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Factors associated with disciplinary and interdisciplinary research collaboration

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ABSTRACT

There is a lack of understanding regarding the optimal conditions for interdisciplinary research. This study investigates what characteristics of researchers are associated with disciplinary and interdisciplinary research collaborations and what collaborations are most rewarding in different scientific disciplines. Our results confirm that female scientists are more engaged in interdisciplinary research collaborations. Further, a scientist's years of research experience are positively related with both types of collaboration. Work experience in firms or governmental organizations increases the propensity of interdisciplinary collaborations, but decreases that of disciplinary collaborations. Disciplinary collaborations occur more frequent in basic disciplines; interdisciplinary collaborations more in strategic disciplines. We also found that in both types of disciplines, disciplinary collaborations contribute more to career development than interdisciplinary collaborations. We conclude with three recommendations for science and innovation policy, while emphasising the need to distinguish between different scientific disciplines.

1. Introduction

Leading institutions claim that many of the complex problems society is currently facing (e.g. in the area of health care, mobility or the environment) demand innovative solutions that combine knowledge from different scientific disciplines (National Academies, 2005). These combinations can be achieved by conducting interdisciplinary research. Interdisciplinary research leads 'researchers in different disciplines to meet at the interfaces and frontiers of those disciplines and even to cross frontiers to form new disciplines (National Academies, 2005, p.16).' A variety of scholars have argued that interdisciplinary science has a positive influence on knowledge production and innovation (e.g. Gibbons et al., 1994; Rhoten and Pfirman, 2007; Schmickl and Kieser, 2008). Today, interdisciplinarity is stimulated by a variety of funding instruments, on the university level (Sa, 2008), on the national level (Lepori et al., 2007), and on the international level (Bruce et al., 2004). The goal of many of these programs is to stimulate collaboration among individual researchers as a means to promote interdisciplinarity. However, these programs operate mainly at an institutional level and there are serious doubts concerning their effects (Metzger and Zare, 1999; Rhoten, 2004). For example, when using citation patterns as an indicator for interdisciplinarity, only a modest increase is found over time (Porter and Rafols, 2009).

Scientifically, much has been written about interdisciplinary research collaborations (e.g. Porter and Rafols, 2009; Rhoten, 2004; Porter et al., 2007; Thompson Klein, 1990; Carayol and Thi, 2005), most of which is based on bibliometric or citation data. Based on these results many recommendations about institutional arrangements have been made to better facilitate interdisciplinary research collaboration (see for example: National Academies, 2005; Porter et al., 2006; Metzger and Zare, 1999). Still, relatively little is known about the characteristics of individual researchers that increase the likelihood of engaging in interdisciplinary research (Rhoten and Pfirman, 2007). Understanding these individual characteristics is important, because it is the individual researcher who has to engage in the research collaborations and who has to produce the scientific result that contributes to the solution of the societal problem. The aim of the current paper is to empirically explore which characteristics of researchers are associated with disciplinary and interdisciplinary research collaboration and which type of research collaborations are most rewarding in different scientific disciplines. Gaining insights into these characteristics enables policy makers, funding agencies and research institutes to stimulate interdisciplinary research collaboration by targeting specific segments of researchers. Moreover, a better understanding of the 'rewards' of (inter)disciplinary collaborations provides starting

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points for enhancing the incentives for interdisciplinarity, which are claimed to be insufficient (National Academies, 2005). Therefore, we also test whether either disciplinary or interdisciplinary research in different scientific disciplines is related to academic career advancement.

Our empirical study consists of a survey conducted among researchers of Utrecht University, a broad research university in the geographical centre of the Netherlands. This dataset has been used in a previous study by Van Rijnsoever et al. (2008). That study explained research collaboration among university researchers and industry from a resource based perspective, but did not address the interdisciplinary dimension specifically.

The remainder of this paper is organized as follows: Section 2 will briefly introduce some motives for (inter)disciplinary research collaborations. Section 3 introduces the dependent variables in our models. In Section 4 we present our independent variables and formulate a set of hypotheses. Section 5 gives the research methods; Section 6 contains our empirical results. The discussion and implications are given in Section 7.

2. Motives for research collaboration

In the literature many reasons have been reported for individual research collaboration, these include: access to expertise, access to instruments, cross fertilisation across disciplines, improving access to funds, obtaining prestige or visibility, learning tacit knowledge about a technique, pooling knowledge for tackling large and complex problems, enhancing productivity, educating a student, increasing specialization of science, and fun and pleasure (e.g. Melin, 2000; Katz and Martin, 1997; Bozeman and Corley, 2004; Rafols and Meyer, 2007).

These reasons partly point to personal motives. Individuals may be intrinsically motivated to collaborate, simply because they enjoy social interactions, or because they are encouraged by a challenging research question which they cannot tackle all by themselves. From a sociological perspective, however, there are also utilitarian drivers for collaborations. If the scientific system is regarded as a social structure that enables and constrains the behaviour of individual researchers, then it either stimulates or inhibits particular collaborations. Scientists aim to build a reputation and to earn peer recognition (Whitley, 2000). Their actions are oriented at gaining 'credibility' (Latour and Woolgar, 1986), different forms of symbolic capital that will help them sustain and expand their positions and activities. Successful collaborations can help to deliver publications, which yield recognition. This will help to acquire additional funding, which in turn forms the basis for new research activities. In today's funding regime, collaborations can also directly help to get funding, as many research councils have programs to stimulate (specific forms of) collaboration (Potì and Reale, 2007). Collaborations do not have benefits only, however, there are costs involved, in terms of time, money and management efforts (Katz and Martin, 1997).

In the case of interdisciplinary collaborations the transaction costs are higher than for 'regular' disciplinary collaborations, due to the cognitive distance between the parties involved (see Nooteboom, 2000). Some researchers may be intrinsically motivated, because they like to learn from distant disciplines of science or because they have come across a specific research topic that they can not tackle without the input from an additional discipline. However, they may also be motivated by expected future benefits in terms of publications, recognition and funding (Melin, 2000). Still, it is generally assumed that interdisciplinary research collaborations are less rewarding than disciplinary collaborations in terms of publications, recognition and career advancement (De Boer, 2006; Levitt and Thelwall, 2008).

3. Dependent variables

3.1. Disciplinary and interdisciplinary research collaboration

In the literature various definitions of interdisciplinarity occur (Thompson Klein, 1990; Porter et al., 2006; Hessels and van Lente, 2008), but they all point in the same direction. According to Gibbons et al. (1994, p. 29): "interdisciplinarity is characterized by the explicit formulation of a uniform, discipline transcending transcending methodology or a common methodology." Qin et al. (1997) define interdisciplinary research as: "the integration of disciplines within a research environment". van Raan and van Leeuwen (2002) state that: "typical interdisciplinary research is based on many different fields, each having their own community". A recent definition comes from Rhoten and Pfirman (2007), who state that: "interdisciplinary refers to the integration or synthesis of two or more disparate disciplines, bodies of knowledge, or modes of thinking to produce a meaning, explanation, or product that is more extensive and powerful than its constituent parts".

These definitions all share the notion that more than one scientific discipline has to be involved in the research project in order to be interdisciplinary. In this paper disciplinary research collaboration is defined as: "the collaboration between scientists from the same discipline with the goal of producing new knowledge." Interdisciplinary research collaboration is defined as: "the collaboration between scientists from different disciplines with the goal of producing new knowledge." The participating scientists often have different educational backgrounds, though this is not always the case. The distinctive feature of interdisciplinary collaboration is rather that scientists bring in skills, techniques or concepts originating from different disciplines. Also note that our definition does not imply that organizational boundaries are crossed; interdisciplinary collaborations can occur within university departments as well.

3.2. Academic rank

Our second dependent variable is a researcher's academic rank in terms of the path to a full professorship. A promotion in academic rank can be seen as a reward a researcher receives for his or her research success. Conducting the right type of research and engaging in the right type of collaboration contribute to this success. Collaboration and academic rank co-evolve over time, there is no clear causality. Higher academic rank often leads to more collaboration, but collaboration is also an important resource in the advancement of an academic career (Van Rijnsoever et al., 2008).

4. Independent variables

The independent variables that are used to predict our dependent variables are global innovativeness (a personality trait), work experience, dynamics of the scientific field, scientific discipline, gender and academic rank. This set of variables captures intrinsic motivations, opportunities from the past and environmental demands. For each variable hypotheses are proposed about their relationship with the dependent variables.

4.1. Global innovativeness

Since our study focuses on individual researchers with intrinsic motivations, it is appropriate to take into account personality traits. Prior research has shown that personality characteristics influence job performance (Mccloy et al., 1994) and career advancement (Creed et al., 2004; Baruch and Hall, 2004; Kuncel et al., 2004; Chin et al., 1998). Here we will confine ourselves to one personality trait: global innovativeness. This can be defined as the degree to which an individual is receptive to new ideas and makes innovation decisions independently of the communicated experience of others (Midgley and Dowling, 1978; Van Rijnsoever and Donders, 2009). Global innovativeness can be a valuable resource for a scientist, because knowledge production is all about having new ideas and exploring the unknown (Van Rijnsoever et al., 2008).

Global innovativeness is a continuum between adaption and innovation (Kirton, 1976; Kirton, 2003). In problem solving, people either try to improve on existing solutions (adaption) or they try to find new solutions (innovation). Adaptive individuals, on the one hand, are known to be precise, reliable, think within existing frameworks and prefer to work with well established procedures. They are more methodological and thorough. Innovators, on the other hand, are less focussed on details and less reliable, but they come up with new perspectives and are more likely to challenge rules and authority (Kirton, 1976). Because of their new perspectives, innovators depend more on other people to help them implement their broader spectrum of ideas. Adaptive individuals, however, perform best in a stable group on which they can depend; this reduces the need for a larger network. Innovative researchers engage more in research collaborations in general (Van Rijnsoever et al., 2008). Moreover, since they seek solutions outside existing structures (Kirton and de Ciantis, 1994), innovative individuals should be more able to step outside existing disciplinary boundaries. Based on the prior theoretical notions, we expect positive relationships between global innovativeness and both disciplinary and interdisciplinary research collaboration.

Hypothesis 1a. There is a positive relationship between global innovativeness and disciplinary research collaboration.

Hypothesis 1b. There is a positive relationship between global innovativeness and interdisciplinary research collaboration.

4.2. Gender

Usually gender is a control variable in behavioural models. However, a recent paper by Rhoten and Pfirman (2007) provided evidence that female scientists are more inclined to step outside their disciplinary boundaries than their male counterparts. This difference can have either biological origins (see for instance Haier et al., 2005) or cultural origins (see for instance Fehr, 2004): women seem better able to see and make connections between ideas and the larger context. Further, in terms of learning styles: women are claimed to be more inclined to work in groups while men prefer to work independently (Severiens and Tendam, 1994). Empirically McDowell et al. (2006) showed that, although in the past men were more likely to collaborate, over time women have become equally likely to collaborate in research. Further, Long (1992) claims that although there are differences in scientific output, there are no differences between men and women with regard to research collaboration. Finally, Van Rijnsoever et al. (2008) also only found small or no differences between men and women in the amount of network activity.

Considering that many earlier studies found no differences between men and women with regard to research collaboration, but that Rhoten and Pfirman (2007) argue that women are more interdisciplinary, we hypothesize:

Hypothesis 2a. There is no difference between male and females researchers with regard to disciplinary research collaboration.

Hypothesis 2b. Female researchers engage more in interdisciplinary research collaboration than male researchers.

4.3. Work experience

We distinguish two dimensions of previous work experience: the length of a scientist's career and the number of previous employements the researcher has had at universities, in industry, the government or at other relevant research institutes.

The longer a scientist has been active, the more opportunities he or she has had to build networks (Lee and Bozeman, 2005). One may thus expect a positive influence on both types of collaborations. Van Rijnsoever et al. (2008) found an inverted U-shaped relationship for the relationship between work experience and research collaboration. The turning point of these curves depended on whether the network activity was inside the faculty or with other universities. After a number of years the researcher may become more independent. The knowledge supplied by the network becomes incorporated into the researchers' individual knowledge base, which decreases the necessity to continue collaborating with others. This explains the inverted U-shape in the relationship between years of working experience and network activity.

Following this line of reasoning, we also expect an inverted U-shaped relationship between work experience and both disciplinary and interdisciplinary research collaboration.

Hypothesis 3a. There is an inverted U-shaped relationship between work experience and disciplinary research collaboration.

Hypothesis 3b. There is an inverted U-shaped relationship between work experience and interdisciplinary research collaboration.

Van Rijnsoever et al. (2008) also found that having more previous employers contributed to network activity. A diverse labour history is positively related to research collaboration, because researchers keep using their contracts from earlier days (Melin, 2000). There might be a difference in the type of previous employers, but we have no reason to expect any clear differences between disciplinary and interdisciplinary research collaboration.

Hypothesis 3c. There is a positive relationship between the number of previous employers and disciplinary research collaboration.

Hypothesis 3d. There is a positive relationship between the number of previous employers and interdisciplinary research collaboration.

4.4. Dynamics of the scientific field

By the dynamics of the scientific field we mean the extent to which an individual researcher experiences the own scientific working field to change. Environmental change enhances the need of an individual to find new behaviour patterns or resources that enable the actor to adapt to new environmental demands (Richerson and Boyd, 2005; Bessant et al., 2001). In the case of a scientific researcher these might entail materials or knowledge (Melin, 2000). These materials and knowledge can come from within the own discipline or they can be borrowed from another discipline. Therefore a positive relation is expected for both disciplinary and interdisciplinary collaboration.

Hypothesis 4a. There is a positive relationship between dynamics of the scientific field and disciplinary research collaboration.

Hypothesis 4b. There is a positive relationship between dynamics of the scientific field and interdisciplinary research collaboration.

4.5. Basic and strategic disciplines

Past research has shown that the degree of collaboration differs across disciplines (Melin and Persson, 1996; Van Rijnsoever et al., 2008). The number of collaborations in medicine, for example, is higher than in mathematics (Liberman and Wolf, 1998). The scientific discipline the researcher is working in may also have an influence on the prevailing type of research collaboration. For example, bibliometric analysis shows that the average share of interdisciplinary citations varies across disciplines (Porter and Rafols, 2009; Lariviere and Gingras, 2010).

Scientific disciplines vary in terms of their social, cognitive and cultural characteristics. Disciplines can be classified in terms of their social organization, using variables like task uncertainty and mutual dependence (Whitley, 2000). Another scheme distinguishes various 'search regimes', based on the rate of growth, degree of diversity and level and type of complementarities (Bonaccorsi, 2008). Alternatively, disciplines can be typified as different 'epistemic cultures', depending on the 'machineries' they employ in the production of knowledge (Knorr-Cetina, 1999).

The distinction we employ here is the difference between basic and strategic disciplines. Following Biglan (1973), Becher and Trowler (2001) state that, the 'degree of concern with application' varies across disciplines. The activities of different disciplines are oriented in varying degrees towards practical applications or contributions to society or the economy. Physics and chemistry, for example, can be regarded as 'basic' disciplines as they are relatively autonomous and primarily aim to develop fundamental knowledge about matter, life or the universe. Disciplines like medicine or human geography, however, are more strongly connected with practical applications (health care and public planning, respectively). We call the work of these disciplines 'strategic' research, defined as: 'basic research carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised current or future practical problems' (Irvine and Martin, 1984). Strategic research differs from applied research, because it is not *directly* oriented at solving practical problems. The results of strategic research rather 'contribute to a reservoir of scientific knowledge and technological options, while it are others who fish in the reservoir and create new combinations' (Rip, 2004).

The distinction between basic and applied disciplines is considered most relevant here, because interdisciplinarity is often associated with application oriented research and complex problem solving (see National Academies, 2005). The concept of 'Mode 2 knowledge production' (Gibbons et al., 1994), for example, implies that the degree to which researchers are oriented towards practical applications correlates with the degree of interdisciplinarity. Indeed, a recent study has shown that the collaboration networks in the strategic field of nanoscience are on average more interdisciplinary than in (basic) astrophysics (Jansen et al., 2010). There is little other empirical evidence for the relationship between interdisciplinarity and degree of concern for applications, therefore it deserves further empirical investigation (Heimeriks et al., 2008; Hessels and van Lente, 2008).

Although Becher and Trowler (2001) claim that a discipline's degree of concern with application should be seen on a continuous scale, and most disciplines include both basic and strategic research activities, it is helpful for the analysis presented in this paper to work with a simplified two-category model.

We expect that interdisciplinarity occurs more in strategic disciplines than in basic disciplines, because the solution of practical problems often requires input from more than one scientific discipline.[2] This does not imply a relationship between type of discipline and *disciplinary* collaboration.

Hypothesis 5a. There is no difference in number of disciplinary research collaborations between researchers working in basic disciplines and researchers working in strategic disciplines.

Hypothesis 5b. Researchers working in strategic disciplines engage more in interdisciplinary research collaboration than researchers working in basic disciplines.

Our second dependent variable is academic rank. Past research has shown that academic career advancement is related to the right types of network activity, but that this relationship is non-causal (Van Rijnsoever et al., 2008). In general the rule applies that the more senior a researcher is, the more years of working experience he has had and the more likely it becomes that a network has been built (Lee and Bozeman, 2005). Further, a larger network increases a researcher's productivity in terms of scientific output (Liberman and Wolf, 1998) which is one of the prime determinants for career advancement (Bozeman and Corley, 2004; Baruch and Hall, 2004).

If basic disciplines indeed demand more disciplinary collaboration and strategic disciplines demand more interdisciplinary collaboration (as is claimed in Hypotheses 5a and 5b), then engaging in the 'right' type of collaboration should also be reflected in terms of the researchers academic rank. From this it follows that:

Hypothesis 5c. In basic disciplines, the amount of disciplinary research collaboration is positively related to academic rank, but the amount of interdisciplinary research collaboration is not.

Hypothesis 5d. In strategic disciplines, the amount of interdisciplinary research collaboration is positively related to academic rank, but the amount of disciplinary research collaborations is not.

5. Methods

A survey was administered among the scientific employees[3] working at Utrecht University in June 2006. This is a large and broad research university in the geographical centre of The Netherlands, in which all major scientific disciplines are incorporated. The survey was administered at the faculty of science, the faculty of geosciences and the academic biomedical cluster. To ensure a high response, during a period of 2 weeks all scientific employees of these faculties were approached personally and asked to fill in the questionnaire. The response was 303 usable questionnaires; the response rate was approximately 17%; the age of the respondents varied between 23 and 74 years, with a mean of 36. There were 209 male respondents and 94 females. The questionnaire enquired about the researchers' research collaborations, past occupations, their current status of employment, the nature of their research, and their global innovativeness.

The entire university has approximately 43% women employed in a scientific function (Utrecht University, 2005), but because our sample contained only exact sciences, our percentage is somewhat lower. Appendix A displays the percentages of the current academic function of the observed sample with the actual distribution of functions at the entire university (Utrecht University, 2005); data for all separate departments or faculties was not available. As can be seen our sample has notably less assistant professors and more PhD students. This can partly be explained by the fact that the faculties in our sample have a relatively high amount of PhD students, compared to other faculties and less assistant professors.

Research collaboration can be assessed from the perception of the respondent, or by measuring their co-authorships. In the past, bibliometric methods have proven to be practical tools for the study of research cooperation (e.g. Oh et al., 2005), but their validity is contested (Laudel, 2002; LaFollette, 1992). Therefore we chose to measure research collaboration from the perception of the respondent. First, respondents were asked to state in which discipline they worked. Next, respondents were asked to self-report

[2] For clarification: we emphasize that our notion of 'strategic disciplines' does not *imply* interdisciplinarity; it only refers to the degree in which a discipline is oriented to practical applications. So whether strategic disciplines are more interdisciplinary than basic disciplines is not given by definition, but is an empirical question.

[3] In The Netherlands, PhD students are also fully paid employees of the university and therefore included in the sample.

the number of disciplinary and interdisciplinary collaborations for research purposes. These two numbers were added to form an indicator for total collaboration. Further, the data suggest that many respondents only gave an approximation of the total number of collaborations, instead of an exact number (for example, respondents were inclined to report approximately 20 collaborations instead of the exact value). This is a source of measurement error and it gives problems with the distribution of the data. Therefore, the data was binned into several ordinal categories. The binning aimed at having twenty cases per category. This resulted in 11 categories for total collaboration, 9 categories for disciplinary collaboration and 6 categories for interdisciplinary collaboration.

Global innovativeness was measured with a translated, adapted version of the innovativeness scale by Kirton (1976). The scale consists of 32 five-point items, with scores ranging theoretically between 32 points (extremely adaptive) and 160 points (extremely innovative).

Utrecht University has organized its research activities in various (mostly) disciplinary departments. Based on their self-presentation on the website of Utrecht University (www.uu.nl), and on the classification by Heimeriks et al. (2008),[4] we have characterized each department as either basic or strategic science, depending on their degree of concern with application. In the resulting classification the 'traditional' natural sciences all belong to the category of basic science. The research in these disciplines produces fundamental knowledge, not necessarily related to practical applications. The disciplines designated as 'strategic' all have a strong relationship with one particular 'context of application'. The outcomes of research in these disciplines can be directly applied in domains like health care, pharmaceutical industry or environmental policy.[5]

The other variables were measured with the use of single items, because they are relatively straightforward. Table 1 presents the descriptive statistics of the variables, Appendix B shows the correlation matrix.

Because the dependent variable consists of ordinal categories, three ordinal regression models (McCullagh, 1980; McCullagh and Nelder, 1998) were fitted. The dependent variable in the first model was the total number of research collaborations. The main function of this model is to verify weather it yields similar results compared to model by Van Rijnsoever et al. (2008), which used more complex measures to measure research collaboration. If the results of the model are similar to those of Van Rijnsoever et al. (2008), the validity of our measure for collaboration is increased. The dependent variables of the next two models are disciplinary and interdisciplinary research collaboration.[6]

Finally, to test the effects of interdisciplinary and disciplinary research collaboration on academic rank, an ordinal regression model was fitted, with the 'basic-strategic' variable interacting with the degree of disciplinary and interdisciplinary research collaboration. The other variables were added as controls.

6. Results

Table 2 displays the results of the ordinal regression models predicting research collaboration, all estimators are unstandardized.

Table 1
Descriptive statistics.

	Mean	S.D.
Dependent variables		
Total collaboration	Median = 6 (10 collaborations)	
Disciplinary collaboration	Median = 5 (7–8 collaborations)	
Interdisciplinary collaboration	Median = 3 (2 collaborations)	
Academic rank	Median = 2 (PhD Researcher)	
Independent variables		
Global innovativeness	98.57	11.15
Gender: Male (1)	*N* = 209 (69.0%)	
Gender: Female (2)	*N* = 94 (31.0%)	
Years of work experience	10.09	10.90
Number of previous universities	1.32	0.96
Number of previous firms	0.57	1.17
Number of previous governmental organizations	0.16	0.44
Number of previous other relevant institutes	0.24	0.82
Dynamics of the scientific field	3.77	1.06
Basic disciplines: mathematics, physics and astronomy, chemistry, earth sciences, physical geography, biology	*N* = 162 (53.5%)	
Strategic disciplines: informatics, medicine, veterinary sciences, pharmacy, human geography and planning and the Copernicus Institute for sustainable development and innovation	*N* = 141 (46.5%)	

To allow for a comparison of effect sizes, the Wald chi-square is given between brackets. The second column contains predictors for total collaboration, the third column contains the predictors for disciplinary collaboration and the final column contains the predictors for interdisciplinary collaboration. Disciplinary and interdisciplinary research collaboration are mildly correlated (Spearman's $\rho = 0.290$, $p < 0.001$).

The model predicting total collaboration is highly significant. Years of work experience does not appear to be significant. However, the correlation matrix (see Appendix B) indicates that there is a relationship between work experience and total collaboration. It is likely that the other variables in the model explain the effect of years of work experience. An additional model in which only the years of work experience variables are used as predictors shows that there is an inverted U-shaped relationship (result not shown here), with the turning point at 22.70 years of work. Previous number of universities and other research institutes are both positively related to total collaboration. Dynamics of the scientific field is also positively related to total collaboration. These results are in line with the findings by Van Rijnsoever et al. (2008); this provides support for the validity of the measurement of collaboration.

Both the model predicting disciplinary research collaboration and the model predicting interdisciplinary research collaboration are highly significant. Global innovativeness has a positive effect on disciplinary collaboration, but not on interdisciplinary collaboration; only hypotheses 1a is thus confirmed. Innovative individuals collaborate more within their own disciplines, but not outside.

As predicted by Hypothesis 2a there is no difference between male en female researchers with regard to disciplinary collaboration; this is in line with earlier observations (see McDowell et al., 2006). However, women engage more in interdisciplinary research collaboration, which confirms Hypothesis 2b and is in line with the previous claims by Rhoten and Pfirman (2007).

Following Van Rijnsoever et al. (2008), Hypothesis 3a predicted an inverted U-shape between years of working experience and disciplinary research collaboration. Again, the model shows no relationship, but the correlation matrix does. An additional model with only years of working experience as predictors shows inverted U-shaped relationships between working experience and both types

4 Heimeriks et al. (2008) classified eight fields in terms of Mode 1 and Mode 2, which roughly correspond with basic and strategic research. We prefer the categories basic and strategic, because the notion of Mode 2 implies that application-oriented research is more interdisciplinary than basic research, while we regard this as an empirical question.

5 We are aware of the limitations of this classification, as disciplines are heterogeneous entities and the degree to which they are oriented at practical applications should probably be seen on a continuous rather than a discrete scale. However, for our purposes it does make sense to cluster the disciplines.

6 No control variables were used in these models, adjunct functions were considered as predictor, but no significant effects were found.

Table 2
The results of the ordinal regression models predicting research collaboration. Unstandardized estimators are given with Wald chi-squares between parentheses: $^{*}p < 0.05$, $^{**}p < 0.01$.

	Total collaboration		Disciplinary collaboration		Interdisciplinary collaboration	
Global innovativeness	0.01	(1.59)	0.02*	(3.85)	−0.03	(0.23)
Gender (Male = 1, Female = 2)	0.20	(0.79)	−0.21	(0.77)	0.43*	(6.63)
Years of work experience	0.05	(2.42)	0.05	(2.18)	0.03	(1.17)
Years of work experience²	−0.00	(1.77)	−0.00	(1.79)	0.00	(0.73)
Number of previous universities	0.36**	(8.54)	0.34**	(7.63)	0.17*	(4.03)
Number of previous firms	−0.07	(0.58)	−0.29**	(8.80)	0.12*	(3.95)
Number of previous governmental organizations	−0.02	(0.01)	−0.09	(0.12)	0.19	(1.08)
Number of previous other relevant institutes	0.29*	(4.76)	0.30*	(5.07)	0.12	(2.10)
Dynamics of the scientific field	0.28**	(8.18)	0.21*	(4.50)	0.10	(1.97)
Basic disciplines	−0.14	(0.46)	0.25	(1.36)	−0.36*	(5.39)
Strategic disciplines	Redundant		Redundant		Redundant	
Nagelkerke R^2	.12		.15		.10	

of research collaboration (result not shown here), the turning points are at 23.78 (disciplinary collaboration) and 23.05 years (interdisciplinary collaboration). Both Hypotheses 3a and 3b are thus confirmed.

Concerning previous employers, both the number of previous universities and the number of other relevant institutes positively correlate with disciplinary collaboration. The number of previous firms is negatively related while the number of governmental organizations shows no relationship. Hypothesis 3c is thus only confirmed with respect to previous universities and other relevant institutes, and partly confirms the claims made by Melin (2000). With interdisciplinary research collaboration, again the number of previous universities is positively related, but also the number of previous firms. This partly confirms Hypothesis 3d. Altogether, it turns out that previous work experience at firms stimulates interdisciplinary research collaboration, while it hinders disciplinary research collaboration.

There is a relationship between dynamics of the scientific field and disciplinary collaboration, but not with interdisciplinary collaboration; this confirms Hypothesis 4a but rejects Hypothesis 4b. Researchers who perceive their disciplinary environment to be more turbulent engage more in disciplinary collaboration, but not in interdisciplinary collaboration.[7] This may indicate that researchers only use disciplinary collaboration as a manner to cope with change in a scientific discipline. However, it could also be that researchers who collaborate intensively with their disciplinary colleagues tend to regard their own discipline as more 'dynamic' than others. Ethnographic laboratory studies, for example, have shown that collaborations are sometimes large scale endeavours that require a large amount of communication (Knorr-Cetina, 1999).

Finally, compared to researchers working in a 'strategic' discipline (the reference category), researchers working in a basic discipline do not engage more in disciplinary research collaborations. Hypothesis 5a is thus confirmed. Compared to working in a strategic discipline, researchers in a basic discipline do engage less in interdisciplinary research collaboration, which confirms Hypothesis 5b.

Table 3 displays the results of the model predicting academic rank. Again, unstandardized estimators are given with the Wald chi-square between brackets. The Nagelkerke pseudo R^2 is 0.47, which is high. Based on these variables we can predict academic rank with fair accuracy. Again the results largely replicate the results by Van Rijnsoever et al. (2008), with years of working experience explaining most of the dependent variable. New is the interaction effect that was predicted in Hypotheses 5c and 5d. The results show that researchers in a basic discipline that engage more in disciplinary collaboration are indeed more likely to have a higher academic rank; which confirms Hypothesis 5c. Contrary to our expectations, at the 10% level, it is found that researchers working in a strategic discipline, who engage more in disciplinary research collaboration are also more likely to have a higher academic rank, which rejects Hypothesis 5d. It can thus be concluded that for career advancement in both types of disciplines it matters to engage in the disciplinary collaboration, but not in interdisciplinary collaboration.

Table 4 provides an overview of all hypotheses and shows whether they were supported by the results or not.

7. Discussion and implications

7.1. Limits to generalizability

Before drawing general conclusions, we would like to point to some limitations of this study. First, the response rate of the survey is rather low. Many researchers were approached to fill out the questionnaire, but probably many respondents gave it a low priority. The sample did contain sufficient respondents of all academic ranks for a statistical analysis, but the total sample was not a representation of the population. Moreover the response rate differed across departments. We have attempted to statistically control

Table 3
The results of the ordinal regression models predicting academic rank. Unstandardized estimators are given with Wald chi-squares between parentheses: $^{a}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

	Academic rank	
Basic Disciplines × Disciplinary collaboration	0.12*	(3.89)
Strategic Disciplines × Disciplinary collaboration	0.12[a]	(2.88)
Basic Disciplines × Interdisciplinary collaboration	0.09	(0.78)
Strategic Disciplines × Interdisciplinary collaboration	0.10	(1.01)
Disciplinary collaboration	Redundant	
Interdisciplinary collaboration	Redundant	
Basic Disciplines	−0.28	(0.27)
Strategic Disciplines	Redundant	
Global innovativeness	0.02*	(4.60)
Gender	−0.22	(0.66)
Years of work experience	0.14***	(92.87)
Number of previous universities	0.42**	(10.02)
Number of previous firms	−0.14	(1.75)
Number of previous governmental organizations	−0.05	(0.03)
Number of previous other relevant institutes	−0.08	(0.32)
Dynamics of the scientific field	−0.03	(0.08)
Nagelkerke R^2	.47	

[7] There was no difference in dynamics of the scientific field between basic and strategic disciplines.

Table 4
An overview the hypotheses and the results.

Hypothesis	Result	Remarks
1a	Supported	
1b	Not supported	
2a	Supported	
2b	Supported	
3a	Supported	The effect was masked by other variables
3b	Supported	The effect was masked by other variables
3c	Supported	For previous universities (at the 10% level) and other research institutes
3d	Supported	For previous universities, previous firms
4a	Supported	
4b	Not supported	
5a	Supported	
5b	Supported	
5c	Supported	
5d	Not Supported	At the 10% level disciplinary collaboration is associated with academic rank

for these deficits, but it is still difficult generalize our findings to academia in general.

Second, we have only considered Utrecht University in our study. Each university has it's own specific characteristics that might affect research collaboration, such as location (Katz, 1994), culture and policy. Although Utrecht University is a large and broad research institution, from a methodological perspective it is again difficult to generalize our findings to academia in general or even to the Dutch situation.

However, governments and universities all over the world make attempts to stimulate interdisciplinarity and the challenges they face seem similar (Sa, 2008; Bordons et al., 1999; Bruce et al., 2004). The Dutch science system is characterized by little central steering (Dawson et al., 2009). Over the past few decades, the government has granted increasing autonomy to individual universities and to intermediary organizations such as funding organizations, foresight committees and other advisory boards (De Boer et al., 2007; Van der Meulen, 2008). One can imagine that in more centrally managed science systems, institutional barriers to interdisciplinary research can be removed more easily. Despite these difficulties, the results may very well be indicative for processes that are going on at other universities both within and outside the Netherlands. The actual occurrence of interdisciplinary research collaborations will certainly vary across universities, but their relationships with individual characteristics and with the orientation of the scientific discipline (basic versus strategic) that we have measured may apply in general.

7.2. Conclusions and further research

The research presented in this paper was motivated by claims (see National Academies, 2005) that interdisciplinary research is desirable for solving complex societal problems. The first aim of this paper was to empirically explore which characteristics of researchers are associated with disciplinary and interdisciplinary research collaboration. The results showed that years of work experience, having worked previously at other universities or other research institutes, and dynamics of the scientific field are positively related to *disciplinary* research collaboration. A strong negative effect comes from having worked at firms.

Years of work experience, having worked previously at other universities, having worked previously in firms, being female, and working in a strategic discipline are positively related to *interdisciplinary* research collaboration.

Our second aim was to test whether either disciplinary or interdisciplinary research collaboration is related to academic career advancement. We found that both in basic and strategic disciplines, disciplinary research collaboration is positively related to academic rank, but interdisciplinary research collaboration is unrelated academic rank. In both types of disciplines it is most rewarding to engage in disciplinary research collaboration. This is surprising since researchers in strategic disciplines do engage more in interdisciplinary collaborations. It thus appears that are other motivations to engage in interdisciplinary collaboration in strategic disciplines.

In general this study contributes to the literature by pointing out a number of researcher characteristics that facilitate interdisciplinarity. Some of the relationships which we have found have been mentioned before, but to our knowledge our survey provides the first thorough empirical proof. For example, this paper confirms the popular conviction and claims by Carayol and Thi (2005) and Jansen et al. (2010), that there is a relationship between interdisciplinarity and the degree of concern with applications. An understanding of the characteristics that are related to disciplinary and interdisciplinary research collaborations can provide starting points for the design of policy instruments that stimulate and foster interdisciplinarity (see next section).

Our finding that there are no rewards for interdisciplinary collaborations in terms of academic rank is interesting in the light of debates about the lack of incentives for interdisciplinarity. Existing (disciplinary) reward structures are often mentioned as the main barrier for inter- and transdisciplinary research (De Boer, 2006; Merkx et al., 2007). On average interdisciplinary papers receive less citations than monodisciplinary papers (Levitt and Thelwall, 2008). Carayol and Thi (2005) found that young, unpromoted, scientists have a relatively monodisciplinary research output, and conclude that they are not stimulated to engage in interdisciplinary efforts. Our study signifies that in general disciplinary research collaboration is more rewarding for researchers and that there is a lack of incentives to engage in interdisciplinary research collaboration.

An important avenue for further research is to gain more insight into how researchers from the basic sciences can be triggered more to engage more into interdisciplinary research collaboration.

7.3. Policy recommendations

Many university managers and policy makers aim to stimulate interdisciplinary research. For them, the results of this study have three general implications[8]:

1. Recruitment of women might help to increase interdisciplinary activities. Attracting and keeping enough female scientists in academia is difficult (Romita and Volpato, 2005). Our results provide an additional argument for keeping trying.
2. Attracting staff from outside academia may increase the propensity of interdisciplinary collaborations. University managers should consider relieving the current financial barriers for industrial researchers to return to academia in order to enhance the diversity of university staff.
3. Various instruments can be used to stimulate interdisciplinary research, not all of which are of financial nature. The avail-

[8] Stimulating interdisciplinary research can have negative side effects. Incentives for interdisciplinary collaborations can decrease the rewards for mono-disciplinary contributions, which are crucial for the development of particular scientific fields. However, the following recommendations are formulated from the perspective that interdisciplinarity is a policy goal.

ability of funding for cross-disciplinary projects or programs seems a necessary but not sufficient condition for interdisciplinary research collaborations. In order to change the reward structure interdisciplinarity should also be valued in performance evaluations and in the appointments of academic staff. These procedures are often dominated by bibliometric quality indicators, which overvalue disciplinary success and undervalue interdisciplinary research efforts (Weingart, 2005; Leydesdorff, 2008).

However, as we have found significant differences between scientific disciplines, we advise policy not to design generic instruments, but to distinguish between basic and strategic disciplines. In the latter, interdisciplinarity requires less supportive efforts, even though collaborations across disciplinary borders do not appear to be rewarding in terms of career development. In basic disciplines, however, disciplinary collaborations are more prevalent, roughly corresponding with the idea of Mode 1 knowledge production (Gibbons et al., 1994). Disciplinary, basic research may be cherished for its cultural merits and the possible returns on the longer term. Today, however, most university managers and science policy makers are concerned about enhancing the direct contribution of science to society or the economy (Geiger and Sa, 2008; Etzkowitz et al., 2000; Slaughter and Leslie, 1997). Stimulating interdisciplinarity in basic disciplines could be a step in this direction.

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Appendix A. Sample and population percentages

	Actual percentage Utrecht University	Observed in sample
Professor	9.93%	8.60%
Associate Professor	9.03%	4.60%
Assistant Professor	29.65%	13.20%
Other scientific personnel	18.30%	21.10%
PhD students	30.48%	46.40%
Student assistants	2.61%	6.10%

Appendix B. Correlation matrix

Pearson correlation matrix	Total collaboration	Disciplinary collaboration	Interdisciplinary collaboration	Academic rank	Global innovativeness	Gender (Male = 1, Female = 2)	Years of work experience	Years of work experience^2
Disciplinary collaboration	.859**							
Interdisciplinary collaboration	.656**	.300**						
Academic Rank	.274**	.307**	.192**					
Global innovativeness	.118*	.150*	.018	.284**				
Gender (Male = 1, Female = 2)	.007	−.101	.080	−.218**	−.128*			
Years of work experience	.134*	.154**	.139*	.588**	.168**	−.249**		
Years of work experience^2	.091	.112	.103	.478**	.162**	−.221**	.953**	
Number of previous universities	.211**	.225**	.178**	.351**	.105	−.134*	.313**	.214**
Number of previous firms	−.066	−.188**	.069	−.117*	−.040	.002	−.066	−.068
Number of previous governmental organizations	.044	.011	.090	.111	.088	−.046	.144*	.100
Number of previous other relevant institutes	.158**	.152**	.100	.077	.091	.003	.082	.069
Dynamics of the scientific field	.161**	.145*	.099	.085	.096	−.042	.052	.071
Basic disciplines	.054	−.060	.169**	.026	.051	.136*	−.009	−.030

Pearson correlation matrix	Number of previous universities	Number of previous firms	Number of previous Governmental organizations	Number of previous other relevant institutes	Dynamics of the scientific field
Number of previous firms	−.028				
Number of previous governmental organizations	.027	.079			
Number of previous other relevant institutes	.018	−.004	.139*		
Dynamics of the scientific field	.022	−.074	−.078	−.003	
Basic disciplines	−.047	.025	.111	.069	−.001

Listwise $N = 293$.

* $p < 0.05$.

** $p < 0.01$.

References

Baruch, Y., Hall, D.T., 2004. The academic career: a model for future careers in other sectors? Journal of Vocational Behavior 64 (April (2)), 241–262.

Becher, T., Trowler, P.R., 2001. Academic Tribes and Territories, second edition. SRHE and Open University Press, Maidenhead, Berkshire.

Bessant, J., Caffyn, S., Gallagher, M., 2001. An evolutionary model of continuous improvement behaviour. Technovation 21 (February (2)), 67–77.

Biglan, A., 1973. The characteristics of subject matter in different scientific areas. Journal of Applied Psychology 57 (3), 195–203.

Bonaccorsi, A., 2008. Search regimes and the industrial dynamics of science. Minerva 46, 285–315.

Bordons, M., Zulueta, M.A., Romero, F., Barrigon, S., 1999. Measuring interdisciplinary collaboration within a university: the effects of the multidisciplinary research programme. Scientometrics 46 (3), 383–398.

Bozeman, B., Corley, E., 2004. Scientists' collaboration strategies: implications for scientific and technical human capital. Research Policy 33 (May (4)), 599–616.

Bruce, A., Lyall, C., Tait, J., Williams, R., 2004. Interdisciplinary integration in Europe: the case of the Fifth Framework programme. Futures 36, 457–470.

Carayol, N., Thi, T.U.N., 2005. Why do academic scientists engage in interdisciplinary research? Research Evaluation 14 (April (1)), 70–79.

Chin, M.H., Covinsky, K.E., McDermott, M.M., Thomas, E.J., 1998. Building a research career in general internal medicine – a perspective from young investigators. Journal of General Internal Medicine 13 (February (2)), 117–122.

Creed, P.A., Patton, W., Bartrum, D., 2004. Internal and external barriers, cognitive style, and the career development variables of focus and indecision. Journal of Career Development 30 (Summer (4)), 277–294.

Dawson, J., van Steen, J, van der Meulen, B., 2009. Science Systems Compared: A First Description of Governance Innovations in Six Science Systems. Rathenau Instituut, Den Haag.

De Boer, H., Enders, J., Leišytė, L., 2007. Public sector reform in Dutch higher education: the organizational transformation of the university. Public Administration 85 (1), 27–46.

De Boer, Y., 2006. Building Bridges: Researchers on their Experiences with Interdisciplinary Research in the Netherlands. RMNO, KNAW, NWO and COS.

Etzkowitz, H., Webster, A., Gebhardt, C., Terra, B.R.C., 2000. The future of the university and the university of the future: evolution of ivory tower to entrepreneurial paradigm. Research Policy 29 (2), 313–330.

Fehr, C., 2004. Feminism and science: mechanism without reductionism. National Women's Studies Association Journal 16 (1), 36–156.

Geiger, R.L., Sa, C.M., 2008. Tapping the Riches of Science: Universities and the Promise of Economic Growth. Harvard University Press, Cambridge, MA.

Gibbons, M., Limoges, C., Nowotny, H., Schawartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.

Haier, R.J., Jung, R.E., Yeo, R.A., Head, K., Alkire, M.T., 2005. The neuroanatomy of general intelligence: sex matters. Neuroimage 25 (March (1)), 320–327.

Heimeriks, G., van den Besselaar, P., Frenken, K., 2008. Digital disciplinary differences: an analysis of computer-mediated science and 'Mode 2' knowledge production. Research Policy 37 (October (9)), 1602–1615.

Hessels, L.K., van Lente, H., 2008. Re-thinking new knowledge production: a literature review and a research agenda. Research Policy 37 (May (4)), 740–760.

Irvine, J., Martin, B.R., 1984. Foresight in Science: Picking the Winners. Frances Pinter, London.

Jansen, D., von Görtz, R., Heidler, R., 2010. Knowledge production and the structure of collaboration networks in two scientific fields. Scientometrics 83, 219–241.

Katz, J.S., 1994. Geographical proximity and scientific collaboration. Scientometrics 31 (1), 31–43.

Katz, J.S., Martin, B.R., 1997. What is research collaboration? Research Policy 26 (March (1)), 1–18.

Kirton, M., 2003. Adaption-Innovation in the Context of Diversity and Change. Routledge, London.

Kirton, M.J., 1976. Adaptors and innovators: a description and measure. Journal of Applied Psychology 61 (5), 622–629.

Kirton, M.J., de Ciantis, S.M., 1994. Cognitive style in organizational climate. In: Kirton, M.J. (Ed.), Adaptors and Innovators: Styles of Creativity and Problem Solving. Routledge, London.

Knorr-Cetina, K.D., 1999. Epistemic Cultures. Harvard University Press.

Kuncel, N.R., Hezlett, S.A., Ones, D.S., 2004. Academic performance, career potential, creativity, and job performance: can one construct predict them all? Journal of Personality and Social Psychology 86 (January (1)), 148–161.

LaFollette, M.C., 1992. Stealing into Print. University of California Press, Berkeley.

Lariviere, V., Gingras, Y., 2010. On the relationship between interdisciplinarity and scientific impact. Journal of the American Society for Information Science and Technology 61 (January (1)), 126–131.

Latour, B., Woolgar, S., 1986. Laboratory Life: The Construction of Scientific Facts, second edition. Sage, London.

Laudel, G., 2002. What do we measure by co-authorships? Research Evaluation 11 (April (1)), 3–15.

Lee, S., Bozeman, B., 2005. The impact of research collaboration on scientific productivity. Social Studies of Science 35 (October (5)), 673–702.

Lepori, B., van den Besselaar, P., Dinges, M., Potì, B., Reale, E., Slipsaeter, S., Thèves, J., van der Meulen, B., 2007. Comparing the evolution of national research policies: what patterns of change? Science and Public Policy 34 (6), 372–388.

Levitt, J.M., Thelwall, M., 2008. Is multidisciplinary research more highly cited? A macrolevel study. Journal of the American Society for Information Science and Technology 59 (12), 1973–1984.

Leydesdorff, L., 2008. Caveats for the use of citation analysis in research and journal evaluation. Journal of the American Society for Information Science and Technology 59 (2), 278–287.

Liberman, S., Wolf, K.B., 1998. Bonding number in scientific disciplines. Social Networks 20 (July (3)), 239–246.

Long, J.S., 1992. Measures of sex-differences in scientific productivity. Social Forces 71 (September (1)), 159–178.

Mccloy, R.A., Campbell, J.P., Cudeck, R., 1994. A confirmatory test of a model of performance determinants. Journal of Applied Psychology 79 (August (4)), 493–505.

McCullagh, P., 1980. Regression models for ordinal data. Journal of the Royal Statistical Society 42 (2), 109–142.

McCullagh, P., Nelder, J.A., 1998. Generalized Linear Models, 2nd ed. Chapman & Hall, London.

McDowell, J.M., Singell, L.D., Stater, M., 2006. Two to tango? Gender differences in the decisions to publish and coauthor. Economic Inquiry 44 (January (1)), 153–168.

Melin, G., 2000. Pragmatism and self-organization – research collaboration on the individual level. Research Policy 29 (January (1)), 31–40.

Melin, G., Persson, O., 1996. Studying research collaboration using co-authorships. Scientometrics 36 (July–August (3)), 363–377.

Merkx, F., Versleijen, A., van den Besselaar, P., 2007. Kustverdediging: wetenschap, beleid en maatschappelijke vraag, Rathenau Instituut SciSA rapport 0704, Den Haag.

Metzger, N., Zare, R.N., 1999. Science policy – interdisciplinary research: from belief to reality. Science 283 (January (5402)), 642–643.

Midgley, D.F., Dowling, G.R., 1978. Innovativeness: the concept and its measurement. Journal of Consumer Research 4 (4), 229–242.

National Academies, C.o.S., Enginering and Public Policy, 2005. Facilitating Interdiscplinary Research. National Academies Press, Washington, DC.

Nooteboom, B., 2000. Learning by interaction: absorptive capacity, cognitive distance and governance. Journal of Management and Governance 4, 69–92.

Oh, W., Choi, J.N., Kim, K., 2005. Coauthorship dynamics and knowledge capital: the patterns of cross-disciplinary collaboration in information systems research. Journal of Management Information Systems 22 (Winter (3)), 265–292.

Porter, A.L., Cohen, A.S., Roessner, J.D., Perreault, M., 2007. Measuring researcher interdisciplinarity. Scientometrics 72 (July (1)), 117–147.

Porter, A.L., Rafols, I., 2009. Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. Scientometrics 81 (3), 719–745.

Porter, A.L., Roessner, J.D., Cohen, A.S., Perreault, M., 2006. Interdisciplinary research: meaning, metrics and nurture. Research Evaluation 15 (December (3)), 187–195.

Potì, B., Reale, E., 2007. Changing allocation models for public research funding: an empirical exploration based on project funding data. Science and Public Policy 34 (6), 417–430.

Qin, J., Lancaster, F.W., Allen, B., 1997. Types and levels of collaboration in interdisciplinary research in the sciences. Journal of the American Society for Information Science 48 (October (10)), 893–916.

Rafols, I., Meyer, M., 2007. How cross-disciplinary is bionanotechnology? Explorations in the specialty of molecular motors. Scientometrics 70 (3), 633–650.

Rhoten, D., 2004. Interdisciplinary research: trend or transition. Items - Social Science Research Council 5 (1–2), 6–11.

Rhoten, D., Pfirman, S., 2007. Women in interdisciplinary science: exploring preferences and consequences. Research Policy 36 (February (1)), 56–75.

Richerson, P.J., Boyd, R., 2005. Not by Genes Alone: How Culture Transformed Human Evolution. The Universtity of Chicago Press, Chicago and London.

Rip, A., 2004. Strategic research, post-modern universities and research training. Higher Education Policy 17 (2), 153–166.

Romita, P., Volpato, C., 2005. Women inside and outside Academia: a struggle to access knowledge, legitimacy and influence. Social Science Information 44 (1), 41–63.

Sa, C.M., 2008. 'Interdisciplinary strategies' in U.S. research universities. Higher Education 55, 537–552.

Schmickl, C., Kieser, A., 2008. How much do specialists have to learn from each other when they jointly develop radical product innovations? Research Policy 37 (July(6–7)), 1147–1163.

Severiens, S.E., Tendam, G.T.M., 1994. Gender differences in learning styles – a narrative review and quantitative metaanalysis. Higher Education 27 (June (4)), 487–501.

Slaughter, S., Leslie, L.L., 1997. Academic Capitalism: Politics, Policies, and the Entrepreneurial University. The John Hopkins University Press, Baltimore.

Thompson Klein, J., 1990. Definitions of interdiscplinarity. In: Thompson Klein, J. (Ed.), Interdisciplinarity: History, Theory, and Practice. Wayne State University Press, Detroit.

Van der Meulen, B., 2008. Interfering governance and emerging centres of control. In: Whitley, R., Gläser, J. (Eds.), The Changing Governance of the Sciences: The Advent of Research Evaluation Systems. Springer, Dordrecht, pp. 191–204.

van Raan, A.F.J., van Leeuwen, T.N., 2002. Assessment of the scientific basis of interdisciplinary, applied research – application of bibliometric methods in Nutrition and Food Research. Research Policy 31 (May (4)), 611–632.

Van Rijnsoever, F.J., Donders, A.R.T., 2009. The effect of innovativeness on different levels of technology adoption. Journal of the American Society for Information Science and Technology 60 (5), 984–996.

Van Rijnsoever, F.J., Hessels, L.K., Vandeberg, R.L.J., 2008. A resource-based view on the interactions of university researchers. Research Policy 37 (September (8)), 1255–1266.

Weingart, P., 2005. Impact of bibliometrics upon the science system: inadvertent consequences? Scientometrics 62 (1), 117–131.

Whitley, R., 2000. The Intellectual and Social Organization of the Sciences, second edition. Oxford University Press, Oxford.