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Abstract

The present analysis looks at how scientists use the Internet for informal scientific communication. It investigates the relationship between several explanatory variables and Internet use for social communication, information retrieval and information dissemination in a cross-section of scientists from seven European countries and five academic disciplines (astronomy, chemistry, computer science, economics, and psychology). The analysis confirmed some of the results of previous US-based analyses. In particular, it corroborated a positive relationship between scientific productivity and Internet use. Furthermore, the relationship was found to be non-linear, with very productive (non-productive) scientists using the Internet less (more) than would be expected according to their productivity. Also, being involved in collaborative R&D and having large networks of collaborators is associated with increased Internet use, again with a non-linear relationship for the latter variable. In contrast to older studies, the analysis did not find an equalizing effect of higher Internet use rates for potentially disadvantaged researchers. Obviously, everybody who wants to stay at the forefront of research and keep up-to-date with developments in their research fields has to use the Internet. This also applies to renowned academics who are very well integrated into invisible colleges, and to social scientists – in our analysis economists and psychologists – who do not have lower usage rates than their peers from the natural sciences when it comes to the most common tools such as e-mail and the World Wide Web.

Keywords

Science communication, Internet

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1 Introduction

Scientific research is a social rather than isolated undertaking which is heavily dependent on social interactions such as communication and collaboration. Garvey (1979) called communication the “essence of science”. Scientific communication has been pictured in the form of flow models (Garvey and Griffith 1972, pp. 123-136; Hurd 1996, pp. 9-33) and cycles (Lievrouw and Carley 1990, pp. 457-477): a new scientific finding is disseminated to the research community via a process of communication, evaluation by fellow scientists, publication in different media, corroboration through repetition and comparison with other results, citation and integration into the knowledge body of a research field.

Essentially two different types of science communication can be distinguished: formal and informal communication. Formal communication is impersonal and it takes place in scientific journals, books and to some extent at conferences. The journal article is expected to be a robust and reliable piece of information. Informal communication is personal and social. The communication partners know each other, and in many cases they are friends. The entire range of one-to-one communication channels, from face-to-face discussions through to e-mail exchanges is used, as well as one-to-many channels for reaching larger groups of people (for instance postal or computer-based mailings). The information which is communicated informally is very diverse and can range from a mere thought, hypothesis or measurement result through to more elaborate draft papers, preprints and finished articles. Scientific information communicated informally is less robust and more redundant than information communicated formally (Garvey 1979, pp. 23-26).

Both formal and informal communication are important for the advancement of scientific knowledge and both had become increasingly inefficient in the past. For the majority of scientists the situation before the onset of the Internet age was rather depressing: Current information could be accessed only by a fraction of all scientists working in a field. In particular younger and less established scientists, scientists in developing countries or at less renowned institutions participated in informal information flows in a manner which was partial at best (Crane 1972, p. 117; Mulkay 1977, p. 112). Their work was also frequently hampered by poorly stocked libraries and limited resources for acquiring current literature. The growth of the knowledge producing system and the increasing specialization of individual academics, research institutes and national communities (Ziman 1994, p. 65) increased the distance between scientists working in a field and made personal encounters and face-to-face discussions more difficult and expensive (Hiltz and Turoff 1993, pp. 213-215). Communication costs were high: subscription fees for scientific journals devoured library budgets; travelling to research meetings and conferences cost a lot of time and money; joint research centres, where scientists could meet and collaborate, required considerable investment at national and international levels. And yet scientists were still largely ignorant of what was happening in other fields outside their own, and when they needed a piece of information from another field they often had to undertake time-consuming searches which produced incomplete results (Crane 1972, pp. 115-128).

Some of these problems still persist, such as the high subscription prices for scientific journals. However, the dissemination of computer networks and the Internet might have alleviated others in particular. We can even assume that the demand for efficient means and tools of communication and collaboration in science itself contributed significantly to the development of computer networks: the developers of the Internet and its predecessors were driven by the search for an efficient medium for long-distance communication (Leiner et al. 2003, <http://www.isoc.org/internet/history/brief.shtml>). It is therefore no wonder that e-mail usage rates have nearly

reached 100% in science: Walsh et al. (2000, p. 1298) reported 95-100% for American biologists, mathematicians, physicists, and sociologists. Barjak and Harabi (2004) reported 99.7% for European astronomers, chemists, computer scientists, psychologists and economists. They also found a WWW usage rate of close to 99% for the same dataset.

The spread of the Internet has been accompanied by considerable hopes and fears in regard to the effects on scientists' communication practices. For instance, researchers like Paul Ginsparg (1994), Stevan Harnad (1991, 1997) and Andrew Odlyzko (2001) have contributed to the view that the Internet will revolutionize formal academic communication. Others are more critical about how eager scientific communities are to change the established communication conventions (e.g. Kling and McKim 2000; Kling and Callahan 2001, <http://www.slis.indiana.edu/csi/WP/wp01-04B.html>). Several academics assumed that computer networks improve and increase informal communication among non-collocated colleagues and shrink the "communication gap" (Tibbo 1991, p. 281; see also Carley and Wendt 1991, p. 412; Clark 1995, p. 194; Noam 1995, pp. 247-249; Van Alstyne and Brynjolfsson 1996, pp. 1479-1480). Moreover, they feared that local science networks, interdisciplinary communication and the cross-fertilisation of scientific disciplines might be disrupted. However, somewhat more optimistically, it has also been proposed that the Internet might help to integrate disadvantaged scientists – such as those from less renowned organisations and developing countries, as well as younger and less established scientists – into the communication flows (Lievrouw and Carley 1990, pp. 468-469; Hurd 1996, p. 14; Liebscher, Abels and Denman 1997, p. 496; Nentwich 2003, pp. 250-255).

Since the early years, researchers have carried out empirical analyses on Internet use in science and monitored the intensity of Internet use and its possible effects (see chapter 3 for a review). However, the available literature has three inherent major weaknesses:

- The majority of studies were carried out in the US; there are very few cross-country and comparative analyses.
- The studies are often "technology-driven". They look at the simple use of Internet applications such as e-mail or the WWW but fail to consider the functions for which the applications are needed.
- The studies rarely go beyond mere empiricism and seldom contain frameworks that put the use of computer networks into the general context of scientific communication.

The present investigation sets out to overcome these weaknesses. Also, the present empirical work was carried out after the dramatic period of Internet diffusion in science which in the industrialised countries mainly took place in the 1990s. Due to network effects, the benefits of using the Internet increase with the number of users and we can assume that the spread of Internet applications also changes their role in science. In particular, a comparative analysis of Internet use is carried out for different activities of informal scientific communication. Formal communication will not be considered in detail. How the new information and communication technologies might affect formal communication in science has been discussed to a considerable extent. New models of formal communication processes have been proposed (Hurd 1996, pp. 20-33). Electronic publishing as a new form of computer-supported scientific publishing has been debated widely. In particular, the problems of peer review, authors' disapproval of e-journals, reliable identification and sustainable archiving of electronic documents have triggered considerable controversy (see e.g. Butterworth 1998; OECD 1998; Stevens-Rayburn and Bouton 1998; Tenopir and King 2000; Kling and Callahan 2001; *The Journal of Electronic Publishing*; Nentwich 2003, chapters 7 and 8). Scientific databases have been discussed as a new type of publication (see for instance Hilgartner 1995).

The present paper will therefore concentrate on the role that computer networks play in informal scientific communication. The role of informal scientific communication in two important theories of scientific knowledge production is briefly debated in chapter 2. Chapter 3 gives an overview of the empirical literature concerning the use of computer networks for informal science communication. In chapter 4 the data of the SIBIS R&D survey is presented; this constitutes the empirical basis of this contribution. Chapter 5 elaborates on the results and in chapter 6 some conclusions are drawn.

2 Scientific communication in two theories of scientific knowledge production

In science studies various models of scientific knowledge creation have been developed (see Zuckerman 1988 and Callon 1995 for overviews). Two of these, perhaps the most important, are known as the *sociology of science* and the *sociology of knowledge*; they differ in regard to the role of communication.

2.1 Sociology of science

The sociology of science model is characterized by treating scientific information as a commodity with a particular value for both the producers and the users (Lievrouw 1990, pp. 8-11). The producers of new scientific knowledge receive prestige and social recognition (Hagstrom 1965, p. 13; Ravetz 1971, p. 283) and the accompanying personal promotion and resources for further scientific work. The users benefit from new knowledge because scientific knowledge production is to some extent a cumulative undertaking and it can be incorporated by users in their own work (Kuhn 1962/1996; Garvey 1979, p. 14; Callon 1995, p. 37). In their flow model of scientific communication, Garvey and Griffith (1972, pp. 123-136) distinguished between several forms of formal and informal communication and pointed out the stage of the research process and the point in time in which they are used.

Formal communication fulfils several functions. New findings become publicly available information through their publication in scientific journals and books and presentations at scientific conferences. Whether a scientific result qualifies as new knowledge and the producer deserves recognition is evaluated in the process of formal communication, *ex-ante* through reviews of submitted papers and *ex-post* through citations and the inclusion in reviews, yearbooks, and abstract books (Crane 1972, p. 116; Garvey 1979, pp. 21, 28). Also, formal communication serves an archiving function, preserves knowledge and makes its subsequent retrieval possible (Garvey and Griffith 1972, p. 132). It is governed by certain norms which on the one hand are technical: a piece of information that is communicated has to appear in a certain form with a certain content. On the other hand, the norms can also be social: universalism, communism, disinterestedness and organised scepticism rule the communication process (Merton 1942, pp. 550-561).

Informal communication takes place through discussions with close co-workers, talks and reports to small colloquia, working papers and presentations to conferences. At each stage of this process the audience increases. Depending on the phase of research, it helps to identify suitable topics, focus the research approach, refine the findings and put them into the context of other current research. Two different groups of researchers which communicate informally have been

distinguished (Hagstrom 1965, p. 112; Price and Beaver 1965, p. 1015; Crane 1972, pp. 34-35): The first is the team of researchers and collaborators which jointly work on a project; the second is the invisible college, i.e. the “*power group of everybody who is really somebody in a field*” (Price and Beaver 1965, p. 1011). An invisible college controls research resources and decides on the research strategies in its field. It serves as a channel for the dissemination of research ideas and research results which it has evaluated positively. It also represents a regulator that matches the volume of information with the absorptive capacities of the researchers (Mulkay, Gilbert and Woolgar 1975, p. 189).¹ Last but not least, invisible colleges might be viewed as exchanges for skills and access to costly research apparatus, where for one reason or another researchers seek each other out in order to collaborate (ibid.).

Though informal scientific communication is deemed to be important at all stages of a research project, the major focus is laid on the communication and dissemination of (intermediate) results to fellow scientists in the invisible college. For this communication the status of a scientist becomes important: usually it is only established scientists who have access to the network and who are accepted as equivalent communication partners. Scientific recognition, professional status and reputation of the university are important factors which determine the extent to which scientists communicate informally with the invisible college. Also, the existence of something that can be communicated – a new research result or theory – is necessary. Informal communication is not a pastime but serves to announce new knowledge, evaluate and refine it, and test its acceptance by fellow scientists. Therefore, a relationship between informal communication and productivity can be expected: the more output scientists produce, the more they must communicate and the more visible they will be to their fellow scientists.

2.2 Sociology of knowledge

This sociology of science model was contrasted by what has become known as the sociology of knowledge model. In particular, this approach deviates from the understanding of scientific information and knowledge as a commodity and instead describes it as socially constructed (Lievrouw 1990, p. 14). This means that scientific knowledge is not taken from nature or reality, but it is constructed in discussions between scientists from often contradictory evidence, previous findings, and theories (Latour and Woolgar 1979, p. 37).

“Laboratory studies display scientific products as emerging from a form of discursive interaction directed at and sustained by the arguments of other scientists.”
(Knorr-Cetina 1983, p. 128)

Also, the results of this knowledge production through discussion are highly contingent on local circumstances (Latour and Woolgar 1979, p. 239; Knorr-Cetina 1983, p. 123). This includes the products of research such as the scientific paper which should not be considered as a one-to-one report of the research, but rather as a particular performance which can only be completely understood and repeated in another context if additional, tacit knowledge is provided (Knorr-Cetina 1981, pp. 94-133).

Informal communication is therefore already a salient feature of scientific knowledge production and not only of the dissemination of results. In particular, in the sociology of knowledge model all types of informal communication are much more relevant to the production of scientific

¹ Mulkay, Gilbert and Woolgar (1975, p. 189) use the term “research network” to describe a “relatively intensive concentration of interest ties”.

knowledge than in the sociology of science model. Furthermore, the relevant group of people that affects knowledge production is transepistemic, including scientists and external agencies such as funding bodies, firms and other stakeholders (Knorr-Cetina 1983, pp. 132-133). The increased importance of informal communication in the production of knowledge points again to the productivity of a scientist as a determinant of their communication activities. In addition, by emphasising the discursive character of scientific research, the constructivists also stress the importance of scientific collaboration. Besides being a tool for realising the division of labour and integration of differing capabilities, scientific collaboration serves to carry out the interpretations, negotiations, and discussions that characterise knowledge production (Latour and Woolgar 1979; Knorr-Cetina 1981, 1983).

The constructivist approach to science has been criticized from various angles. For instance, Zuckerman (1988, pp. 546, 556) questions whether the fact of multiple discoveries can be reconciled with the local contingency postulated by the constructivist approach. Whitley (2000, p. 10) proposes that the organization and control of activities of knowledge production remain rather obscure and it does not become clear how different types of knowledge are obtained.

3 State of knowledge on the use of computer networks for informal communication in science

In the previous chapter it was deduced that the professional status of a scientist, their productivity and participation in collaborative R&D are factors which should determine informal communication activities. Various analyses on the use of computer networks for informal scientific communication have included variables for these factors. Moreover, they have presented evidence on further relevant issues. The review in this chapter pools the variables found in the literature into seven groups: country, network-related infrastructure, academic discipline, scientific status, collaboration activities, productivity, and attitude and skills.

Country: Science is probably one of the areas where national differences in communication habits are not particularly pronounced. In many social situations, communication is subject to more national peculiarities and idiosyncrasies than it is in science. Science is very much a global undertaking, and research teams and science communities are often multinational. English is predominantly the language of choice, due to the dominance of scientists from the USA and English-language journals in many fields. However, in some countries a sizable proportion of academic communication takes place in the national language(s), in particular in countries with large national research systems. Also, the systems of higher education and research and their funding differ at the national level. Careers are also to some extent national. A strong argument for national differences in scientific communication is the notable variation of *per capita* publications between countries: For instance, according to the latest European Report on Science and Technology Indicators, from 1996-99 a researcher in Switzerland published on average 2.24 scientific articles, a researcher in the UK 1.65, in Germany 0.99, in the US 0.86 and in Japan 0.46 (European Commission 2003, p. 283). These differences have been attributed partially to the differing specialisations of the national research and innovation systems (European Commission 2003, p. 282) and to a bias of the data towards the English language which affects in particular larger non-English speaking countries (Van Leeuwen et al. 2001, pp. 335-346).

To the best of our knowledge, the use of informal communication media in general and computer-based communication in particular has not yet been analysed from a cross-country perspective.

Network-related infrastructure – computers, network connections, access to electronic libraries, archives, databases and others – is the material basis for using computer networks. Infrastructure is costly and therefore its quality varies according to the funding available. Few studies have assessed the importance of network-related infrastructure for scientific communication. In the second half of the nineties, infrastructure-related problems did not receive high priority in the US (Holmquist 1997, <http://www.eso.org/gen-fac/libraries/lisa3/holmquistj.html>; Lenares 1999, <http://www.ala.org/ala/acrl/acrl/events/lenares99.pdf>), whereas they were still highlighted as problems in European countries. In particular, problems of electronic access such as time consuming searches (Day and Bartle 1998, <http://sosig.ac.uk/iriss/papers/paper06.htm>) and high access costs and low access speeds (Stevens-Rayburn and Bouton 1998, <http://www.eso.org/gen-fac/libraries/lisa3/stevens-rayburns.html>) were highlighted. The lack of standardisation of electronic sources was also deplored (Brockman et al. 2001, p. 29).

The *academic discipline* or research field to which scientists belong can affect their communication behaviour in various ways and consequently their use of computer networks for communication. The size of academic disciplines, the possibilities of exploiting research results commercially and the locus of critical information differ (Walsh and Bayma 1996b, pp. 689-691). For instance, in the mid 90s in some disciplines a part of the empirical data was moved to on-line databases; this included genetic sequencing in molecular biology and digital space images in astronomy (OECD 1998, pp. 28-29). Research costs, the necessity to collaborate, and the visibility of the work performed by other scientists can vary (Kling and McKim 2000). There are also differences in communication conventions, e.g. at what time and in what media new findings are announced, what informal communication media are used, and how academic societies deal with previous informal publications (Kling and McKim 2000). Work is organized differently in different academic disciplines (Whitley 2000); in particular interdependence of work organization – such as the "*extent to which a person's daily tasks depend on the actions of others in the collaboration*" (Walsh et al. 2000, p. 1302) – varies. The importance of collaboration also differs (Walsh and Bayma 1996a, p. 347). Michael Nentwich (2003, pp. 148-181) explores a long list of hypotheses on the relationship between scientific disciplines/specialties and the use of several Internet applications. He finds that no single factor can explain the overall differences between the disciplines. Factors which can support the use of certain Internet tools in an academic discipline are a high importance of collaborative research, an existing pre-print culture, high time pressure, a cumulative tradition, and an extensive use of data and models; whereas a closeness of the field to a commercial exploitation and a tradition of book-publishing rather work against using the Internet.

The effects of these differences on the use of computer networks were analysed in the past: Persistently higher Internet usage rates were found for scientists than for social scientists, humanists and physicians (Abels et al. 1996; Cohen 1996, p. 49; Lazinger et al. 1997, pp. 508-518; Kling and Callahan 2001, <http://www.slis.indiana.edu/csi/WP/wp01-04B.html>). Mathematicians and computer scientists have the highest computer network and computer-mediated communication (CMC) usage rates (Abels et al. 1996; Walsh and Roselle 1999, p. 51; Walsh et al. 2000, p. 1298). Only more recent results suggest that social scientists have caught up with the sciences and even by-passed them in some aspects (Walsh et al. 2000, p. 1298; Nentwich 2003, pp. 129-147; 164).

Status and peripherality: Seniority, position and age can determine to what extent scientists benefit from using the Internet: Firstly, it can be assumed that less established researchers use

computer networks more often, as they make up for the lack of the personal information flows derived from invisible colleges at which they participate to a lesser extent; also, computer networks might help to provide access to an invisible college (Nentwich 2003, p. 251). Secondly, more senior scientists are involved with more tasks and in particular with more ambiguous tasks. Ambiguous tasks require the use of information-rich media (Trevino, Daft and Lengel 1990, p. 82; Fulk, Schmitz and Steinfield 1990, p. 130).² As face-to-face communication is more information-rich than computer-based communication, status and seniority should be negatively correlated with CMC use. Thirdly, younger scientists may show more affinity to new technologies, accumulate more benefits from learning how to use them, and therefore be more skilled than older scientists. Fourth, another incentive for scientists of lower status to use computer networks for communicating with higher ranked peers stems from the absence of status cues on electronic networks (Dubrovsky, Kiesler and Sethna 1991, pp. 122-124; Walsh and Roselle 1999, p. 61). Thus, the Internet contributed to creating more equal communication situations. However, more recent work has not been able to corroborate this finding, which it attributed to the increasing use of inserted status cues such as addresses, biographies and photos into Internet sites (Walsh and Roselle 1999, p. 61; Nentwich 2003, p. 253). Moreover, network use may itself simultaneously increase status, through providing access to scarce resources, increasing productivity and visibility of the networks users. However, the empirical results are anything but clear. The findings of Hesse et al. (1993, pp. 94-96) support a positive relation between network use and status; Walsh and Roselle (1999, pp. 61-66) report rather inconclusive findings.

Empirical analyses over the last decade have largely confirmed a negative relationship between Internet use and the degree of establishment in science: More senior scientists have lower Internet use (Lazinger et al. 1997, p. 512) whereas younger scientists use CMC more often (Cohen 1996, pp. 50-51; Mitra et al. 1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>). E-journal readers tend to be younger than non-readers (Kling and Callahan 2001, <http://www.slis.indiana.edu/csi/WP/wp01-04B.html>). A 'lower' professorial status (assistant versus associate and full professors) also corresponded to a higher use of computer networks for communication (Cohen 1996, pp. 50-51). Only the findings on gender differences between scientific CMC users were inconclusive: Whereas Cohen (1996, pp. 50-51) reports higher CMC use by women, Mitra et al. (1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>) and Walsh et al. (2000, p. 1301) did not find any gender-related differences regarding e-mail.

Collaboration and integration into scientific networks: Being involved in R&D collaboration should also increase the use of computer networks for communication as e-mail can be used to coordinate work more efficiently (Kling et al. 1996, <http://www.slis.indiana.edu/kling/pubs/CTCT97B.htm>). It is asynchronous, fast, leaves a permanent record, and simplifies communication between people in different time zones or with irregular desk-based work hours (Walsh and Bayma 1996a, p. 348; Nentwich 2003, pp. 189-192). Also, written messages permit greater reflection and non-native English speakers are more at ease communicating in the written form (Sanderson 1996, pp. 106-107). Moreover, e-mail can be used to exchange documents, data, information and software quickly among individual collaborators or groups. However, the range and level of selectivity of network applications can vary. For instance, we may assume that somebody with a large collaboration network can distribute his or her work via e-mail to selected peers, whereas somebody without this kind of network may choose the World Wide Web, which represents a less defined audience.

² "Richness" is understood as the information-carrying capacity of a medium consisting of (1) the availability of instant feedback, (2) the capacity to transmit multiple cues (voice tone, facial expression, body language), (3) the use of natural language compared for instance to numbers, and (4) the personal focus of the medium (Daft and Lengel 1984, p. 196-197; Trevino, Daft and Lengel 1990, p. 75).

More sophisticated technologies such as video conferencing are more information-rich than previously available telecommunications media and facilitate the transfer of a broader range of knowledge. Remote access and shared working spaces on computer networks facilitate the collaborative work of non-located research teams (Herbsleb et al. 2000, http://www-2.cs.cmu.edu/~jdh/collaboratory/research_papers/cscw_delay.pdf). Some collaborations depend to such a large extent on the electronic transmission of information that they are even considered as a new type of collaboration, called *extended research groups* (Carley and Wendt 1991, pp. 406-440) or *collaboratories* (Hurd 1996, pp. 29-31; OECD 1998, pp. 44-46; European Technology Assessment Network 1999, pp. 40-42; Finholt, T.A. 2001, http://www.crew.umich.edu/Technicalreports/Finholt_Collaboratories_03_07_01.pdf).

However, not all the high expectations can be fulfilled. For instance, case studies and descriptions of different tools for on-line meetings and remote collaboration suggest that there are still several technical shortcomings relating to hardware and software and that the technical staff and users' proficiency with the new technologies is rather limited (Sanderson 1996, pp. 103-105, 110; Finholt et al. 1998, pp. 66-69; Mark et al. 1999, pp. 159-178; Olson and Olson 2002, pp. 139-179). Moreover, the utility of computer-mediated communication tools for collaborative research depends on the phase of the research: At the beginning, intensive conceptual work requires face-to-face discussions. When the research is being performed, telecommunications media are used and at the end face-to-face meetings are again more important (Kraut, Egido and Galegher 1990, pp. 161-162; Walsh and Bayma 1996a, p. 349; Merz 1998). Face-to-face meetings are essential for discussing and orienting the collaborative research, demonstrating expertise, solving disagreements and making decisions (Sanderson 1996, p. 108).

All in all, empirical research has indeed shown that scientists who collaborate use the Internet more frequently: Scientists involved in collaborations have higher e-mail usage rates and in particular remote collaborations are correlated with e-mail use (Walsh et al. 2000, pp. 1303-1304). Computer-mediated communication users publish more co-authored articles than non-users (Cohen 1996, p. 53; Walsh et al. 2000, p. 1303). The quality of the collaborations can also affect communication: The stronger the ties between collaborators, the more they communicate and the more media they use for this communication (Carley and Wendt 1991, pp. 426-435; Koku, Nazer and Wellman 2001). The evidence on the relationship between the size of collaboration networks and the use of CMC is mixed: Hesse et al. (1993, p. 96) state that computer network users know more colleagues whereas Walsh et al. (2000, p. 1303) did not find a strong relationship between the size of collaborative workgroups and e-mail use. However, this might be explained by a U-shaped relationship: poorly connected scientists do not use CMC much because they do not communicate much, and very well connected scientists use CMC less due to time constraints. Early evidence (Hiltz 1984, p. 48) also points into this direction.

Furthermore, some authors assume that computer-mediated communication is not only the result but also a cause of collaboration (Brockman et al. 2001, p. 12). However, a deterministic stance should be avoided in this context. As Sanderson (1996, p. 102) notes:

"The communication technologies may make it easier to sustain collaboration, but it is the researchers themselves who initiate and create the collaboration."

Productivity effects: The relationship between scientific output and the use of computer networks may be twofold: (1) Use of computer networks may affect the scientists' productivity and the quality of output produced (scientific articles, other publications). In general, more information is available over computer networks and the search and retrieval of information is faster (Rusch-Feja and Siebeky 1999, <http://www.dlib.org/dlib/october99/rusch-feja/10rusch-feja-full-report.html>; Brockman et al. 2001, p. 31, Nentwich 2003, p. 210). Access to remote instru-

ments and data sets is also easier and faster (Walsh et al. 2000, p. 1296). Research may become better connected and more modular (Kircz 1998, <http://www.science.uva.nl/projects/commphys/papers/nicem.htm>; Nentwich 2003, p. 210). E-mail threads and groupware may help groups to memorize discussions and decisions and increase the efficiency of group interactions (Steinmueller 2000, pp. 366-370).

However, computer networks may also reduce productivity. First of all, the time spent on becoming familiar with a technology and learning how to use it is nothing else but learning costs (Nentwich 2003, p. 211). Complaints of information overload and too many and excessively broad hits on web-based information searches are documented (Stevens-Rayburn and Bouton 1998, <http://www.eso.org/gen-fac/libraries/lisa3/stevens-rayburns.html>; Day and Bartle 1998, <http://sosig.ac.uk/iriss/papers/paper06.htm>; Nentwich 2003, p. 212). In addition, SPAM – unsolicited e-mail not related to work issues – clutters mailboxes and wastes time, whilst viruses distributed over the Internet can erase hard drives and files. The possibilities of accessing information on computer networks might have a distracting effect and could increase “*the amount of time spent fooling around*” (Bishop 1994 cited in Walsh and Roselle 1999, p. 66). More efficient information searches may lead to the inclusion of more information overall, with decreasing marginal gains.

(2) The second effect would run counter to this. More productive academics are more visible to their peers. Therefore, we should expect that they also receive more comments, requests for publications or further explanation via computer-mediated communication media. In addition, they have been found to be more aware of electronic information sources such as e-journals (see the evidence cited in Kling and Callahan 2001, <http://www.slis.indiana.edu/csi/WP/wp01-04B.html>).

Empirical evidence supports a positive relationship between productivity and the use of computer networks (Hesse et al. 1993, pp. 95-96). Various authors have found positive correlations between publication rates and the use of CMC tools (Cohen 1996, p. 52; Walsh et al. 2000, p. 1304). But the use of other, non-communication applications is also related to publication rates: Kaminer and Braunstein (1998, p. 727) found a correlation between the use of remote login software, ftp and Kermit (file transfer, management and communication software) and the number of average annual publications.

Attitude: When use of computer networks and specific applications is voluntary and not required by the organisation of work, scientists' attitudes may influence their usage patterns. These attitudes may be generally their openness to technology and interest in trying out new ways of working. More specifically, attitudes can also reflect expectations about the functionality of networks for getting work tasks done, or the understanding of the organisation's culture, tradition and climate (Mitra et al. 1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>). However, the use of computer networks may also shape attitudes towards their usefulness by reconfirming and rationalising the decision to adopt them (Brown 2001, <http://informationr.net/ir/6-2/paper99a.html>).

Empirical evidence on this aspect is scarce: E-mail users were more positively predisposed towards the use of computers and had higher expectations in regard to their functionality for their work (Mitra et al. 1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>). The lack of willingness to use new information sources has been found as one factor that determines the use of electronic journals (Day and Bartle 1998, <http://sosig.ac.uk/iriss/papers/paper06.htm>). In surveys of variables reflecting aspects of an academic's capacity for innovation, such as knowledge of e-journals and acceptance of the properties of electronic media versus traditional media, a high proportion preferred not to use electronic journals (Holmquist 1997, <http://www.eso.org/>

gen-fac/libraries/lisa3/holmquistj.html; Lenares 1999, <http://www.ala.org/ala/acrl/acrlvents/lenares99.pdf>).

Another determinant of the use of computers and Internet applications are the *skills of the users*. A skills gap may represent an important barrier to the effective use of computer/Internet applications, particularly if the person is familiar with other methods of carrying out the task (Brockman et al. 2001, pp. 20-23). Learning and improving the skills for using computer networks to perform research takes time. Also the acquisition of skills is an investment which must be made before an application can be used efficiently. Older academics have less incentive for learning how to use computer networks because they expect lower cumulated returns in the future. It is difficult to measure skills and therefore empirical investigations very rarely include this. One attempt by Mitra et al. (1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>) finds that e-mail users rated their computer skills higher than non-users. However, it is not clear whether this self-disclosure regarding skills level is really valid.

4 Operationalisation, data basis and methods of the analysis

4.1 Operationalisation

Dependent variables

The use of computer networks was assessed for different R&D-related activities: social communication on R&D issues, the search and retrieval of information for R&D projects, and the dissemination of R&D results. Each of these activities was assessed using different variables.

The most important and widely used new communication tool is e-mail. Chat room applications and video conferencing are other markedly less common tools. Based on the responses to a question which assessed the use of these computer-based and various 'off-line' communication media for R&D during an average working week, two hybrid indicators were constructed:

- A computer-mediated communication (CMC) index reflects the ratio of CMC to all R&D communication. The higher the index, the larger the proportion of a respondent's communication that is transmitted via computer networks.
- The second indicator used the same question and built three clusters in a hierarchical cluster analysis which were labelled 'silent researchers', 'e-mail communicators' and 'communicators' according to their overall communication behaviour in general and e-mail use in particular.

The extent to which the Internet is used for retrieving scientific information was also assessed using two types of indicators:

- Simple usage rates of on-line information sources (Internet sites of libraries and archives, e-journals and full text databases, peers' websites, websites of other institutions, others) were the most basic indicators.

- A compound indicator, based on the relationship of on-line sources to all on-line and off-line sources (existing collections of information items, off-line electronic sources, libraries, colleagues, conferences and other off-line sources) was constructed to obtain a more condensed picture.

Scientists not only require information for their work, they are also suppliers of information. Traditionally this was achieved through the publication of research results in working papers, scientific journals, books and other publication media. Most of these media have set up sites on the Internet. However it is not always transparent for scientific authors in what form and to what degree their research findings are available on the Internet. Two indicators were therefore included on information dissemination over the Internet, which to a large extent are controlled by the scientists themselves:

- A simple and straightforward indicator is binary and measures only whether scientists have a personal homepage outlining their professional activities.
- The most important content for readers with a background in science are the results of scientific work reported in scientific publications. The second indicator is again binary and assesses whether scientists have working papers, full text articles, other forms of R&D output, or hyperlinks pointing to these on their website.

Independent variables

The seven groups of independent variables were operationalised for the analysis:

Country: The address data collected for the survey included the country of the scientist. However, in order to obtain more reliable data and control for multiple affiliations, the respondents were also asked for the country of their main organisation. Dummy variables were constructed for the countries in the sample.

Network-related infrastructure: Issues related to infrastructure were covered in the analysis by means of two types of variables: the first related to the scientists themselves and the second related to their organisation. The respondents were asked for their computer hardware. Based on the answers a hybrid indicator was constructed consisting of the type of computer available (standalone PC, workstation, mainframe, supercomputer/cluster) and the age of the computer used most often (as an indicator of its computing power). In addition, another indicator was constructed from a question which asked the respondents whether they had access to the most important network-based information sources in their discipline. The organisation-related variables include a categorical variable for the number of persons working for it and the type (university, university of applied sciences, non-university research institute and others).

The *academic discipline* of the respondent was determined by assessing their main field(s) of research. The analysis aimed at juxtaposing the Internet use of five academic disciplines, a basic science (astronomy), a more applied science (chemistry), an engineering discipline (computer science) and two social sciences (economics and psychology). For the five disciplines, dummy variables were constructed. All respondents who performed research outside the core fields of one of these disciplines were included in the category 'others'. According to the findings of previous studies it was expected that academics from the science and engineering disciplines would have higher Internet usage rates than the social scientists.

Four different *status dimensions* were included in the analysis: (1) The position of a scientist in regard to R&D (junior researcher, senior researcher, R&D manager), (2) the academic recognition measured as an index of the four nominal variables scientific awards, membership of a pro-

professional committee, service on the editorial board of a scientific journal, and membership of an advisory committee, (3) the respondent's age, and (4) gender. A higher reliance on computer networks was expected for the more 'disadvantaged' groups in terms of status (junior researchers, little academic recognition, young and female).

Four different concepts in regard to *scientific collaboration* were used in the analysis:

- The occurrence of a collaboration is a binary variable that is based on the question whether a respondent has been involved in collaborative R&D during the previous two years or not.
- Network size was assessed as the (estimated) number of collaborators. A more limited concept of network size included only the external collaborators from organisations other than a respondent's home organisation. In order to account for U-shaped effects – that is decreasing computer network use by scientists with very large collaboration networks, e.g. due to time constraints – the squared size variable was also included.
- Third, the respondents were asked for the typical number of their co-authors.
- A fourth variable was based on the proportion of co-authored journal articles during the previous two years (according to estimates by the respondents).

In accordance with the literature, a positive correlation was expected between all variables which measure the use of computer networks and the collaboration variables, except for the squared network size.

In order to assess the *productivity* of scientists, a question was included in the questionnaire which asked for the number of publications during the years 2001 and 2002, differentiated according to the type of publication (working paper, journal article, book chapter, monograph, conference presentation, report, others). This self-assessment does of course have some inherent weaknesses, in particular in regard to reliability of the responses. However, other than the standard figure of journal publications, it also includes less well-documented and counted types of publication. In particular, working papers and conference presentations are more informal than journal articles and tend to occur at different stages of the research process. A correlation between network use and informal publication but not formal publication forms may be interpreted as a general trend of 'informalisation' in scientific communication. In addition to the regular indicators, squared indicator values were also calculated in order to control for non-linear relationships between productivity and computer network use. These could appear for different reasons, such as decreasing returns on Internet use, time constraints of very productive scientists or validity problems of the data.

The aspect of a scientist's *attitude* towards the Internet can be deduced from a set of questions targeted at the importance of the Internet for selecting R&D topics. The questions referred to WWW and e-mail communication as sources for new research ideas, the Internet as a tool for supporting the performance of R&D, and as an application which helps to keep researchers up-to-date and focus their R&D on the hot topics in the field.

Scientists' *computer skills* were included with a rather general indicator based on the number of computer applications used and their sophistication. The more types of software a respondent used, and the more sophisticated this software was judged to be, the higher the assumed computer skills level.

4.2 Data basis

The data basis for the present analysis was gathered in a postal survey among higher education organisations (universities, polytechnics), as well as private not-for-profit R&D institutions and government-funded research institutes. The basic unit of observation was the individual scientist themselves. Scientists were defined as research managers, senior researchers and junior researchers. The latter category also includes PhD students who in some countries (e.g. Germany or Switzerland) are often simultaneously junior researchers.

Five academic disciplines were selected for which differing Internet usage patterns were expected according to the results of previous research: astronomy and astrophysics, chemistry, computer science, economics and psychology. For practical reasons seven European countries were included in the analysis: Denmark, Germany, Ireland, Italy, the Netherlands, Switzerland and the UK.³ In order to obtain a sufficient representation of all disciplines and countries included in the analysis, we set out to build an address data set of at least 150 scientists per academic discipline in the smaller countries (Denmark, Ireland, the Netherlands and Switzerland) and 200 scientists in the larger countries (Germany, Italy, and the UK). However, this was not always possible; in Denmark and Ireland it was not possible to find enough addresses in the smaller disciplines. The addresses were gathered from academic associations at European and national level (either from their published membership records or from their internal address databases). Any gaps were closed by using address searches via the World Wide Web which employed the following procedure:

- Step 1: random selection of research organisations (based on national or international lists of web links for an academic discipline);
- Step 2: random selection of individual researchers from the staff lists of these organisations as published on their homepages.

The questionnaire was mailed twice to all participants between April and July 2003 with a covering letter and a postage-paid return envelope (except for the UK). Overall 1,602 out of the 6,518 respondents replied to the questionnaire. 183 letters were returned because the respondent had died or left the organisation. This leads to an overall net response rate of 25%. The 1,602 responses resulted in 1,482 questionnaires which could be included in the empirical analysis. Descriptive statistics for all variables are provided in the annex tables A-1 and A-2.

The address collection via academic organisations and the Internet left some doubt as to the actual academic discipline in which the respondents carried out their research. The questionnaire also included a question on the three major research disciplines of each respondent and it was decided to use the responses to this question to determine the academic discipline relevant to the researcher.

4.3 Analysis of the data

In addition to frequency distributions, cross-classified tables and variance analyses, several multivariate methods were employed. These served on the one hand to condense the data and on the other hand to relate dependent and several independent variables.

³ These were the countries of the seven SIBIS partners which provided considerable help in the administration of the empirical work.

In order to condense the data, mainly cluster analyses were carried out using the statistics package SPSS. The social communication groups 'silent scientists', 'e-mail communicators', and 'communicators' are based on such a clustering of variables that reflect the use of different computer-based and traditional communication media for R&D.

The relationship between variables for Internet use and country, infrastructure, academic discipline, status, collaboration, productivity, attitude and skills were estimated by means of various types of models.

- For binary dependent variables (such as the existence of a personal web page and the inclusion of full text on the web page) binary logit and probit models were used.
- Dependent variables with more than two possible values (e.g. the social communication groups) were estimated by means of multinomial logit models.
- Ordinal dependent variables, such as the use of e-journals and peers' websites for obtaining information, were estimated using ordered probit models.
- Last but not least, two indexes were constructed which reflected the relation between the use of on-line and off-line information sources or on-line and off-line communication media. These indexes were standardised on the value range 0-100. In order to estimate the relationship between the explanatory variables and the indexes, the tobit model was employed.

The estimates were performed with the LIMDEP software. Since our main goal was to analyse the existence and direction of relations, marginal effects were not calculated. The results of the estimates are included in the tables in chapter 5. Regarding the technical results of the estimates c.f. the annex table A-3. In each case, the best performing model is presented.

5 Discussion of the results

The picture of *country differences* that emerges is very fuzzy. Overall, only scientists in Germany show a markedly different – lower – use of computer networks for R&D than scientists in Switzerland. The results for all the other countries varied around the Swiss values, which were chosen as the reference group. In particular, the use of the Internet for social communication and for obtaining information is less common in Germany. Swiss, Italian and British scientists use the Internet particularly often for obtaining information compared to scientists in the other countries. Scientists from the UK also carry out a large percentage of their social communication via computer-based media. In Denmark the World Wide Web is more important than in the other countries for disseminating scientific information: a higher than average proportion of Danish scientists have personal web pages and include full text documents, probably the most important content on a scientist's website.

[Table 1]

The *network-related infrastructure* variables are only important for information retrieval and dissemination. They do not have any influence on the used communication variables. It would seem that infrastructure deficits continue to limit the use of Internet applications by some scientists. The higher the quality of computers and the better the access to information sources, the higher the use of computer networks for information retrieval and dissemination. However, according to the respondents' remarks to an open question, the limiting factor in the use of

computer networks for R&D is not so much inadequate hardware but rather expensive licenses for journals, databases and other electronic sources. There were no clear correlations between the type or size of an organisation and its use of Internet applications.

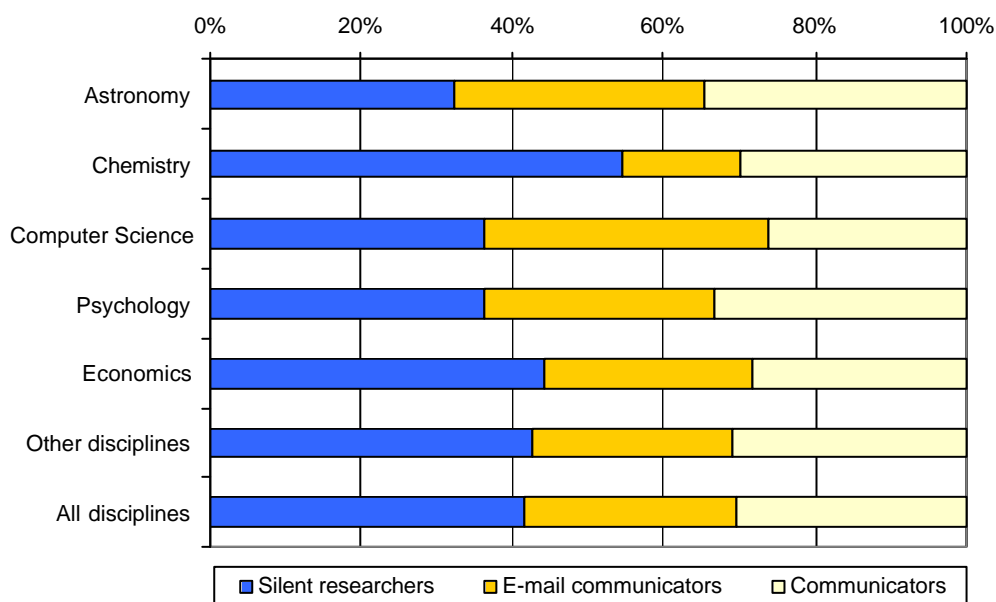
[Table 2]

Academic disciplines: The use of computer networks varies between academic disciplines. However, the expected general difference between scientists and social scientists which emerged in older analyses was not repeated (Abels et al. 1996; Cohen 1996, p. 49; Lazinger et al. 1997, pp. 508-518; Walsh and Roselle 1999, p. 51; Kling and Callahan 2001, <http://www.slis.indiana.edu/csi/WP/wp01-04B.html>). The use pattern is more varied. Economists and computer scientists are more reliant than scientists from other disciplines on the WWW for obtaining and disseminating information. Computer scientists depend predominantly on personal web sites when searching for information; astronomers do not use personal web pages very often, but rely mostly on impersonal electronic information sources (libraries, archives, databases, and e-journals). Economists use all types of electronic sources. Psychologists and chemists source less information from the Internet than scientists from other disciplines.

[Table 3]

In the social communications domain it is notable that psychologists are the most active communicators (see also figure 1). Though computer scientists communicate less overall, CMC media (e-mail, video and chat tools) nevertheless have a higher relative importance (also documented in the positive and significant coefficient for the CMC index estimation). Chemists, on the other hand, communicate less and use computer-based media to a lesser extent.

Figure 1: Respondents by academic discipline and communication groups



Source: SIBIS R&D survey.

The *status differences* found were mostly not as expected. First, senior researchers and R&D managers had largely similar computer network usage rates which are markedly higher than those of junior researchers. This runs counter to our expectation – and some previous findings (see e.g. Cohen 1996, pp. 50-51; Lazinger et al. 1997, p. 512) – that less renowned researchers

use the Internet more often. Academic recognition is very poorly correlated with computer network use. A greater proportion of renowned scientists have their own web page, but this is probably either an automatism brought about by the public relations policy of the institution, or a necessity resulting from the larger information demands which prominent academics encounter. Gender differences are not very marked and are contrary to expectations: male respondents were more likely to have their own web page and these featured full text documents more often. Also, they communicate more than female respondents. The only variable that supports the hypothesis of disadvantaged scientists using the Internet more often is age: younger respondents consistently had higher values for the network use variables. However, a competing interpretation would be that it is not only academic status but also technological competence and the size of the acquired knowledge base which vary with age. Hence the necessity and the willingness to source information externally and from the Internet also vary.

All in all, we cannot conclude that the less integrated and, in terms of off-line information flows, disadvantaged groups of scientists – young, female, and less established – make more use of computer networks in order to overcome the disadvantages. The consistently high use of networks by established scientists for social communication and for retrieval and dissemination of information suggests the use of these computer networks for performing such tasks are dominant - to such an extent that any scientist, regardless of whether they are established or not, has to use the available tools and applications in order to carry out their work effectively.

[Table 4]

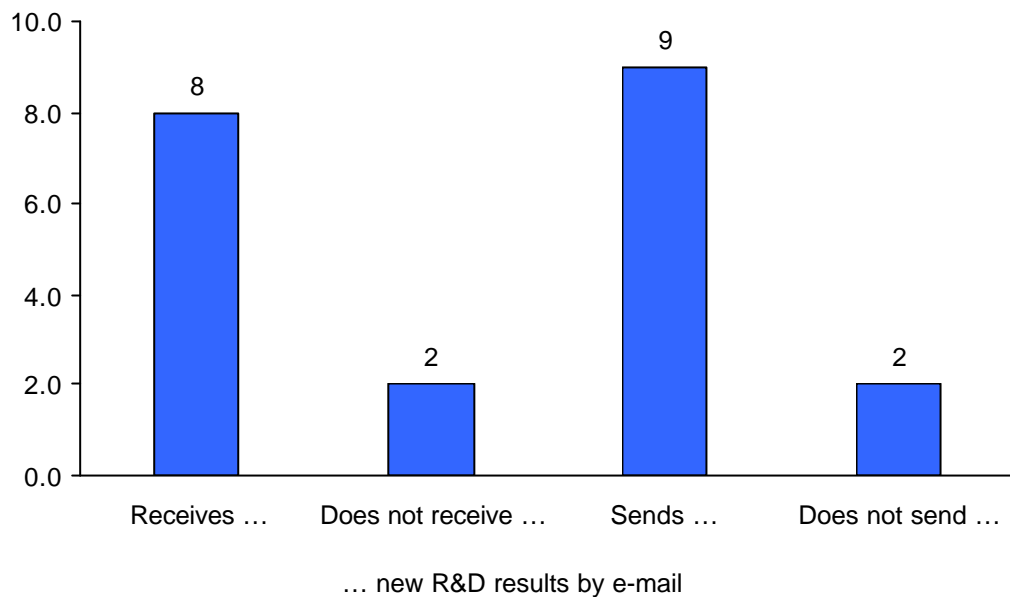
Collaboration and integration into scientific networks: Collaboration was very common in the dataset: Some three out of four scientists were involved in collaborative R&D in 2001 and 2002. A large majority (70%) collaborated with partners from other organisations. On average, every respondent had seven collaborators and two co-authors for their scientific publications (median values).⁴ More than 80% of all journal articles were denoted as co-authored.

There are marked differences between collaboration and scientific network variables: neither of the two variables on co-authorship suitably reflects the effects of collaboration on network use. They are therefore omitted from the following discussion. The collaboration variable and the network size variables, however, show a consistent picture: Collaborating scientists communicate more over the Internet and use it more for sourcing and disseminating information than non-collaborating scientists. This is consistent with previous findings (Walsh et al. 2000, pp. 1303-1304). The size of the collaboration network exerts a U-shaped effect, as expected: Scientists with very large collaboration networks use computer networks less than scientists with moderately sized collaboration networks. This could be due to an upper time limit for computer network use which is not exceeded even if a scientist has many collaborators. Considering only external collaborators returns similar results with slightly increased coefficients (not shown in the table). It is also interesting to note that the larger the collaboration network, the smaller the volume of information obtained from electronic sources, with a correspondingly lower importance of the WWW for disseminating research findings. Well-connected scientists obviously have more efficient ways of disseminating information than using impersonal computer networks, for instance by exchanging e-mail attachments with their collaborators (see figure 2).

[Table 5]

⁴ The distribution of R&D collaborators is notably skewed to the right. The arithmetic mean is 14.8 collaborators per respondent (see table A-2 in the annex).

Figure 2: Median number of R&D collaborators as a function of e-mail use for exchanging R&D results



Source: SIBIS R&D survey.

Scientific productivity: The respondents to the SIBIS survey published an average of 4.0 articles in journals, 2.2 working papers, 1.0 book chapters, 0.25 monographs, 1.2 reports and 0.2 publications in other media (such as edited books, brochures, articles in professional journals and general outreach). They also gave on average 4.4 presentations at scientific conferences. However, a comparison of the journal data from the SIBIS survey and the publication data from the Institute of Scientific Information (ISI) shows a difference of an order of magnitude. The ISI data lead to an average of 0.4 publications per researcher for the year 1999 for the seven European countries included in the SIBIS survey (calculations based on data published in the US by National Science Board 2002, vol. 2, table 5-41 and Frank 2003, p. 5). SIBIS covers two calendar years, and the respondents stated that they published 4.0 journal articles, or ten times more than according to the ISI figure. There are of course various systematic differences between the two data series,⁵ but we cannot exclude the possibility of an overestimation by the SIBIS respondents.

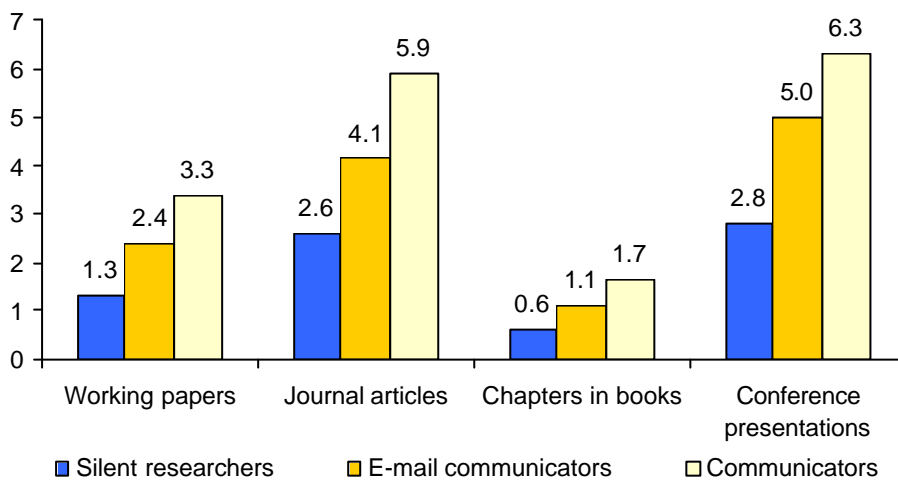
[Table 6]

The relationship between productivity and computer network use is positive (see table 6, figures 3 and 4), as in most previous analyses (Hesse et al. 1993, pp. 95-96; Cohen 1996, p. 52; Kaminer and Braunstein 1998, p. 727; Walsh et al. 2000, p. 1304). Journal articles are clearly the most stable predictor of computer network use among the different publication forms considered. For journal articles, positive coefficients were found for the use of e-mail, the existence of a personal website and the use of e-journals to obtain information. In addition, evidence of a weak but significant non-linear effect was found. As already stated above, this could be due to three reasons: first, decreasing returns on Internet use may be responsible for less pronounced differences in internet use than would be expected from productivity differences alone; second, an alternative explanation would be a certain upper limit of time that scientists are willing to invest for communication and information

⁵ These systematic differences are due to different sets of disciplines (only five in SIBIS versus all disciplines in ISI), the sets of journals included (scientists' own judgment in SIBIS, selected journal list in ISI), and counting procedures (fractional counting of co-authored articles in ISI and full counting in SIBIS).

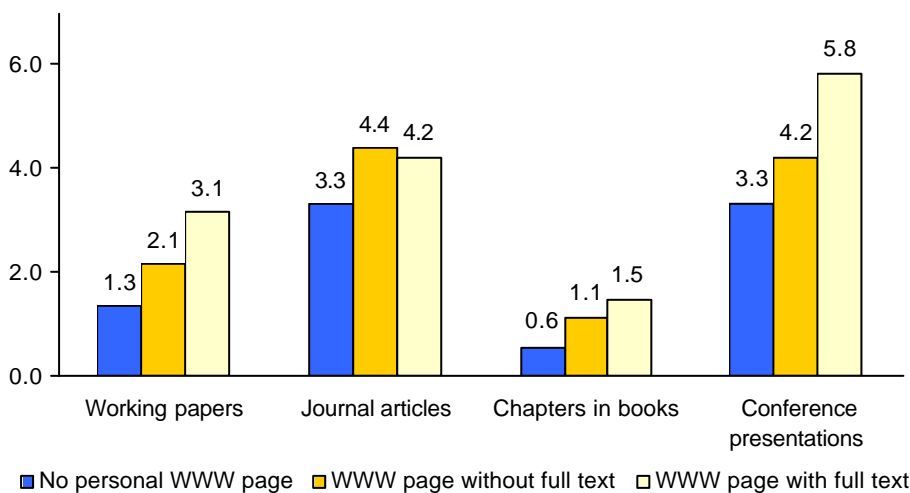
obligations, and therefore for the use of computer networks for these purposes; third, the result could be an artefact of the measurement of publications: in particular, the publication activity of researchers with many co-authored articles is overestimated because of the full counting method. Their Internet use, however, is measured correctly. Given the available information, it is not possible to determine which explanation is valid. Unfortunately, our data does not permit any conclusions about the direction of the relationship between Internet use and productivity either. Last but not least, in our view it is interesting to note that the use of personal websites (both as author/producer and as user) is correlated with the number of conference presentations (see figure 4). This points to an electronically enhanced communication model and the greater importance of self-publishing for some scientists.

Figure 3: Publications in 2001 and 2002 by type and communication group



Source: SIBIS R&D survey.

Figure 4: Publications in 2001 and 2002 by type and use of the WWW



Source: SIBIS R&D survey.

Attitude and skills: The respondents were asked about the relevance of the Internet in general, and the WWW and e-mail in particular, for selecting R&D topics. Positive statements about the WWW and the Internet as a tool for staying up-to-date correlate particularly well with the use of Internet

tools for obtaining information. The statement about the usefulness of e-mail communication for obtaining new research ideas correlates with e-mail use. Hence, we find that the previously established relationship between attitudes and use schemes still holds (see e.g. Holmquist 1997, <http://www.eso.org/gen-fac/libraries/lisa3/holmquistj.html>; Day and Bartle 1998, <http://sosig.ac.uk/iriss/papers/paper06.htm>; Mitra et al. 1999, <http://www.ascusc.org/jcmc/vol4/issue3/mitra.html>; Lenares 1999, <http://www.ala.org/ala/acrl/acrl/events/lenares99.pdf>).

[Table 7]

Whenever it was significant, the computer skills variable also showed the expected positive relationship. The higher the computer skills of a respondent, i.e. the more sophisticated the software they use, the more they use e-mail for social communication, the more likely they are to have a personal website and the more often they use peers' web pages for obtaining information.

6 Summary and conclusions

The empirical analysis showed that Internet use has become a ubiquitous feature of European science. Some of the results which were based on previous, mainly US-based research were corroborated and others were not. This might be attributable to country idiosyncrasies: the intensity of Internet use also differs across the countries of the dataset. However, we prefer a different explanation: The widespread diffusion of the Internet in industrialised countries has also changed its role in scientific R&D in some respects. We therefore have to review some of the older results.

Based on theories of scientific knowledge production, the *ex-ante* expectations are that professional status, productivity and collaboration activities would contribute to explaining the use of computer networks in science. These expectations were partially confirmed: productive scientists use the Internet more than average for all the investigated purposes (social communication, information retrieval and dissemination). Above all journal articles and conference presentations are significant predictors of Internet use. The number of conference presentations correlates in particular with the use of the Internet for disseminating research results. This points toward a computer-based model of self-publication which represents a substantially new mode of communication in science. For the variables journal articles and conference presentations, a slight non-linear effect on Internet use is also evident. Highly productive scientists do not use the Internet as much as their publication activities would suggest. This could be due to decreasing returns on Internet use and/or a certain time limit for communication and information-related activities.

Scientists who collaborate also use the Internet more often than scientists who do not. This applies not only to Internet-based communication tools but also to applications which are essentially used for obtaining or disseminating information. The more collaborators scientists have, the more intensively they use the Internet. However, the relationship is U-shaped: scientists with very large collaboration networks don't use computer networks much more than scientists with moderately sized collaboration networks.

In general, the results support the assumption that invisible colleges have integrated the Internet into their communication practices. Hence, everybody who wants to stay at the forefront of research and keep up-to-date with developments in their research field has to use the Internet. Scientists who belong to rather disadvantaged groups in terms of access to information do not

use the Internet more often than established academics. An equalizing effect of the Internet cannot therefore be corroborated. Even the idea that traditional information sources have become less important and that equality of access to on-line sources improves the situation for unknown researchers is not supported in any particular measure: The analysis also shows that the quality of the infrastructure (computers, network access) does affect the use of Internet applications. And it can be assumed that established academics tend to have better computer equipment and network access than their less established co-workers.

Another finding of the analysis is that social scientists have caught up with the sciences in terms of e-mail and World Wide Web use. Academic disciplines differ to some extent in regard to the overall use of Internet applications – in our dataset, computer scientists and astronomers use Internet applications more intensively than chemists, economists and psychologists. Apart from these general differences it becomes clear that different disciplines have integrated the Internet differently into their communication habits: for instance computer scientists rely more heavily on personal sources like their peers whereas astronomers prefer impersonal sources such as libraries or electronic journals for sourcing information.

The analysis was based on a cross-section of nearly 1,500 scientists from seven European countries and five academic disciplines. In order to better understand the use of Internet applications in science it is worth broadening the scope, both in terms of countries and disciplines. Moreover, it would also be beneficial to incorporate time series and panel analyses in the future. These are necessary in order to reliably determine the effects of Internet use which are often – and also in the present analysis – beyond the scope of the available empirical data.

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Annex

Table A-1: Nominal variables of the analysis

| Variable | n | Total valid N | Percentage |
|---|------|---------------|------------|
| Country of the organisation | | | |
| Switzerland | 232 | 1482 | 15.7 |
| Germany | 281 | 1482 | 19.0 |
| Denmark | 183 | 1482 | 12.3 |
| Italy | 307 | 1482 | 20.7 |
| Ireland | 154 | 1482 | 10.4 |
| The Netherlands | 144 | 1482 | 9.7 |
| United Kingdom | 177 | 1482 | 11.9 |
| Other countries | 4 | 1482 | 0.3 |
| Individual WWW presentation | 1003 | 1455 | 68.9 |
| Thereof having working papers, articles, hyperlinks included | 482 | 1010 | 47.7 |
| Clusters of communication media use | | | |
| Silent researchers | 594 | 1433 | 41.5 |
| E-mail communicators | 404 | 1433 | 28.2 |
| Communicators | 435 | 1433 | 30.4 |
| Type of organisation | | | |
| University or technical university | 1206 | 1481 | 81.4 |
| Non-university research institute | 202 | 1481 | 13.6 |
| Polytechnic/university of applied sciences | 44 | 1481 | 3.0 |
| Other | 29 | 1481 | 2.0 |
| Discipline of R&D | | | |
| Astronomy | 191 | 1475 | 12.9 |
| Chemistry | 284 | 1475 | 19.3 |
| Computer Science | 261 | 1475 | 17.7 |
| Psychology | 277 | 1475 | 18.8 |
| Economics | 307 | 1475 | 20.8 |
| Other disciplines | 155 | 1475 | 10.5 |
| Current position from an R&D perspective | | | |
| Research Manager | 281 | 1468 | 19.1 |
| Senior Researcher | 656 | 1468 | 44.7 |
| Junior Researcher | 493 | 1468 | 33.6 |
| Other positions | 38 | 1468 | 2.6 |
| Gender | | | |
| Male | 1130 | 1479 | 76.4 |
| Female | 349 | 1479 | 23.6 |
| Involved in R&D collaborations | 1116 | 1451 | 76.9 |

Table A-2: Variables of the analysis with ordinal and rational scales

| Variable | Total valid N | Arithmetic mean | Standard deviation |
|---|---------------|-----------------|--------------------|
| Computer-mediated communication (CMC) index (range 0-100) | 1431 | 32.05 | 10.31 |
| Index of usage of on-line information sources (range 0-100) | 1271 | 46.71 | 5.89 |
| Internet access to the important information sources (range 1-4) | 1465 | 3.70 | 0.55 |
| Age | 1476 | 42.88 | 11.90 |
| Total number of collaboration partners | 1408 | 14.83 | 30.21 |
| Number of co-authors | 1372 | 1.96 | 3.24 |
| Percentage of coauthored journal articles (range 0-100) | 1031 | 82.74 | 31.73 |
| Publications | | | |
| Working papers total | 1416 | 2.23 | 4.16 |
| Journal articles, total | 1435 | 4.01 | 5.23 |
| Chapters in books | 1439 | 1.06 | 2.09 |
| Monographs | 1438 | 0.25 | 0.78 |
| Presentations at scientific conferences | 1433 | 4.48 | 5.29 |
| Reports | 1428 | 1.26 | 3.42 |
| New ideas for new research through browsing the WWW (range 1-5) | 1473 | 2.59 | 1.39 |
| Considers whether the Internet supports realisation of R&D (range 1-5) | 1465 | 2.54 | 1.43 |
| Internet used to stay up-to-date and focus the R&D (range 1-5) | 1473 | 3.73 | 1.28 |
| New ideas for R&D through e-mail communication (range 1-5) | 1470 | 3.05 | 1.27 |
| Use of electronic journals for obtaining scientific information (range 0-3) | 1462 | 2.18 | 0.82 |
| Use of peers' websites for obtaining scientific information (range 0-3) | 1383 | 1.48 | 0.88 |
| Computer quality index (range 0-5) | 1456 | 2.49 | 0.92 |
| Scientific recognition (range 0-4) | 1476 | 1.04 | 1.18 |
| Level of computer skills (range 0-3) | 1473 | 2.25 | 0.80 |

Table A-3: Technical results of the estimations

| | Type of model | Number of observations | Log-L(0) | Log-L |
|--|-------------------|------------------------|-----------|-----------|
| Social communication | | | | |
| E-mail communicators, Communicators | Multinomial logit | 1223 | -1318.912 | -1019.855 |
| CMC Index | Tobit | 1255 | - | -4575.856 |
| Information retrieval | | | | |
| On-line information index | Tobit | 1111 | - | -3452.839 |
| E-journals | Ordered probit | 1245 | -1395.475 | -1206.927 |
| Peers' web pages | Ordered probit | 1181 | -1439.038 | -1318.644 |
| Information dissemination | | | | |
| Individual WWW page | Logit | 1262 | -778.7094 | -634.6376 |
| Full text articles or links on the web site | Logit | 882 | -609.7017 | -461.8807 |

Log-L(0): Restricted log likelihood, Log-L: log likelihood

Tables

Table 1: Country parameters from the estimations

| | Social communication | | | Information retrieval | | | Information dissemination | |
|-----------------|----------------------|---------------|-----------|---------------------------|------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Switzerland | . | . | . | . | . | . | . | . |
| Germany | -* | + | -* | -‡ | -** | - | - | + |
| Denmark | - | - | + | -‡ | - | -* | + | +** |
| Italy | - | +‡ | + | + | - | -* | -** | - |
| Ireland | -* | - | +* | - | -* | -* | -* | - |
| The Netherlands | - | - | + | - | - | -** | -** | + |
| UK | +‡ | - | +** | + | - | -* | - | + |

Reference groups: respondents from Switzerland, for 'e-mail communicators' and 'communicators' also the 'silent scientists'.

+ Positive coefficient, - negative coefficient; significance levels: ** $p < 0.01$, * $p < 0.05$, ‡ $p < 0.1$ (significant coefficients are bold)

Table 2: Parameters for infrastructure variables

| | Information retrieval | | | Information dissemination | |
|--|---------------------------|-------------|------------------|---------------------------|---|
| | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Computer quality index | + | + ** | + | + * | + |
| Internet access to important information sources | + ** | + ** | + ** | + | + |
| Organisation of the respondent | | | | | |
| University | . | . | . | . | . |
| Non-university research institutes | + | + | - | - | - |
| University of applied sciences | + * | + | - | - ** | + |
| Others (multinatl. org., government, business) | - | - | + | - ** | + |
| Size of the organisation | + ** | - | + | + ‡ | - |

Reference group: university scientists

+ Positive coefficient, - negative coefficient; significance levels: ** $p < 0.01$, * $p < 0.05$, ‡ $p < 0.1$ (significant coefficients are **bold**)

Table 3: Parameters for academic disciplines

| | Social communication | | | Information retrieval | | | Information dissemination | |
|-------------------|----------------------|---------------|-----------|---------------------------|------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Astronomy | –* | –** | + | +** | +** | – | –** | +* |
| Chemistry | –** | –** | –** | + | +** | –‡ | –* | –‡ |
| Computer Science | – | –* | +** | +** | –** | +** | +* | +** |
| Economics | –** | –** | + | +** | +** | +** | +* | +** |
| Psychology | . | . | . | . | . | . | . | . |
| Other disciplines | –‡ | –‡ | + | + | + | –* | – | +‡ |

Reference groups: psychologists, for 'e-mail communicators' and 'communicators' also the 'silent scientists'.

+ Positive coefficient, – negative coefficient; significance levels: ** $p < 0.01$, * $p < 0.05$, ‡ $p < 0.1$ (significant coefficients are bold)

Table 4: Parameters for status groups

| | Social communication | | | Information retrieval | | | Information dissemination | |
|---------------------------|----------------------|---------------|-----------|---------------------------|------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Position in regard to R&D | | | | | | | | |
| R&D manager | +* | +** | +‡ | +* | + | +‡ | +* | + |
| Senior researcher | +** | +** | +* | +** | +‡ | +‡ | +* | + |
| Junior researcher | . | . | . | . | . | . | . | . |
| Age | -* | -* | -* | -** | -** | - | - | -* |
| Gender | | | | | | | | |
| Female | . | . | . | . | . | . | . | . |
| Male | - | + | - | - | - | +‡ | +* | +** |
| Academic recognition | + | +** | + | + | + | + | +* | - |

Reference groups: junior researchers, females, for 'e-mail communicators' and 'communicators' also the 'silent scientists'.

+ Positive coefficient, - negative coefficient; significance levels: ** p < 0.01, * p < 0.05, ‡ p < 0.1 (significant coefficients are bold)

Table 5: Parameters for the collaboration variables

| | Social communication | | | Information retrieval | | | Information dissemination | |
|--------------------------------|------------------------|------------------------|------------------------|---------------------------|------------------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Collaborative R&D | - | - | + ^{**} | + | + [*] | + | + ^{**} | + |
| Size of network | + ^{**} | + ^{**} | + | - | - ^{**} | + | + [‡] | - ^{**} |
| (Size of network) ² | - [*] | - ^{**} | - | + | + [*] | - | - [‡] | + |

Reference group for 'e-mail communicators' and 'communicators' the 'silent scientists'

+ Positive coefficient, - negative coefficient; significance levels: ** $p < 0.01$, * $p < 0.05$, ‡ $p < 0.1$ (significant coefficients are **bold**)

Table 6: Parameters for productivity

| | Social communication | | | Information retrieval | | | Information dissemination | |
|--|----------------------|---------------|-----------|---------------------------|------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Working papers | +* | +** | . | . | . | . | . | . |
| Articles in scientific journals | +* | +** | +‡ | + | +** | + | +* | - |
| (Articles in scientific journals) ² | - | - | - | . | -** | . | -‡ | + |
| Book chapters | + | + | . | . | . | . | +* | . |
| Monographs | - | - | . | . | . | . | . | . |
| Conference presentations | +* | + | . | . | +* | +* | + | +** |
| (Conference presentations) ² | - | - | . | . | -* | - | . | . |
| Reports | - | + | . | . | . | . | . | . |

Reference group for 'e-mail communicators' and 'communicators' the 'silent scientists'

+ Positive coefficient, - negative coefficient; significance levels: ** p < 0.01, * p < 0.05, ‡ p < 0.1 (significant coefficients are **bold**)

Table 7: Parameters for attitude and skills

| | Social communication | | | Information retrieval | | | Information dissemination | |
|---|----------------------|---------------|------------|---------------------------|------------|------------------|---------------------------|---|
| | E-mail communicators | Communicators | CMC Index | On-line information index | E-journals | Peers' web pages | Individual WWW page | Full text articles or links on the web site |
| Get ideas while browsing the WWW | + | + | + | +* | +** | +** | . | . |
| Consider the Internet in project planning | + | + | - | - | - | -** | . | - |
| Use the Internet to stay up-to-date and focus the R&D | + | + | + | +** | +** | +* | . | +** |
| Get ideas from e-mail communication | +** | +** | +** | - | - | +** | +* | . |
| Computer skills | + ‡ | - | + ‡ | + | + | +* | +* | + |

Reference group for 'e-mail communicators' and 'communicators' the 'silent scientists'

+ Positive coefficient, - negative coefficient; significance levels: ** $p < 0.01$, * $p < 0.05$, ‡ $p < 0.1$ (significant coefficients are bold)

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