying reactions to institutional changes across scientific disciplines (Gläser *et al*, 2010; Reale and Seeber, forthcoming; Albert, 2003). This study confirms their call for disciplinary differentiation in science policy studies. Moreover, it reinforces it with a call for an even more fine-grained perspective that discriminates not only within complete disciplines but also within specific fields. Some of the diagnoses of changing science systems differentiate across scientific fields or disciplines – in particular, literature about post-normal science, finalization in science, Triple Helix and innovation systems. However, none contains a satisfactory framework for understanding the varying dynamics of scientific fields. Our study has indicated some possible building blocks for such a framework, in particular the concepts of search pattern regimes (Bonaccorsi, 2008), strategic task uncertainty (Whitley, 2000), communication culture (Becher and Trowler, 2001) and upstream end-users (Lyall *et al*, 2004).

Notes

[1]The idea of 'struggles for relevance' was coined by Rip (Rip, 1988) in an analysis of changing science systems. He observed that with the emergence of '...a new layer of institutions, explicitly oriented to "missions", to programming, to strategic mobilization' in the 1970s and 1980s a shared repertoire for judging relevance had also emerged. This development gave rise to struggles for relevance, '...on top of struggles for fundability' (Rip 1988, p 70). In this paper we adopt the idea of 'struggles for relevance' in a generalized sense: we consider these struggles for relevance as a universal aspect of academic research with different manifestations over time and place.
[2]Personal preference is known to be a very important criterion in scientific problem choice (Cooper, 2009).
[3]NVivo is proprietary software used for data classification and analysis. See also: http://www.qsrinternational.com/products_nvivo.aspx, last accessed 24 August 2011.
[4]A list of documents is available on request.
[5]NWO (2010), 'Begroting 2010 en meerjarencijfers 2011 tot en met 2014', NWO, Den Haag.
[6]Between 2000 and 2006 the success rate of this funding instrument was only 20% (Technopolis and Dialogic, 2007), while the overall average success rate at NWO was about 50% (see NWO (2005), *Jaarboek 2004*, NWO, Den Haag).
[7]VSNU, NWO & KNAW (2003), *Standard Evaluation Protocol 2003–2009 for Public Research Organisations*.
[8]The newest protocol for Dutch research evaluations demands more explicitly 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.
[9]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).

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