Soc. Geogr., 3, 23–36, 2008
www.soc-geogr.net/3/23/2008/

Social Geography

International collaboration, mobility and team diversity in the life sciences: impact on research performance

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Received: 1 December 2006 – Published in Soc. Geogr. Discuss.: 16 February 2007
Revised: 9 June 2008 – Accepted: 10 June 2008 – Published: 23 June 2008

Abstract. The combination of knowledge and skills from different backgrounds or research cultures is often considered good for science. This paper describes the extent to which academic research teams in the life sciences draw on knowledge from different research cultures and how this is related to their research performance. We distinguish between international collaboration of research teams from different countries and cultural diversity of research teams resulting from team members with different countries of origin. Our results show that the most successful teams have a moderate level of cultural diversity; in addition, successful teams engage in collaboration activities with teams from other European countries and the US leading to joint publications. These results have implications for research team management and for research policy, in particular in relation to supporting measures for mobile scientists.

1 Introduction

Research has long been at the forefront of globalization: many research problems and their solutions are of global relevance and in no way constrained by country borders, particularly in basic research. At the same time, scientific excellence is spread all over the world, and leading scientists are used to communicating with their peers however distant. 'Denationalizing science' has been the prevailing trend for some years (Crawford, Shinn and Sörlin 1993) and the globalisation of research continues to grow in intensity: the level of international collaboration has been shown to have increased significantly over the past twenty to thirty years (European Commission, 2003; Narin et al., 1991; National Science Board, 2002, 2004). Data on the growth of mobility among scientists are still very limited. Lauriol (2007) reports that between 1993 and 2003 the number of doctorate holders who work in the US and were born outside of the country increased by more than 80%. Also in the US the number of foreign scholars increased by more than 20% from 80000 in the academic year 2000/01 to 97000 in 2005/06 (Moguérou and Di Pietrogiacomo, 2007).

The conviction that increasing trans-border interaction is beneficial for research is prevalent among policy-makers. The European Commission states in its Communication on the Mobility Strategy:

"[Mobility] permits the creation and operation of multinational teams and networks of researchers, which enhance Europe's competitiveness and prospective exploitation of results." (European Commission, 2001:4)

Indeed, increasing the mobility of researchers has become a prominent goal in European research policy (European Commission, 2000, 2001, 2005). Despite the extent of policy measures to promote the mobility of researchers, few studies have investigated the impact of mobility in science on the performance and output of the receiving science system. This study aims to reduce this gap. International researcher mobility, with the cultural diversity of teams it causes, is addressed as one of two principal modes by which pools of knowledge and scientific expertise interact across national boundaries. The second mode is international collaboration among research teams, where scientists join forces across borders in their work but remain located with their teams in different countries.[1] The study sets out to explore the following questions:

- What are the patterns of cultural diversity and international collaboration in Europe in a large scientific domain, the life sciences?

[1]These two modes are a useful simplification of all possible interaction types along the dimensions of duration, distance and interaction intensity (see Fiol and O'Connor, 2005).

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Published by Copernicus Publications.

- Does the cultural diversity of research teams have an effect on the performance of these teams?

- Does the international collaboration between research teams have an effect on team performance?

2 Sourcing knowledge internationally

2.1 Transnational versus national science

Dean K. Simonton (2004) proposes that there are four factors underlying scientific creativity. At the core is a combinatorial process in which so many different and unknown causes are combined that the best representation appears to be *chance*. *Logic* underlies the formulation of arguments and enables justification of a novel finding before the scientific community. With *zeitgeist* Simonton refers to discipline-specific and more general sociocultural influences, including in particular those ideas that are accepted as legitimate in the scientific domain and in society. Last (and least) *genius* denotes some personality traits of eminent scientists, like intelligence, associative richness and openness to experience. The *chance* and *zeitgeist* factors are most relevant to our study. Here, Simonton points to cultural diversity as being an underinvestigated influence on creativity, asserting that, in general, "cultural heterogeneity associates with creativity, whereas homogeneity correlates with stagnation." (Simonton, 2004:133).

It seems reasonable to expect that scientists draw some benefit from working and speaking with their colleagues from other countries. The ability to source partners from a global market of scientific competencies and skills should enable improved complementarity of skills – scientists not finding the ideal complementary expertise in their country may enter a division of labour with peers abroad to be better capable of addressing their research problems. When human and physical resources from several countries are combined, a richer mixture of research inputs can be generated (Georghiou, 1998) – an argument that fits quite well with Simonton's combinatorial process. It is plausible that scientific creativity benefits from international combination and cross-fertilization of expertise, and that as a result scientific knowledge is advanced more rapidly. Beyond international division of labour in specific research endeavours it might be expected that any type of international exchange and cooperation has positive effects on scientific research and its outcomes. We investigate as a first hypothesis the proposition:

H1: Transnational scientific research that mobilises foreign contributions is more successful than purely national research without foreign contributions.

Transnational research that involves people, equipment and funds from more than one country can take on a range of different forms, from informal exchange at conferences, scholarly associations or advisory boards or short-term visits to collaborators' labs and universities, to joint research projects, protracted stays in another country extending potentially to permanent migration. Two types of internationalization and transnational knowledge flow lend themselves particularly well to empirical investigation in that each leaves traces which are relatively easy to access: 1) international mobility of scientists - identified simply through comparing research location with country of origin; 2) international collaboration - identified through scientific publications with co-authors from another country. Each of these types is briefly introduced below.

2.2 Impact of international mobility and resultant team diversity

Much research today is done in groups or teams (cf. Simonton, 2004:153–157). Given the importance of combinatorial processes, more heterogeneous groups can be expected to be more creative than homogeneous groups: "The more diverse are the collaborator backgrounds and expertise, the greater the level of mutual stimulation. The upshot is group problem solving that is more creative." (Simonton, 2004:155) There is virtually no direct empirical evidence of the importance of cultural diversity in research group productivity, but we can learn from two related strands of research: 1) on the relationship between the mobility of scientists and their research productivity and 2) on team diversity and performance.

1. Relationship between the mobility of scientists and their research productivity. Empirical studies have provided some support to the idea that the mobility of scientists is good for research output. An investigation into the scientific success of the Rockefeller Institute showed a positive contribution of foreign permanent staff as well as of visiting scientists (Hollingsworth and Hollingsworth, 2000). However, the authors point out that the impact found may well have been due to the greater scientific eminence of the visitors rather than their geographic origins per se. It has been shown for the USA that foreign-born and foreign-educated scientists make more exceptional contributions to scientific output than would be expected from their proportion of the scientific workforce (Stephan and Levin, 2001). Jöns (2003, 2006) pointed out how geographical mobility helps to generate a productive combination of localised knowledge and fertilises intellectual exchange. However, in addition to inspiration and cooperation, cross-border interaction might also lead to irritation and confrontation, depending on the degree of heterogeneity between the parties involved. Thus, the impact of migration is ambivalent. Comparing one of the most notable events of migration in the history of science, the emigration of German theoretical physicists to the US from the Third Reich, with a different migration at the same time, the emigration of the 'Vienna Circle', Hoch and Platt (1993) argue that the consequences of migration are complex, ranging from fruitful cross-fertilization, to assimilation and displacement of disciplinary affiliations.

2. Team diversity and performance. When more general findings relating to the impact of group diversity on performance are applied to the possible impact of cultural diversity on research team performance, a purely positive assessment is further opened to question. Research on groups in various settings has shown that diversity may have negative as well as positive effects on group processes and performance (Williams and O'Reilly, 1998). Positive effects are attributed to a broader range of knowledge, skills and contacts in the group, whereas negative effects arise from reduced and less efficient communication, less cooperation and more conflict (Bunderson and Sutcliffe, 2002; Williams and O'Reilly, 1998).

The introduction of the term "faultline" by Lau and Murnighan (1998) to refer to "hypothetical dividing lines that may split a group into subgroups based on one or more attributes" has generated a spate of research (e.g. Earley and Mosakowski, 2000; Li and Hambrick, 2005; Thatcher et al., 2003), driven by the plausible argument that large subgroups within a team, homogeneous on some key characteristic such as country of origin, will have the effect that individuals within the subgroup will identify with the subgroup and interact more strongly with its members than with others in the team, reducing communication and raising the potential for conflict across the subgroup boundary.

Whether positive or negative effects of diversity within a group or team prevail has been related to its origin, degree and type. In terms of degree of diversity, Williams and O'Reilly suggest that positive effects may prevail at low levels of diversity, but that at higher levels, group cohesion may reduce to an extent which negates the positive effect (Williams and O'Reilly, 1998:90). Jehn et al. found that whereas differences in knowledge have a positive impact on performance, the impact of a diversity of values is negative (Jehn et al., 1999). Cummings (2004) pointed out positive effects on team performance resulting from structural diversity, that is diversity of team members in regard to location, functional assignments, reporting managers and business units (mediated through knowledge sharing). He did not find such effects for demographic diversity relating to age, gender, company, and industry experience.

We summarise from these empirical findings the following hypotheses:

H2: Culturally diverse scientific research teams perform better than culturally homogeneous teams.

H3: The marginal benefit of cultural diversity decreases rapidly, i.e. moderately culturally diverse teams perform better than very diverse teams.

Internal cultural diversity is only one possible channel for a team to combine knowledge and technical skills from different national backgrounds. Another channel is the acquisition of knowledge through research collaboration.

2.3 Impact of international collaboration

In principle, the benefits quoted for international research collaborations are of the same nature as those listed for collaboration in general, see for example the benefits listed by Georghiou (1998). However, international collaboration clearly gives rise to additional costs, for instance due to the necessity of bridging linguistic and cultural differences or finding suitable contractual arrangements. It is clear that international collaboration must bring additional benefits which outweigh the transaction costs; otherwise it would be hard to explain its impressive growth rate. Such benefits might be access to equipment, local resources, data or other objects of study, or to eminent scientists and groups (Georghiou, 1998; Thorsteinsdóttir, 2000; Wagner, 2005).

Empirical evidence of the impact of international research collaborations on research productivity generally shows a positive effect, with several studies confirming this for the life sciences specifically. A study of Spanish biomedical research showed that international collaboration increased the productivity of team leaders and the impact of the published work (Bordons et al., 1996). Italian studies found a positive effect of the number of research collaborations with foreign non-profit institutions on the productivity of molecular biology and genetics research groups (Arora et al., 1998; Cesaroni and Gambardella, 2003). According to Narin et al. (1991), their finding that biomedical papers with international co-authors have greater impact than single-author and nationally co-authored papers can be generalised to other disciplines. Other studies have shown that international collaboration generally has a more pronounced positive effect on citation impact than local or domestic collaboration (Adams et al., 2005; Persson et al., 2004).

The conclusion might be drawn that positive impacts are due to a positive effect of flows of knowledge between peers of different intellectual backgrounds. However, we do not want to conceal that this conclusion has been questioned. From a methodological point of view, the same effects may be the result of self selection – only the best scientists collaborate at international level (Bordons and Gomez, 2000) – or of increased self-citation (Herbertz, 1995). Also, the positive pattern is not universal across countries and disciplines (Glänzel, 2001; Glänzel and Schubert, 2001). To add to the mixed picture, Adams et al. (2005) report a trade-off between quantity and quality such that international collaboration has a negative effect on the number of publications but a positive effect on citations.

The empirical evidence to date on international research collaboration thus also shows a mixture of positive and negative impacts. However, the former generally prevail, which leads us to investigate the hypothesis that:

H4: Internationally collaborating scientific research teams perform better than non-collaborating teams.

Table 1. Dataset of life sciences research teams by country (source: authors).

Country	Research population	Sample	Usable questionnaires				
			Number	In % of sample	Mean no. of inlinks	Mean team size	% of female heads
CZ	173	119	30	25.2	1.6	12.8	23.3
DE	1447	271	60	22.1	9.5	16.6	20.0
ES	896	164	37	22.6	1.9	14.8	8.1
FR	1384	225	56	24.9	4.4	16.8	12.5
HU	214	108	34	31.5	5.8	22.3	17.6
IT	952	186	52	28.0	1.5	8.8	21.2
NO	199	122	37	30.3	7.8	11.0	18.9
PT	229	123	44	35.8	11.4	12.6	50.0
SE	650	148	41	27.7	7.3	12.3	26.8
UK	1588	307	77	25.1	8.7	13.1	13.0
Total	7732	1773	468	26.4	6.4	14.3	20.5

3 Concepts and methods

3.1 The research team as the unit of analysis

The main unit of analysis in this study is the research team or group. This is understood as a group of people, scientists and non-scientists, some or all of whom are employed by a university, who work at the same location for a significant period of time to produce new scientific knowledge, such that the group is recognisable from outside the university as a distinct entity. Our definition is a blend of an institutional approach, which relies on organisational affiliation (Cohen, 1981; Hagstrom, 1965) and a functional approach, based on the specification of joint research activities (Andrews, 1979).

Limiting team membership to those who work at the same location allows us to address the impact on research performance of collaborative work spanning multiple locations. "Virtual teams", whose emergence is facilitated by the internet and other networks, are thus analysed not as a type of team but as collaborative activity between teams. For similar reasons, visiting scientists and research workers are not regarded as members of a team unless they stay collocated longer than a minimum period, set here at six months.

Our definition sets few limits on employment patterns or role in the team, allowing us to include Europe's diverse research structures in the analysis. In France, for instance, scientists with different organisational affiliations, usually universities and non-university research organisations, join forces in "mixed" research teams.

As we were able to elicit information directly from teams, it was not necessary to find definitions of team boundaries based on co-authorship (e.g. Adams et al., 2005; Bordons and Zulueta, 1997; Seglen and Aksnes, 2000). This allows us to address adequately the relationship between group size and research productivity without missing the impact of young researchers – many with no publications to their name (Stankiewicz, 1979).

3.2 Survey sampling and response

Webometric techniques were used to build a representative sample of 1773 university-affiliated research teams in the life sciences across 10 European countries. Through internet searches a population of 7732 teams was identified (see Table 1) working at PhD-granting universities in the life sciences, defined as ISCED 1997 category 42. The life sciences were chosen because they are a large and growing scientific domain. The study needed to focus on one domain to reduce the number of influences on team performance that could not be considered in this partial analysis. The teams in the sample were drawn from this population by stratified random sampling. The stratification variable was the number of hyperlinks pointing to the team's internet homepage (inlinks), which is a readily available proxy for the research performance of the team. Previous research has shown that for academic organisations, the number of hyperlinks is related to research performance (see Thelwall, 2003). Teams with more inlinks received a higher probability for being included in the sample (see in more detail Barjak, 2006b). For the sample teams we identified the names and email addresses of the team leaders via the internet; for the majority of the teams we were also able to obtain some staff information about the total scientific and non-scientific staff (77.5% of the teams), the PhD students (53.8%) and the post-docs (39.3%).

Questionnaires were provided to team leaders electronically – online and via email. The questionnaire was opened by 811 respondents leading to 468 usable questionnaires (26.4% of the sample, see Table 1). A comparison of number of inlinks, team size and gender of the team leader between responding and non-responding teams revealed little bias in response. The Italian teams that responded tended to have somewhat fewer hyperlinks than those which did not respond. Teams with female team leaders were slightly over-represented in Germany and underrepresented in Spain.

Using the information obtained from the internet and the survey it was possible to retrieve bibliographic data for the responding teams from the Thomson ISI Web of Science. Publication data was collected for the year 2001 and citation data for the years 2001–2003.

3.3 Metrics for key variables

3.3.1 Research performance

In line with suggestions by Simonton (2004) the creativitiy or (in our terminology) performance of research teams was measured through their products. We built three variables from bibliographic data extracted from the Science Citation Index Expanded (SCIE) provided by Thomson ISI:

- TOTPAP (output volume): TOTPAP is the total number of papers recorded in the 2001 SCIE volume as article, letter, note, or review authored or co-authored by a member of the team;

- ZTOTPAP (team productivity): This variable is TOTPAP divided by team size;

- TOTMOCR (output quality): The number of citations received up to 2003 for a team's 2001 papers is divided by TOTPAP to obtain the Mean Observed Citation Rate (MOCR) per publication for that team.

These indicators and the SCIE database itself have several well documented weaknesses, for instance, not all co-authors of publications really contribute intellectually, the bias towards English language publications might inflate values for native speakers of that language, self-citation inflates citation scores, citations are sometimes created for other reasons than the quality of a paper, etc. (Borgman and Furner, 2002; Cronin, 1984; Herbertz, 1995; Leeuwen et al., 2001; Raan, 2003). Notwithstanding these weaknesses, publications and citations are viewed as good measures for comparing and analysing research performance.

A major weakness of the dataset lies in the differing points in time to which the data refer. Whereas the publication data refer to the year 2001 – and the citations to the years 2001–2003 of the 2001 papers – the survey collected data for 2003. However, the publication activities of life sciences teams do not change rapidly.[2] Moreover, team structures and collaboration activities also tend to be path-dependent, i.e. a team that is diverse in year t will also be diverse in t+1 and t+2, because young researchers usually stay for more than a year: according to our data 62% of the PhD students had funding for more than 3 years and 84% of the post-docs for 2 or more years. Hence, this increases the stability of the data across time.

3.3.2 Cultural diversity

Cultural diversity of a research team was defined as the number of different countries in which the team's young researchers had obtained their most recent degrees. We focused on young researchers because they are the most mobile group of researchers (see Mattsson in this special issue). Mobility as measured in the survey can be seen for young researchers as a good indicator for actual mobility and for the diversity this introduces into teams; for older researchers more biographical information would be needed to properly represent mobility over longer time spans.

Using an approach similar to Carayol and Nguyen Thi (2004) separate Shannon Diversity Indices of country of origin were calculated for PhD students (CDIVPHD) and for post-docs (CDIVPDOC). These indices represent in one value the degree to which different national pools of knowledge are present in the team. The larger the index, the larger the variety of countries in which the PhD students (post-docs) obtained their last degree.

$$\text{CDIVPHD}=-\sum_{i=1}^{C}(p_i * \ln p_i) \qquad (1)$$

with CDIVPHD Cultural diversity index of PhD students.
C Total number of different countries i where the PhD students of a team obtained their last degrees.
p_i Proportion of C made up of the ith country.

3.3.3 Collaboration

International collaboration was measured in this analysis by using data retrieved from the Thomson ISI database. Three binary indicators were built on co-author fields:

- ICPAP01 takes the value of one if the team has published one or more papers with co-authors from any foreign country, otherwise it is zero.

- EUCPAP01 takes the value of one if the team has published one or more papers with co-authors from another EU member state, otherwise it is zero.

- USCPAP01 takes the value of one if the team has published one or more papers with co-authors affiliated to organisations in the USA, otherwise it is zero.

We expect higher costs for collaborating with US-based researchers than with European researchers, as it is more demanding to obtain matching funds and communication is

[2] In order to verify this we took a random subsample of 50 research teams from the responding 468 teams and collected for this subsample the publications per year between 2001 and 2004 from the online version of the Web of Science. We obtained correlation coefficients between the number of publications in 2001 and the following years of 0.81 (2002), 0.65 (2003) and 0.72 (2004).

Table 2. Shannon's Diversity Index for country of last degree (Note: Shannon's Diversity Index in brackets [PhD students/post-docs]. The classification as above or below average is based on the 95% confidence intervals of the mean indexes per country).

		Cultural diversity of PhD students		
		Above average	Average (∅=0.41)	Below average
Cultural diversity of post-docs	Above average	SE (0.65/0.64) UK (0.70/0.55)		
	Average (∅=0.38)	DE (0.60/0.37)	ES (0.35/0.28) FR (0.33/0.43)	PT (0.14/0.50)
	Below average		NO (0.33/0.20)	CZ (0.19/0.06) HU (0.22/0.07) IT (0.16/0.18)

hampered by different time zones and higher travel costs. Hence, we would also expect higher pay-offs from these collaborations and a bigger impact on team performance.

A word of caution is necessary regarding the three publication-based indicators. It is known that co-authorship often reflects an intense research interaction between the authors (Harsanyi, 1993; Laudel, 2001), and this is appropriate in indicators which are to represent the degree to which a team accesses pools of knowledge outside its country of location. However, there is at least anecdotal evidence that co-authors might be included in a publication for other reasons, e.g. because they secured the resources for a project. Nevertheless, it is difficult to conceive of a reason for co-authorship which does not indicate some degree of collaboration, so that we do not expect significant bias.

3.4 Modelling approach

The analytical approach is a combination of bivariate analysis – the "initial view" reported below – and multivariate modelling using linear regression techniques.[3] In the latter we provide first a baseline model. This incorporates factors apart from knowledge-pooling mechanisms which impact on research productivity such as country of location or simply team size. The impact on research productivity of international collaboration and cultural diversity is then examined in an extension of the baseline model.

Independent variables of theoretical relevance and expected to improve the explanatory power of the model were included in baseline models. One set consists of team characteristics found to be influential in previous work such as country of team location, principal research discipline, age (time since foundation, also interpreted as team "maturity") and team size. Characteristics of team leaders which might affect research performance were also included, in particular the experience (number of years leading a research team) and recognition (specific acts of professional recognition received since 2000).[4]

The properties of the dependent variables for team productivity (ZTOTPAP) and output quality (TOTMOCR) – non-negative metrics – allow use of ordinary least squares (OLS) estimation. Residuals were tested for heteroscedasticity on team size using the Goldfeld-Quandt test and adjusted using the White estimator or by including team size as weighting variable (Greene, 2000).

TOTPAP, the number of papers listed in the SCIE database in 2001, is a non-negative integer, for which a Poisson distribution is a better approximation than the Gaussian. Count data models are known to deal efficiently with such variables. If the dependent variable is subject to overdispersion – the variance exceeds the mean – the negative binomial regression model (NEGBIN) is preferable to the Poisson model (Cameron and Trivedi, 1998). We tested for overdispersion as described in Cameron and Trivedi and include the alpha values from the NEGBIN estimation in the results tables – significant alphas indicate overdispersion. The difference between the Log-L and restricted Log-L (NEGBIN versus Poisson) was used as indicator of goodness of fit – as a substitute

[3]The work reported here extends linear modelling of the impact of team structure on research performance (Robinson, S., Mentrup, A., Barjak, F., Thelwall, M., Li, X., Glänzel, W.: The Role of Networking in Research Activities. NetReAct D4.1 – final, Report to the Institute for Prospective Technological Studies, Commission of the European Communities, April 2006, http://www.netreact-eu.org/documents/NetReAct_D41.pdf, 2006.) by including additional co-determinants of research performance, using regression models appropriate to the statistical properties of discrete integer dependent variables and including explicit modelling of non-linear relationships.

[4]This was assessed through five related questions: "Since 2000, has your work been recognised in any of the following ways? Have you (a) won a scientific award, (b) been invited to serve on a major professional committee, (c) been invited to serve on the editorial board of a scientific journal, (d) organised an international conference, (e) been invited to serve on a national or international advisory committee."

Table 3. International collaboration of research teams in the life sciences (no. of co-authored ISI journal articles and share of total no. of published articles in 2001; source: Glänzel, W. Co-authorship links of life sciences institutes. Bibliometric measures of networking activities and of their impact [NetReAct Deliverable 2.2]. Report to the Institute for Prospective Technological Studies, Commission of the European Communities, January 2006, 97–98, http://www.netreact-eu.org/documents/NetreactDeliverable2.2.pdf).

	International collaboration		Collaboration with partners from EU15		Collaboration with partners from the USA	
Country	N	Share (%)	N	Share (%)	N	Share
CZ	48	39.7	35	28.9	7	5.8%
DE	168	39.2	64	14.9	45	10.5%
ES	54	30.5	34	19.2	12	6.8%
FR	103	33.3	57	18.5	18	5.8%
HU	78	40.4	44	22.8	22	11.4%
IT	58	39.2	33	22.3	18	12.2%
NO	45	47.4	39	41.1	7	7.4%
PT	87	47.0	56	30.3	27	14.6%
SE	68	44.7	37	24.3	16	10.5%
UK	110	34.6	50	15.7	33	10.4%

for the role of R^2 in OLS. Also, the Vuong statistic was used to test for "zero inflation" (Greene, 2000). The result was negative, indicating no need to use corrective techniques such as Zero Inflated models or Hurdle models.

4 An initial view

4.1 International cultural diversity

As we would expect, post-docs are more internationally mobile than PhD students. Whereas 80% of the PhD students write their PhD in the country in which they graduated, i.e. obtained their master degree or equivalent, only 60% of the post-docs continue to work in the country in which they obtained their PhD. The target of mobility is mainly Europe rather than countries outside Europe for both, PhD students (10% moved to another European country) and post-docs (25%).

Table 2 shows Shannon's Diversity Indexes for country of last degree of PhD students and post-docs in life sciences teams. Across all countries we obtain average cultural diversity indexes of 0.41 for PhD students and 0.38 for post-docs. Broken down by country, we see that in 7 out of 10 countries cultural diversities for PhD students and for post-docs are more or less in line. Universities in the United Kingdom (UK) and Sweden (SE) have the most international research teams, in Spain (ES) and France (FR) diversity is close to the average, and in Czech Republic (CZ), Hungary (HU) and Italy (IT) the teams have only few PhD students and post-docs from other countries. German teams (DE) have a large diversity of PhD students but only average diversity of post-docs. Portuguese teams (PT) are below the average diversity when it comes to PhD students and at the average for post-docs, for Norwegian teams it is the other way around.

We conclude that the differences between countries in regard to cultural diversity are notable and that they depend to some extent on the category of researcher considered.

4.2 International collaboration

International collaboration is one of the two modes studied here for achieving international knowledge flows. Using the number of journal articles published jointly with scientists from other countries as an indicator of the degree of international collaboration, we obtain the breakdown by country shown in Table 3. The highest rates of international collaboration as a proportion of total collaboration are found in Norway, Portugal and Sweden, rates in Spain, France and the UK are below average – under 35% of total collaboration.

The pattern of collaboration within and with the EU is striking. The three countries that were not members of the EU in 2001, namely Norway, Czech Republic and Hungary, show some of the highest rates of joint publication with scientists from EU countries. With some exceptions, the rate of joint EU-publication of teams in EU member states is lower, particularly in the case of Germany and the UK. Collaboration with scientists from the United States, one of the leading countries for research in the life sciences, was found to be rather low. The maximum was found in Portugal, where nearly 15% of papers published by life sciences research teams are published jointly with scientists from the USA. In several countries such as France, the Czech Republic, Spain and Norway the rate of joint publication with the USA is well below 10%.

In Fig. 1 we contrast the performance – team productivity and output quality – of teams that had engaged in any

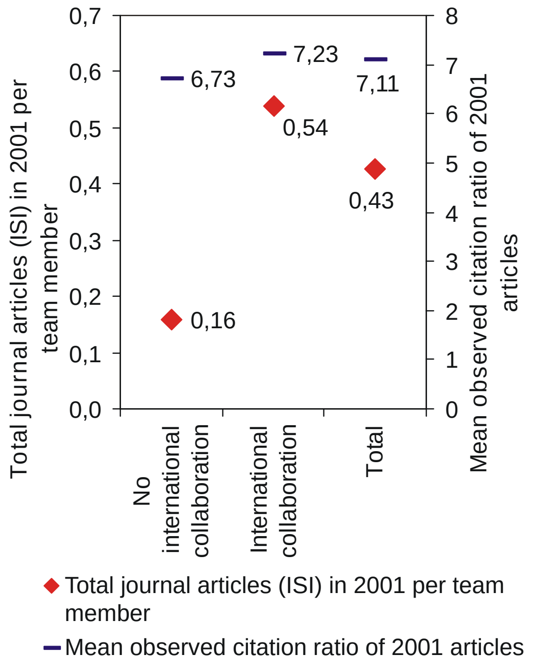

Fig. 1. Team productivity and output quality for teams with and without international collaboration partners (Note: ANOVA-results: Journal articles: F=42.54, p<0.01; MOCR: F=0.18, p=0.67).

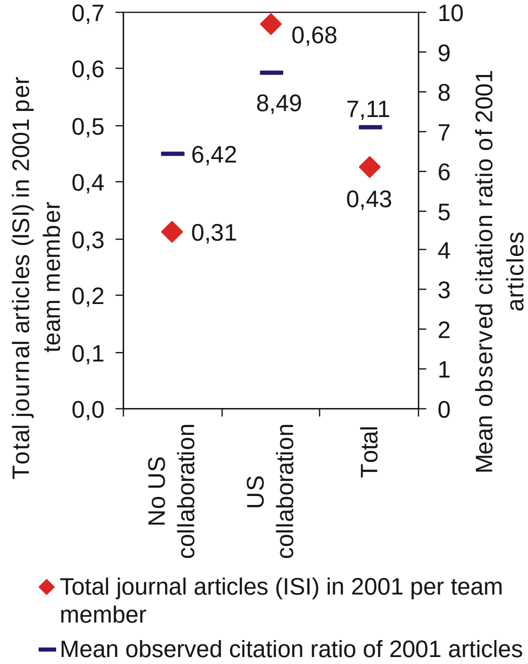

Fig. 2. Team productivity and output quality for teams with and without collaboration partners from the US (Note: ANOVA-results: Journal articles: F=39.95, p<0.01; MOCR: F=3.80, p=0.052).

collaboration, i.e. those which had published at least one research article jointly with a scientist from any other country, with the performance of teams not having exhibited any collaboration of this kind. Figure 2 presents the same contrast between collaborating and non-collaborating teams, but limiting collaboration to cases of collaboration with the USA.

We see in both figures that team productivity is higher for teams with collaboration compared to teams without. It also appears that teams collaborating internationally achieve a higher quality of publications, measured by TOTMOCR, than teams with no international collaboration. However, only in the specific case of collaboration with the USA is the difference in research output quality (citations) statistically significant. This can be explained with the higher costs of collaborating with US teams (e.g. for setting-up the project, management, communication). Hence, this type of collaboration should also create higher benefits, i.e. more output (publications) or better/more visible output (more citations). In general these findings support our hypothesis 4. The relationship between collaboration and publications is more stable than between collaboration and citations, a finding contradictory to that of Adams et al. (2005).

5 Modelling the performance of research teams

Tables 4 and 5 show some of the regression models we examined.[5] The first pair in Table 4 (Models 1 and 2) model factors affecting research output volume (TOTPAP – total number of publications in 2001) and the other models 3–6 productivity (ZTOTPAP – output volume per team member). The models in Table 5 show the results for output quality (using the TOTMOCR indicator). Models 1, 3, 4 and 7-9 are baseline models to examine influences on team performance other than knowledge pooling such as team size or characteristics of the team leader. Models 2, 5, 6 and 10–12 are extended or full models including, where possible, variables for both modes of knowledge pooling – cultural diversity and international collaboration.

Model 1 in Table 4 (a negative binomial model for count data) shows the results of the baseline estimation for research output. Significant positive relationships can be confirmed between output and the size of the research team (TEAMSIZE) and the recognition of the team leader (RECOG). As with team size, the experience of the team leaders – measured as the number of years since attaining leadership of a

[5]In addition to the variables shown the estimations included dummy variables for country, life sciences discipline and – only the full models – further variables on the team composition and collaboration activities by research field and by sector (industry collaboration). The results for these variables are not shown, but can be obtained from the authors upon request (see also Barjak, 2006a).

Table 4. Regression models of research output and productivity on international collaboration and cultural diversity with other team characteristics (Note a: The Goldfeld-Quandt test returns a test value of 1.682 significant at $p<0.01$, indicating heteroscedasticity due to the team size variable. A weighted regression may control for this. Note b: b: estimated coefficient; t-ratio: quotient of estimated coefficients and standard errors; Significance levels ** <0.01, * <0.05, $^{+}$<0.1. Note c: See appendix on variable definitions and descriptive statistics.).

	Model 1 TOTPAP		Model 2 TOTPAP		Model 3 ZTOTPAP		Model 4 ZTOTPAP[a]		Model 5 ZTOTPAP		Model 6 ZTOTPAP	
Variable	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio
Constant	0.862	3.936**	0.895	3.186**	0.514	4.211**	0.529	5.301**	0.364	2.844**	0.400	2.995**
TEAMAGE	0.005	0.822	0.011	1.484	0.002	0.540	0.003	1.676^{+}	−0.29E-03	−0.077	0.002	0.803
TEAMSIZE	0.023	3.469**	0.019	2.419*	−0.019	−4.874**	−0.012	−5.749**	−0.019	−5.175**	−0.013	−5.127**
TEAMSIZE2	−0.11E-03	−1.983*	−8.4E-05	−1.404	0.11E-03	3.269**	6.1E-05	4.932**	0.10E-0.3	3.542**	6.1E-05	4.478**
RECOG	0.106	3.256**	0.137	3.403**	0.044	2.254*	0.024	1.504	0.029	1.468	0.015	0.839
EXPRNCE	0.038	2.318*	0.014	0.699	0.016	1.694^{+}	0.005	0.746	0.010	1.050	−4.9E-04	−0.071
EXPRNCE2	−0.001	−2.771**	−0.001	−1.238	−0.001	−1.961^{+}	−2.7E-04	−1.529	−0.41E-03	−1.419	−1.0E-04	−0.491
EUCPAP01	–	–	–	–	–	–	–	–	0.331	6.312**	0.230	7.028**
USCPAP01	–	–	–	–	–	–	–	–	0.206	3.684**	0.190	3.768**
CDIVPHD	–	–	0.674	1.930^{+}	–	–	–	–	0.314	1.896^{+}	0.378	2.633**
CDIVPHD2	–	–	−0.581	−2.002*	–	–	–	–	−0.267	−1.935^{+}	−0.307	−2.444*
CDIVPDOC	–	–	0.122	0.362	–	–	–	–	0.043	0.257	0.106	0.664
CDIVPDOC2	–	–	-0.127	-0.486	–	–	–	–	−0.053	−0.413	−0.123	−1.118
Model type		NEGBIN		NEGBIN		OLS		OLS, weighted by teamsize		OLS		OLS, weighted by teamsize
Alpha	0.534	7.571**	0.461	4.560**		–		–		–		–
Log-L		−1037.516		−770.4513		–		–		–		–
Rest. Log-L		−1334.189		−939.0459		–		–		–		–
F		–		–		2.62**		4.11**		6.08**		6.40**
Adjusted R2		–		–		0.076		0.136		0.348		0.362
Cases		395		296		395		395		296		296

Table 5. Regression models of research quality (TOTMOCR) on international collaboration and cultural diversity with other team characteristics (Note a: The Goldfeld-Quandt test returns a test value of 2.755 significant at $p<0.01$, indicating heteroscedasticity due to the team size variable. A weighted regression may control for this. Note b: b: estimated coefficient; t-ratio: quotient of estimated coefficients and standard errors; Significance levels ** <0.01, * <0.05, $^{+}$< 0.1. Note c: See appendix on variable definitions and descriptive statistics.).

	Model 7, OLS unweighted[a]		Model 8, OLS weight = teamsize		Model 9, OLS weight = teamsize		Model 10, OLS unweighted[a]		Model 11, OLS weight = teamsize		Model 12, OLS weight = teamsize	
Variable	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio	b	t-ratio
Constant	5.953	3.345**	5.516	3.489**	5.647	3.904**	7.382	3.364**	6.372	2.696**	5.789	2.920**
TEAMAGE	0.013	0.230	−0.012	−0.370	−0.015	−0.531	0.023	0.350	−0.001	−0.035	−0.007	−0.201
TEAMSIZE	0.007	0.134	−0.031	−0.928	−0.022	−2.815**	0.014	0.219	−0.022	−0.555	−0.012	−1.233
TEAMSIZE2	−1.88E-04	−0.405	0.61E-05	0.306	–	–	−1.36E-04	−0.273	−1.21E-04	0.488	–	–
RECOG	0.172	0.604	0.336	1.207	0.326	1.178	−0.287	−0.855	−0.029	−0.084	0.052	0.153
EXPRNCE	0.135	0.970	0.119	1.137	0.082	1.737^{+}	0.101	0.613	0.172	1.262	0.074	1.259
EXPRNCE2	−0.004	−0.838	−0.001	−0.339	–	–	−0.003	−0.558	−0.003	−0.707	–	–
EUCPAP01	–	–	–	–	–	–	1.377	1.533	1.323	1.802^{+}	1.395	1.868^{+}
USCPAP01	–	–	–	–	–	–	2.477	2.584*	1.807	1.713^{+}	1.684	1.672^{+}
CDIVPHD	–	–	–	–	–	–	−2.990	−1.056	−3.938	−1.693^{+}	−1.181	−1.299
CDIVPHD2	–	–	–	–	–	–	1.710	0.724	2.563	1.283	–	–
CDIVPDOC	–	–	–	–	–	–	−2.716	−0.958	−1.978	−0.626	1.596	1.726+
CDIVPDOC2	–	–	–	–	–	–	3.602	1.629	2.728	1.012	–	–
F		2.01**		3.58**		3.99**		2.00**		3.28**		3.65**
Adjusted R2		0.054		0.128		0.133		0.096		0.193		0.189
Cases		353		353		353		296		296		296

team for the first time – has a non-linear but positive effect on the team's publication output: the more experienced the team leader, the higher the output. Only for higher values of experience – team leaders with many years of leadership and probably close to the end of their careers, expressed in the squared experience variable (EXPRNCE2) – does the curve slope downward again, i.e. the publication output is smaller. This finding is in line with Simonton's theoretical considerations and with previous work (e.g. Wray, 2003), showing an influence of career trajectory on output. In the first estimations we also included a control variable for the gender of the team leader that was generally not significant, neither for TOTPAP nor the other dependent variables. Moreover, all models included controls for countries and life sciences sub-disciplines (also not shown).

In model 2 we added to the baseline model a set of variables reflecting the different dimensions of internal structure at international level. The variables for research collaboration with foreign partners – at global level, from the EU or from the US – had to be excluded due to estimation problems. We obtain a curvilinear relationship for the cultural diversity of the PhD students in the teams (CDIVPHD). The magnitude of the coefficients for the upward and downward slopes (squared variable CDIVPHD2) is similar. Hence, it appears that the optimum level of cultural diversity for maximal output is quite low.

In models 3–6 the dependent variable is specific output, i.e. the number of papers published in 2001 (and listed in the Thomson ISI database) divided by the number of staff in the team (ZTOTPAP). Given the properties of this variable, the estimation method used was changed to OLS regression. Model 3 – without the variables on team diversity and collaboration – generally shows a similar pattern to that of Model 1, with the notable exception of the two variables relating to team size. The measured effect of team size here is such that the larger the team, the smaller the number of published articles per team member. The effect associated with the squared variable (TEAMSIZE2) points to the presence of a curvilinear relationship and Goldfeld-Quandt and Breusch-Pagan tests revealed heteroscedasticity of residuals. In a weighted model (Model 4) the coefficients for the recognition and experience variables do not reach statistical significance.

Adding variables on international orientation and further control variables improved the predictive quality of the model as measured by adjusted R-squared and exposed the effect of collaboration with scientists from both other EU countries (EUCPAP01) and the US (USCPAP01) more clearly (cf. Models 5 and 6). As for the gross output variable, total number of papers, the relationship between specific output and cultural diversity of PhD students is curvilinear with a maximum at a low level of diversity (CDIVPHD and CDIVPHD2 are of similar magnitude). This indicates that cultural diversity of PhD students is conducive to research output, if it is at a low level.

The models shown in Table 5 use the total Mean Observed Citation Rate MOCR as the explained variable. The MOCR can be considered as an indicator of the quality of publications. Again the tests point to heteroscedasticity of the residuals and we show the results of weighted estimations (Models 8, 9, 11, 12) in addition to the standard OLS models. Estimation with the restricted variable set (Models 7–9) shows a negative effect of team size without significant deviation from the linear (compare Models 7/8 and 9), i.e., papers of large teams are less often cited than papers of smaller teams. A positive effect of the team leader's experience is also visible, if slight in size, and more clearly when the squared variable is excluded (Model 9). In the full models (Models 10–12), we obtain positive coefficients for the variables assessing international collaborations (EUCPAP01 and USCPAP01). The results for the diversity indexes (CDIVPHD, CDIVPDOC) are not consistent in the models of Table 5.

The estimated models provide a variety of results which corroborate some of the previous findings in the bivariate analyses and help specify others:

- First, in all models which include at least one variable on access to knowledge from another cultural background, be it internal to the team or external through collaboration, a positive effect is visible. This provides some confirmation that transnational scientific research is more successful than research that does not have these international influences (but possibly others that we did not measure) (H1).

- Next we find, broadly in line with H2 and H3, that the cultural diversity of PhD students is related to the number of publications. The relationship is curvilinear: with other factors kept constant, the publication output is highest for teams with moderate levels of PhD student cultural diversity and lower for teams with high or zero diversity. However, no such relationship is visible in respect of the cultural diversity of post-docs. This casts doubt on the general applicability of H2 and H3, however, the problems associated with identifying post-docs may play a role in confusing the picture - post docs are a less well-defined personnel category than PhD students and there is notable variation across countries.

- As with previous studies (Arora et al., 1998; Bordons et al., 1996; Cesaroni and Gambardella, 2003) and in line with our H4, we find a positive relationship between international collaborations and research productivity. We also added confirmation to other work in regard to the positive effect of international collaborations on the impact of research papers (Adams et al., 2005; Glänzel, 2001; Narin et al., 1991; Persson et al., 2004).

A further remark on team size is appropriate: this was included as a control variable and has been discussed controversially in previous research (see the reviews in Bonaccorsi and Daraio, 2005; von Tunzelmann et al., 2003). We found an inverse relationship between size and performance and an optimum team size of only a few team members (the maximum average publication per capita is reached for teams with 7 members). This contradicts the expectation voiced by Bonaccorsi and Daraio (2005) that increasing returns of size might apply at the team level, as they themselves could not find them at the level of institutes.

Table A1. Variable definitions.

Variable	Variable definition
TOTPAP	Total number of papers published in the Thomson ISI SCIE database in 2001
ZTOTPAP	Total number of papers published in the Thomson ISI SCIE database in 2001 per team member
TOTMOCR	Mean Observed Citation Rate 2001–2003 of the 2001 papers
TEAMAGE	Year of the survey (2005) minus the year in which the team was formed (= team age)
TEAMSIZE	Total staff of the team including the team leader, scientific and non scientific team members in 2005
TEAMSIZE2	Team size squared
RECOG	Recognition of the team head in 2005 (Scale 1 "very low" to 5 "very high")
EXPRNCE	Experience of the team head in 2005, measured as years of leading a research team
EXPRNCE2	Experience of the team head squared
ICPAP01	Papers with foreign co-authors published in the Thomson ISI SCIE database in 2001 per team member (binary-coded as 0/1)
EUCPAP01	Papers with co-authors from the EU published in the Thomson ISI SCIE database in 2001 per team member (binary-coded as 0/1)
USCPAP01	Papers with co-authors from the US published in the Thomson ISI SCIE database in 2001 per team member (binary-coded as 0/1)
CDIVPHD	Cultural diversity of PhD students in 2003, measured according to formula shown in the text
CDIVPHD2	Cultural diversity of PhD students squared
CDIVPDOC	Cultural diversity of post-docs in 2003, measured according to formula shown in the text
CDIVPDOC2	Cultural diversity of post-docs squared

6 Summary and conclusions

Our results show that those life sciences teams appear to be most successful which have a strong domestic base but collaborate actively enough outside the country to ensure a moderate amount of external involvement in the team. Extreme management or policy strategies which result in teams which are all domestic or mostly from non-domestic origins are clearly at a disadvantage compared to those leading to an appropriate mix. Non-zero but small proportions of students from domestic origins, from the EU and from further abroad are linked to the highest rates of publication.

The message to research managers and team leaders is that team composition matters, and that it is indeed beneficial to integrate researchers from another country. A well-balanced team is characterised by some heterogeneity, but this should not be excessive. Diversity provides a team with different skills, experience and cognitive frameworks which is believed to underlie the enhanced productivity we have found. At the same time diversity gives rise to additional costs, as people from different cultural backgrounds may speak different "scientific languages", attach different significance to concepts and research questions, and have been taught different norms for research procedures etc., placing burdens on communication and consensus formation.

Our results suggest that finding the right mix in recruiting researchers from at home and abroad might raise research output and productivity of many research teams. Picking the right mix is made more complex if, as seems likely, the best composition for research output volume and productivity differs from the best for research output quality as measured by citations.

Though negative impacts are visible today in the performance of over-diverse teams, these effects might be counteracted by improvements in research management. The integration of scientists from abroad could be improved, e.g. by reinforcing mentoring schemes and allocating specific responsibility for integration of new team members.

A message to research policy-makers is that further increases in the mobility of scientists between countries are not necessarily beneficial to research performance, unless flanked by other measures. The requirement to improve integration is already well recognised, for instance, the EC Mobility Strategy specifies as an objective "to encourage host organisations to take more responsibility for their foreign staff and visiting researchers". (European Commission, 2001:11). However, if appropriate improvements in diversity accommodation cannot be made, it seems that financial support to mobility of scientists should be limited to a certain proportion per team of guest scientists, PhD students or post-docs, or otherwise spread as widely as possible over recipient teams.

7 Limitations of the analysis

Though our analysis includes variables on the sourcing of knowledge from different backgrounds and some control variables on the teams and their leaders, not all possible influences on team performance could be covered, including some found important in previous work. These include financial resources of the group and available research infrastructure (Baird, 1986; Ramesh Babu and Singh, 1998; Johnston 1994) and several "soft" issues like the quality of

Table A2. Descriptive statistics for included variables (Note a: VIFs have been calculated for the specifications of the most comprehensive models 5, 6, 10, and 11. For other models with fewer variables VIFs are lower. The high VIFs for TEAMSIZE, EXPRNCE, CDIVPHD, CDIVPDOC are due to the inclusion of squared variables. If the squared variables are excluded, VIFs are reduced to less than 2. Even though multicollinearity obviously is a problem in this type of specification, we don't find any reason to change the estimation or interpretation of the results. The number of cases is sufficiently large to permit for this collinearity and the standard errors for the main variables of interest CDIVPHD, CDIVPDOC and their squares are not inflated.)

Variable	Mean	S. Dev.	VIF[a]
TOTPAP	5.350	5.833	–
ZTOTPAP	0.417	0.526	–
TOTMOCR	6.253	7.076	–
TEAMAGE	9.803	8.526	1.89
TEAMSIZE	16.196	16.514	7.28
TEAMSIZE2	534.433	1854.060	6.26
RECOG	2.771	1.549	1.50
EXPRNCE	10.419	8.504	12.34
EXPRNCE2	180.713	246.062	10.58
ICPAP01	0.147	0.268	1.20
EUCPAP01	0.083	0.162	1.20
USCPAP01	0.036	0.103	1.26
CDIVPHD	0.369	0.438	9.67
CDIVPHD2	0.327	0.500	9.22
CDIVPDOC	0.310	0.465	11.68
CDIVPDOC2	0.312	0.568	11.22

group interactions, climate and leadership that have been considered influential – mainly in older studies (Knorr et al., 1979; Stankiewicz, 1979; Fox, 1983; Bland and Ruffin, 1992 among others). The low coefficients of determination of the models reflect in some measure failure to include all important factors.

In the course of this work, a metric for the disciplinary diversity of the team, i.e. the presence of different research fields, has been examined but without any clear results (Barjak, 2006a). Still, disciplinary diversity and cultural diversity might both measure the presence of different schools of thought, as suggested by one of the reviewers. However, this would need to be assessed in a separate study with different methods.

Some words of caution are also appropriate in respect of specific recommendations. Our analysis uses publications and citations as metrics for the performance of research teams. However, scientific work has a number of other valuable outputs, such as new methods and tools, well- trained graduates, and knowledge or other products of use to private enterprise, the public sector and the general public (Larédo and Mustar, 2000). There may well be a trade-off between optimising levels of publication-based research output and achieving other valuable results. Clearly, our analysis of the link between diversity in a research team and publication-based research output is only valid for the output we have chosen to study.

Our recommendations also assume that some mechanism of pooling knowledge and expertise across countries underlies the relationship found here between the presence of researchers of different geographical origin in a research team and research output. However, what these underlying mechanisms are is not yet entirely clear. Education systems in different countries may give rise to ideas and perceptions, behaviours and practices etc. which are complementary in some general way. In addition, the fact that research programmes tend to be relatively homogeneous within countries may mean that mixing research staff exposed to different programmes might be a route to improving research productivity. Methods learned elsewhere for other problems may be found to be useful in the research task at hand.

Pooling knowledge is not the only imaginable link between team diversity and performance. Diversity may instead improve job satisfaction and promote stability in team composition (Williams and O'Reilly, 1998). It is also possible that mechanisms work in the reverse direction, for instance, high research productivity and visible success might well attract researchers from other countries into a team. Though these alternative hypotheses are possible, it is difficult to imagine that they are responsible for the magnitude of the effects found.

The possible underlying mechanisms for the impact of knowledge-pooling appear plausible and we therefore believe we have provided substantial evidence of the impact of pooling knowledge internationally on research performance. However, until the underlying mechanisms are better understood, there remains some uncertainty attached to specific recommendations to research and policy decision-makers on the optimal levels of team cultural diversity and international collaboration they should strive for.

Acknowledgements. This paper builds on data gathered and analytical approaches developed in the "Study on the role of networking in research activities" (NetReAct) for the Institute for Prospective Technological Studies of the European Commission under contract 22540-2004-12 F1ED SEV DE. Wolfgang Glänzel, Xuemei Li, Mike Thelwall, Alexander Mentrup and Gordon Wiegand are thanked for their contributions to NetReAct, without which this work would not have been possible.

Edited by: M. Hoyler

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