The Role of the Internet in Informal Scholarly Communication

Franz Barjak
University of Applied Sciences, Solothurn Northwestern Switzerland, Riggenbachstrasse 16, CH-4600 Olten, Switzerland. E-mail: franz.barjak@fhso.ch

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 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 U.S.-based analyses. In particular, it corroborated a positive relationship between research productivity and Internet use. The relationship was found to be nonlinear, with very productive (nonproductive) 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. In contrast to older studies, the analysis did not find any equalizing effect whereby higher Internet use rates help to overcome the problems of 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.

Introduction

Scientific research is a social rather than isolated undertaking which is heavily dependent on social interactions such as communication and collaboration (Lievrouw, 1990; Meadows, 1998). Garvey (1979) called communication the "essence of science." The communication of scientific work is a precondition for adding it to the knowledge corpus of a scientific community. It determines the extent to which division of labor is realized, results are compared with each other and replication is made possible. Thus, the effectiveness of scientific communication affects the pace of scientific progress.

Despite its importance, certain aspects of scientific communication had become increasingly inefficient some 30 years ago (Cole & Cole, 1973; Crane, 1972; Mulkay, 1977): Younger and less-established scientists, scientists in developing countries, or at less-renowned institutions participated to a lesser extent in scientific information flows. Insufficient funds for traveling to conferences, limited resources for subscribing to academic journals and purchasing new books inhibited the timely access to new knowledge. Scientists were largely ignorant of what was happening in other fields outside their own, as efficient search strategies and tools were lacking.

The dissemination of the Internet has been accompanied by considerable hopes of overcoming these inefficiencies and improving scholarly communication. 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 academic communication. Others, however, are more critical about how eager scientific communities are to change the established communication conventions and point to different academic cultures and communication behaviors (e.g. Cronin, 2003; Fry, 2004; Kling, 2004; Kling & Callahan, 2001; Kling & McKim, 2000).

Since the early years, researchers have monitored the use of the Internet for scientific communication (see the literature review below). However, these analyses were mainly carried out with data on scientists in the United States and cross-country studies have been demanded (Walsh, Kucker, Maloney, & Gabbay, 2000). In addition, most of the work dates back to the first half of the 1990s, but since then a dramatic diffusion of the Internet has taken place, at least among the scientists of the industrialized countries. Now, virtually all scientists use e-mail and the World Wide Web (WWW; Barjak & Harabi, 2004; Walsh et al., 2000). Moreover, the issue gains added importance as many observers assume that new communication practices mirror deep and fundamental changes in the social structure of science. Several authors hypothesized that computer networks improve and increase informal communication among noncollocated

Received October 26, 2004; revised September 6, 2005; accepted September 12, 2005

 • Published online 8 June 2006 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/asi.20454

colleagues and disrupt localized science networks and interdisciplinary communication (Carley & Wendt, 1991; Clark, 1995; Noam, 1995; Van Alstyne & Brynjolfsson, 1996). Walsh and Roselle (1999) see the appearance of "virtual colleges." Though Koku, Nazer, and Wellman (2001) stress the interrelatedness of traditional (face-to-face, phone) and computer-mediated communication, they also expect that the new technology provides the technological basis for changing relationships, for "a movement from tightly-bounded, highly-structured bureaucracies to social networks with amorphous boundaries and shifting sets of work relationships" (Koku et al., p. 1772). Hilgartner (1995) proposes that new biomolecular databases also give birth to "new communication regimes." Several others see the "collaboratory" as a new form of large-scale collaboration with a virtual lab in cyberspace (Finholt, 2002; Finholt & Olson, 1997; Glasner, 1996; Hurd, 1996; Organization for Economic Co-operation and Development [OECD], 1998). Opposing these views, Gläser (2003) argues that the Internet leaves the social structure of scientific communities unchanged, but reforms their work practices. In particular, he points to the possibility of a new and more rapid communalization of knowledge production related to the publication (and possibly production) of raw data. However, further analyses are necessary to broaden the empirical knowledge on how the Internet is used for communication and how this relates to social structures in science.

Hence, the present analysis attempts to deepen and improve our understanding of how the Internet is currently used in different scientific communities. In particular, it explores the characteristics of Internet proponents and resistors. Is there a digital divide between younger and older, male and female, established and less-known scientists? What is the relationship between research productivity and Internet use and how does collaborative research affect it? Is there still a gap between the social sciences and the natural sciences? Do the patterns of informal scientific communication differ between countries? As the Internet is primarily a technology that facilitates the transmission of information, we will limit our analysis to the general purpose of informal communication. How formal communication might be affected does not form part of this article as it has been discussed in other work (see e.g., Hurd, 1996, and on electronic publishing, Butterworth, 1998; Kling & Callahan 2001; Kling & McKim, 1999; Nentwich, 2003; OECD, 1998; Stevens-Rayburn & Bouton, 1998; Tenopir & King, 2000).

In the next section, I debate the role of informal scientific communication in two important theories of scientific knowledge production. Afterwards, an overview of the empirical literature is given, before the empirical approach of this study is presented. The final two chapters elaborate on the results and draw some conclusions. Above all, it will be argued that the diffusion of the Internet in the last 10 years has fundamentally changed its role in science and the significance of informal communication.

Scholarly Communication in Two Different Approaches to Scientific Knowledge Production

Scholarly communication has been represented in the form of flow models (Garvey & Griffith, 1972; Hurd, 1996; UNISIST, 1971 as cited in Fjordback Søndergaard, Andersen, & Hjørland, 2003) and cycles (Lievrouw & Carley, 1990). A new scientific finding is disseminated to the research community via a process of communication, evaluation by fellow scientists, publication in various media, corroboration through repetition and comparison with other results, and finally citation and integration into the knowledge body of a research field.

It is possible to differentiate between two types of scholarly communication: formal and informal communication. Formal communication is impersonal and 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 generally know each other and the entire range of one-to-one communication channels, from face-to-face discussions through to e-mail, exchanges is used. Larger groups of people are reached through one-to-many channels (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 ephemeral, less robust, and more redundant than information communicated formally (Garvey, 1979).

Various models of scientific knowledge creation have been developed in science studies (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.

Informal Communication and the 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, 1988). The producers of new scientific knowledge receive prestige and social recognition (Hagstrom, 1965) 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, which can be incorporated by users into their own work (Callon, 1995; Garvey, 1979; Kuhn, 1996). In their flow model of scientific communication, Garvey and Griffith (1972) distinguished between several forms of formal and informal communication and indicated the stage of the research process and the point in time in which they are used.

Formal communication fulfills several functions. New findings become publicly available information through their publication in scientific journals and books and via

DOI: 10.1002/asi

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; Garvey, 1979). In addition, formal communication serves an archiving function, preserves knowledge, and makes its subsequent retrieval possible (Garvey & Griffith, 1972). It is governed by certain norms that on the one hand are technical: A piece of information that is communicated has to appear in a certain form with certain content. On the other hand, the norms can also be social: Universalism, communism, disinterestedness, and organized skepticism rule the communication process (Merton, 1942).

Informal communication takes place through discussions with close co-workers, talks and reports to small colloquia, working papers, and presentations at 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 that communicate informally have been distinguished (Crane, 1972; Hagstrom, 1965; Price & Beaver, 1965). The first is the team of researchers and collaborators that 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 & Beaver, 1965, p. 1011). 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 (Cronin, 1982).

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 (Lievrouw, 1990). 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 that determine the extent to which scientists communicate informally with the invisible college (Cole & Cole, 1973; Crane, 1972; Cronin, 1982). 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.

Informal Communication and the Sociology of Knowledge

This sociology of science model was contrasted by what has become known as the sociology of knowledge model. In particular, the latter approach deviates from the understanding of scientific information and knowledge as a commodity and instead describes it as socially constructed (Lievrouw, 1988). 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 & Woolgar, 1979). "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).

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

Informal communication is therefore already a salient feature of scientific knowledge production rather than merely a feature 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 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). 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 emphasizing the discursive character of scientific research, the constructivists also stress the importance of scientific collaboration. Besides being a tool for realizing the division of labor and integration of differing capabilities, scientific collaboration serves to carry out the interpretations, negotiations, and discussions that characterize knowledge production (Knorr-Cetina, 1981, 1983; Latour & Woolgar, 1979).

State of Knowledge on the Use of Computer Networks for Informal Communication in Science

The Internet is a ubiquitous tool in modern science. E-mail and WWW usage rates have nearly reached 100% (Barjak & Harabi, 2004; Walsh et al., 2000). Though nearly all scientists use the Internet, they do not use it in the same manner and to the same extent. This chapter reviews the literature on Internet use for informal scientific communication and identifies what variables influence Internet use. It starts with results on scientists' status and research productivity, which are particularly important according to the sociology of science, and research collaborations, which is a key influence according to the sociology of knowledge. Furthermore, it discusses empirical findings on the relationship between Internet use and academic discipline, country, computer infrastructure, and attitudes towards this new technology.

DOI: 10.1002/asi

Status and Peripherality

In accordance with the propositions of the sociology of science, we would expect that scientists who have senior status and those with a higher position communicate more informally than their colleagues of lower status do. However, they can use different online and offline media for this purpose. If the Internet is not yet fully integrated into communication processes and online and offline media are substitutes on an equal footing, there are several reasons why scientists at the top of the hierarchy might use the Internet less often than their less-established colleagues. First, less-established researchers can use computer networks to compensate for the lack of personal information derived from invisible colleges at which they participate to a lesser extent; also, computer networks might help to provide access to such an invisible college (Nentwich, 2003). Second, scientists who have senior status are involved with more tasks and, in particular, with more tasks that are ambiguous. Ambiguous tasks require the use of information-rich media (Fulk, Schmitz, & Steinfield, 1990; Trevino, Daft, & Lengel, 1990).[1] As face-to-face communication is more information-rich than computer-based communication, status and seniority should be negatively correlated with computer-mediated communication (CMC) use. Third, younger scientists may have more of an affinity with new technologies, accumulate more benefits from learning how to use them, and therefore be more skilled than older scientists (Meadows, 1998). 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, & Sethna, 1991; Walsh & Roselle, 1999). Thus, the Internet contributed to creating more equal communication situations. However, 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 on Internet sites (Nentwich, 2003; Walsh & Roselle, 1999). Moreover, network use may itself simultaneously increase status, through providing access to scarce resources, increasing productivity, and the visibility of the networks users. All these arguments lose importance, however, if informal communication takes place on computer networks to such an extent that the traditional offline tools can no longer be used without missing significant chunks of information. Then we would expect that the scientific establishment communicates predominantly through computer networks as a result of the overall higher communication demands.

Empirical analyses over the last decade have largely confirmed a negative relationship between Internet use and the degree of establishment in science: More scientists who have senior status have lower Internet use rates (Lazinger, Bar-Ilan, & Peritz, 1997) whereas younger scientists use CMC more often (Cohen, 1996; Mitra, Hazen, LaFrance, & Rogan, 1999). E-journal readers tend to be younger than nonreaders are (Kling & Callahan, 2001). A "lower" professorial status (assistant vs. associate and full professors) also corresponded to a higher use of computer networks for communication (Cohen, 1996) and information retrieval (Budd & Connaway, 1997). Only the findings on gender differences between scientific CMC users were inconclusive: Cohen (1996) reports higher CMC use by women; Budd and Connaway (1997) state that female scientists in their sample used the Internet more often for searching external library catalogues than male scientists. Several others did not find any gender-related differences regarding e-mail and other Internet tools (Mitra et al., 1999; Walsh et al., 2000; Zhang, 2001). In line with the empirical findings, the following hypotheses are investigated:

Hypothesis 1: Less-established scientists use the Internet more often than well-established scientists for informal communication. In particular:

Hypothesis 1a: Younger scientists use the Internet more often for communicating with their peers than older scientists.

Hypothesis 1b: Female scientists use the Internet more often for informal communication than male scientists.

Hypothesis 1c: Scientists on a lower professorial level use the Internet more often than scientists on a higher level.

Research Productivity

Both the sociology of science and the sociology of knowledge allow us to expect a positive relationship between research productivity and the use of computer networks. Several authors provide arguments as to why Internet use may boost productivity: More information is available over computer networks and the search for and retrieval of information is faster (Brockman, Neumann, Palmer, & Tidline, 2001, Nentwich, 2003; Rusch-Feja & Siebeky, 1999). Access to remote instruments and data sets is also simpler and faster (Walsh et al., 2000). Research may tend to become better connected and more modular (Kircz, 1998; Nentwich, 2003). E-mail threads and groupware may help groups to memorize discussions and decisions and increase the efficiency of group interactions (Steinmueller, 2000).

However, computer networks may also reduce productivity. First, the time spent familiarizing oneself with a technology and learning how to use it is a pure learning cost (Nentwich, 2003). Complaints of information overload and too many and excessively broad hits on Web-based information searches are documented (Day & Bartle, 1998; Nentwich, 2003; Stevens-Rayburn & Bouton, 1998). In addition, spam—unsolicited e-mail not related to work issues—clutters mailboxes and wastes time, whereas viruses distributed over the Internet can erase data, corrupt files, and crash computers. The possibilities of accessing information on computer networks might have a distracting effect and

[1]Richness' is understood as the information-carrying capacity of a medium consisting of (a) the availability of instant feedback, (b) the capacity to transmit multiple cues (voice tone, facial expression, body language), (c) the use of natural language compared, for instance, to numbers, and (d) the personal focus of the medium (Trevino, Daft, & Lengel, 1990).

DOI: 10.1002/asi

could increase "the amount of time spent fooling around" (Bishop, 1994 as cited in Walsh & Roselle, 1999). More-efficient information searches may lead to the inclusion of more information overall, with decreasing marginal gains.

However, cause and effect may also be reversed: academics that are more productive 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 & Callahan, 2001).

In addition to these linear effects, we can also imagine a nonlinear effect that can be explained by a trade-off between research productivity and informal communication: Both activities, writing research papers and communicating with colleagues via the Internet, take time. However, time is a scarce resource and it is therefore possible that scientists who produce a lot of research output would have less time for informal communication.

Empirical evidence supports a positive relationship between productivity and the use of computer networks (Hesse, Sproull, Kiesler, & Walsh, 1993). Previous analyses found positive correlations between publication rates and the use of CMC tools (Cohen, 1996; Walsh et al., 2000). Nevertheless, the use of other, noncommunication applications is also related to publication rates: Kaminer and Braunstein (1998) found a correlation between the use of remote login software, ftp (file transfer protocol), Kermit (file transfer, management, and communication software), and the number of average annual publications. Based on these considerations and results the following hypotheses can be formulated:

> **Hypothesis 2a:** The higher the research productivity of scientists, the more they rely on the Internet for their informal communication.
>
> **Hypothesis 2b:** Scientists with very high research productivity do not use the Internet more for informal communication than scientists with high research productivity.

Collaboration and Integration Into Scientific Networks

The sociology of knowledge highlights the importance of collaboration in the construction of new scientific knowledge. The necessity to coordinate collaborative work and the advantages of personal and face-to-face interactions for this coordination cause the frequency and intensity of collaborations often to be higher at the local level (Kraut, Egido, & Galegher 1990). Computer networks become important if the collaboration partners are not collocated and methods to bridge geographical distance are needed. E-mail can be used to coordinate work more efficiently (Kling et al., 1996). It is asynchronous, fast, leaves a permanent record and simplifies communication between people in different time zones or with irregular desk-based work hours (Nentwich, 2003; Walsh & Bayma 1996a). In addition, written messages permit greater reflection and non-native English speakers are more at ease communicating in the written form (Sanderson, 1996). Moreover, e-mail can be used to exchange documents, data, information, and software quickly between individual collaborators or groups. However, the range and level of selectivity of network applications can vary (Kling & McKim, 1999). 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 to post it on the World Wide Web, which addresses a less-defined audience.

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-collocated research teams (Herbsleb, Mockus, Finholt, & Grinter, 2000). 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 & Wendt, 1991) or *collaboratories* (Finholt & Olson, 1997; Finholt, 2002; Glasner, 1996; Hurd, 1996; OECD, 1998).

However, not all the high expectations can be fulfilled. For instance, case studies and descriptions of different tools for online 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 (Finholt et al., 1998; Mark, Grudin, & Poltrock, 1999; Olson & Olson 2002; Sanderson, 1996). 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 et al., 1990; Merz, 1998; Walsh & Bayma, 1996a). Face-to-face meetings are essential for discussing and orienting the collaborative research, demonstrating expertise, solving disagreements, and making decisions (Sanderson, 1996).

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 remote collaborations in particular are correlated with e-mail use (Walsh et al., 2000). Computer-mediated communication users publish more co-authored articles than nonusers do (Cohen, 1996; Walsh et al., 2000). 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 & Wendt, 1991; Koku et al., 2001). The evidence on the relationship between the size of collaboration networks and the use of CMC is mixed. Hesse et al. (1993) state that computer network users know more colleagues whereas Walsh et al. (2000) 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 as frequently because they do not communicate much, and very well-connected scientists use CMC less due to time constraints. Early evidence (Hiltz, 1984) also points in 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). However, a deterministic stance should be avoided in this context. As Sanderson (1996) notes, “The communication technologies may make it easier to sustain collaboration, but it is the researchers themselves who initiate and create the collaboration” (p. 102). The following hypotheses will be investigated regarding the influence of research collaboration on the use of the Internet for informal scientific communication:

Hypothessis 3a: Scientists that participate in research collaborations use the Internet more intensively than those that do not collaborate.

Hypothessis 3b: The larger the collaboration network of scientists, the more often they use the Internet for informal communication.

Hypothessis 3c: Very well connected scientists (with very large collaboration networks) do not use the Internet more often than only well connected scientists.

Further Control Variables

In addition to the indicators listed above which were deduced from sociological theories of science, we include several control variables whose relevance has been determined in previous analyses.

A multitude of factors that affect communication practices are related to the scientific field or discipline: their size, the possibilities of exploiting research results commercially and the locus of critical information differ (Walsh & Bayma, 1996b). For instance, in the mid-1990s in some disciplines a part of the empirical data was moved to online databases; this included genetic sequencing in molecular biology and digital space images in astronomy (Hilgartner, 1995; OECD, 1998). 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 (Cronin, 2003; Kling, 2004; Kling & McKim, 1999, 2000). If new research findings are published in books rather than journals and topical relevance is low, the acceptance of e-journals is also lower (Talja & Maula, 2003). Differing communication conventions, in turn, are connected to discipline-specific reward systems and the ways in which trust is created and sustained between scientific authors (Cronin, 2003). Further factors that support the use of certain Internet tools in an academic discipline are the high importance assigned to collaborative research, an existing preprint culture, high time pressure, a cumulative tradition, and the extensive use of data and models. In contrast, the proximity of the field to commercial exploitation and a tradition of book publishing tend to work against using the Internet (Nentwich, 2003). Consistently higher Internet usage rates were found for scientists than for social scientists, humanists, and physicians (Abels, Liebscher, & Denman, 1996; Budd & Connaway, 1997; Cohen, 1996; Kling & Callahan, 2001; Lazinger et al., 1997). Mathematicians and computer scientists have the highest computer network and computer-mediated communication (CMC) usage rates (Abels et al., 1996; Walsh et al., 2000; Walsh & Roselle, 1999). Only more recent results suggest that social scientists might have caught up with the sciences and even overtaken them in some aspects (Nentwich, 2003; Walsh et al., 2000).

National traditions in relation to science communication may also affect the uptake of the Internet. Moreover, the systems of higher education and research and their funding differ at the national level, and careers are 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 1996–1999 a researcher in Switzerland published on average 2.24 scientific articles, a researcher in the UK 1.65, in Germany 0.99, in the U.S. 0.86, and in Japan 0.46 (European Commission, 2003). These differences have been attributed partially to the differing specialisations of the national research and innovation systems (European Commission, 2003) 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). To the best of my knowledge, the use of informal communication media in general, and computer-based communication in particular, has not yet been compared across countries.

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 recent studies have assessed the importance of network-related infrastructure for scientific communication. Zhang (2001) shows that the use of Internet tools and resources is correlated with the number of available Internet access points (at work, at home, at libraries). In the second half of the 1990s, infrastructure-related problems did not receive high priority in the United States (Holmquist, 1997; Lenares, 1999), whereas they were still highlighted as problems in European countries. In particular, problems of electronic access such as time-consuming searches (Day & Bartle, 1998) plus high access costs and low access speeds (Stevens-Rayburn & Bouton, 1998) were highlighted. The lack of standardization of electronic sources was also deplored (Brockman et al., 2001).

Scientists’ attitudes to computers and the Internet are important, generally in terms of scientists’ attitudes related to openness to technology and in trying out new ways of working. More specifically, attitudes can also reflect expectations about the functionality of networks for getting tasks done, or the understanding of the organization’s culture, tradition, and climate (Mitra et al., 1999). However, the use of

DOI: 10.1002/asi

computer networks may also shape attitudes towards their usefulness by reconfirming and rationalizing the decision to adopt them (Brown, 2001). Empirical evidence on this aspect is scarce: E-mail users were more positively predisposed towards the use of computers and had higher expectations concerning their functionality for their work (Mitra et al., 1999). A reticence to use new information sources has been found as one factor that determines the use of electronic journals (Day & Bartle, 1998). 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; Lenares, 1999).

Summary of the Literature Review

The role of informal communication was discussed in two distinct approaches to knowledge production, namely the sociology of science and the sociology of knowledge. The former allows us to expect that the status and productivity of scientists specifically influence their communication behavior and hence also Internet use; from the latter we can deduce the significant influence of research collaboration.

Previous empirical analyses did not corroborate the expectation that the scientific establishment communicates more via computer networks than their less-established colleagues. In particular, younger scientists and those of lower professorial status used the Internet more often. The few analyses that investigated the relationship between Internet use and research productivity point to a positive relationship, which is also in line with the expectations drawn from the theories discussed above. In addition, researchers involved in collaborative research with non-collocated project partners can be assumed to use Internet applications more often than their noncollaborating peers because the Internet facilitates project coordination. Empirical work has corroborated this. In addition, differences about Internet use may result according to the academic discipline, country, computer infrastructure, and attitudes of scientists.

However, the available literature has three major weaknesses:

- The majority of studies were carried out in the United States; there are no 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 extend beyond mere empiricism and seldom contain frameworks that set the use of computer networks into the general context of scientific communication.

The present investigation sets out to overcome these weaknesses. It concentrates on the role played by computer networks in informal scientific communication.

Operationalization, Data Basis, and Methods of the Analysis

Operationalization

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 in science (Barjak & Harabi, 2004). Two hybrid indicators were constructed using the responses to a question that assessed the use of these computer-based and various "offline" communication media (face-to-face meetings, phone calls, and letters):

- The 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 realized via computer networks. The index is mainly driven by e-mail use: The Spearman rank correlation coefficients between the index and the variables for e-mails sent and e-mails received are 0.571 and 0.596.
- The second indicator used the same question and built three clusters in a hierarchical cluster analysis according to their R&D-related communication activities, which were labeled *silent researchers*, *e-mail communicators*, and *communicators*.[2] Each respondent was assigned to a cluster that differed mainly as follows. Scientists in both the e-mail communicators and communicators clusters stated that they received between 21 and 50 e-mails for research per week; the silent researchers received only between 3 and 5 e-mails for research per week. Compared to the e-mail communicators and silent researchers, the communicators also made and received significantly more phone calls for research purposes and they communicated slightly more in the form of letters and informal meetings.

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

- Simple usage rates of online information sources (Internet sites of libraries and archives, e-journals, and full-text databases, peers' Web sites, Web sites of other institutions, others) were the most basic indicators.
- A compound indicator, based on the relationship of the listed online sources to all online and offline sources (existing collections of information items, offline electronic sources, libraries, colleagues, conferences, and other offline sources) was constructed to obtain a more condensed picture. This online information index is mainly driven by the use of peer's Web pages, electronic journals' and article databases,

[2]The silent researchers differ from the "silent scientists" specified by Meadows (Meadows, 1974 as cited in Cronin, 2001), as this study looks at informal communication activities and not publications or citations.

DOI: 10.1002/asi

together with other institutions' Web sites (positive correlations) and library use (negative correlation). According to the compound indicator, the Internet is used in 47 of a 100 cases when information is sought (median). The range of the index is rather narrow, with 50% of all respondents using Internet sources in 43 to 50 cases (out of a hundred) and 90% in 37 to 56 cases.

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 scientific journals, books, and other publication media. The Internet has generated the possibility of making research findings and other information publicly available (Kling & McKim, 1999). Two indicators for personal homepages could be included:

- A simple and straightforward indicator is binary and measures only whether scientists have a personal homepage outlining their professional activities or not.
- The most important content for readers with a scientific interest are new research results. The second indicator is again binary and assesses whether scientists have working papers, full-text articles or other forms of R&D output or hyperlinks pointing to these on their homepage.

Three groups of key independent variables were included in the analysis:

1. Four different status dimensions were considered:
   a. The position of a scientist (junior researcher, senior researcher, R&D manager)
   b. The academic recognition measured as an index of four nominal variables: scientific awards, membership of a professional committee, service on the editorial board of a scientific journal and membership of an advisory committee
   c. The respondent's age
   d. Gender
2. Analyses of scientific collaboration have revealed that collaboration does not always lead to co-authorship (Cronin, 1995; Laudel, 2001). Co-authored papers may well be considered as the results of the most intensive and active collaborations which also include a fair amount of creative work from all the involved parties (Laudel 2001; Luukkonen, Persson, & Sivertsen, 1992). However, equating the concept of collaboration with co-authorship will usually exclude the provision of technical assistance, consultancy, access to equipment or any other kind of service that is just acknowledged. Therefore, we employed four different concepts of scientific collaboration in the analysis:
   a. The existence of a collaboration is a binary variable that is based on whether a respondent has been involved in collaborative R&D during the previous 2 years or not.
   b. Network size was assessed as the (estimated) number of collaborators. 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 value of the variable was also included.
   c. The respondents were asked for the typical number of co-authors on a typical publication.
   d. A fourth variable was based on the proportion of co-authored journal articles during the previous 2 years (according to the respondents' own estimates).
3. 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 concerning the 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. In addition to the regular indicators, squared indicator values were also calculated to control for non-linear relationships between productivity and computer network use.

In addition to these key variables, the analysis contains several additional control variables:

- Dummy variables for the countries of the respondents' main affiliation
- Dummy variables for the academic discipline that was determined by assessing the respondents' main field(s) of research
- Variables on the quality of the available computer hardware and access to the most important network-based information sources
- Variables on the importance of the Internet for selecting R&D topics that were interpreted as indicators for the respondents' attitude towards the new information and communication technology (ICT)

Data Basis

The data basis was gathered in a postal survey among higher education organizations (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. Scientists were defined as research managers, senior researchers, and junior researchers. The latter category also includes doctoral 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. To obtain sufficient representation from 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

DOI: 10.1002/asi

(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 obtain enough addresses in the smaller disciplines. The addresses were gathered from academic associations at the 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 organizations (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 organizations 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 researchers in the sample (25%) replied to the questionnaire. One hundred eighty-three letters were returned because the respondent had died or left the organization. The 1,602 responses resulted in 1,482 questionnaires, which could be included in the empirical analysis. Table 1 shows the usable responses by country and discipline. Descriptive statistics for the further variables used in this article are provided in the Appendix Tables A1 and A2.

The response rate of 25% is rather low compared to other surveys among scientists. We assume that the considerable length of the questionnaire (36 questions on 12 pages) and—to a lesser extent—problems in the mailing of the questionnaires are the main reasons for this.[3] However, all countries and academic disciplines of the survey population are represented sufficiently. The responses may contain a bias towards the Internet users—this cannot be disproved because there is a lack of information on the Internet use of the nonrespondents. However, such a bias does not affect the type of correlation analysis that is presented below.

[3]For the UK questionnaires a free postage-paid return envelope could not be included and the mailing of the Dutch questionnaires was delayed due to a mistake in the processing of the addresses. Consequently, the response rates for the UK and the Netherlands were slightly below 20%, whereas they were higher for the other countries.

Analysis of the Data

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

To condense the data, cluster analyses were predominantly carried out using the statistics package SPSS Version 12. 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 the dependent and independent variables were estimated using 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' Web sites for obtaining information, were estimated using ordered probit models.
- Finally yet importantly, the two indexes (online information index and CMC index) were standardized on the value range 0–100. To estimate the relationship between the explanatory variables and the indexes, the tobit model was employed.

The estimates were performed with the LIMDEP Version 8.0 (Econometric Software, 2002) software. Because our main goal was to analyze the existence and form of relations, marginal effects were not calculated. The results of the estimates are included in the tables in the next section. Regarding the technical results of the estimates, cf. the Appendix Table A3. In each case, the best performing model is presented.

TABLE 1. Cases in the dataset by discipline and country.

	Astronomy	Chemistry	Computer Science	Psychology	Economics	Other disciplines	Total
Switzerland	27	36	39	54	48	27	231
Germany	24	43	66	56	54	35	278
Denmark	30	35	34	21	28	33	181
Italy	44	70	40	61	65	25	305
Ireland	13	32	31	20	41	17	154
The Netherlands	23	35	14	24	36	12	144
United Kingdom	30	33	35	39	32	6	175
Other countries	0	0	0	1	3	0	4
Total	191	284	259	276	307	155	1472

DOI: 10.1002/asi

Results and Discussion

Status and Internet Use

The relationships found between status and Internet use were generally not as expected based on previous studies (see Table 2). First, senior researchers and R&D managers had largely similar computer network usage rates and these were markedly higher than those of junior researchers. This runs counter to epectation—and some previous findings (see e.g., Cohen, 1996; Lazinger et al., 1997)—that less-renowned researchers use the Internet more often (Hypothesis 1c, rejected). Academic recognition is only poorly correlated with computer network use. A greater proportion of renowned scientists have their own Web page, but this is probably because of their prominent hierarchical positions, where a Web page is routine, or a necessity based on the larger information demands that distinct scholars encounter. Gender differences are not very marked and are contrary to expectations (Hypothesis 1b, rejected): Male respondents were more likely to have their own Web page and these featured full-text documents more often. In addition, male respondents communicated more than female respondents did. The only variable that supports the hypothesis of disadvantaged scientists using the Internet more often is age (Hypothesis 1a, confirmed): 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 the size of the acquired knowledge base and technological competence that vary with age (Meadows, 1998). Younger scientists tend to have smaller stocks of offline knowledge (books, journals, etc.) and higher technological competence, or more incentives and fewer barriers to make themselves familiar with a new technology. Hence, the necessity and the willingness to source information externally and from the Internet may be greater.

Overall, we cannot conclude that the less integrated and, in terms of offline information flows, disadvantaged groups of scientists—young, female, and less established—make more use of computer networks to overcome the disadvantages. The consistently high use of networks by established scientists for social communication and for retrieval and dissemination of information suggests that the use of these computer networks for performing such tasks is dominant: Any scientist, regardless of whether they are established or not, must use the available tools and applications to carry out their work effectively. As Koku et al. (2001) state "If almost everyone is using e-mail, then the recalcitrants will be using e-mail or be left out of the loop" (p. 1755).

Research Productivity and Internet Use

The respondents to the 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) in the years 2001 and 2002. They also gave on average 4.4 presentations at scientific conferences. However, a comparison of the journal data from our survey and the publication data from the Institute of Scientific Information (Thomson ISI, Philadelphia, PA) shows a difference of an order of magnitude (Barjak & Harabi, 2004, Annex Table A-27). The ISI data lead to an average of 0.4 journal publications per researcher for the year 1999 for the seven European countries included in the SIBIS survey (calculations based on data published in the United States by the National Science Board, 2002 and Frank, 2003). The SIBIS survey covers two calendar years, and the respondents stated that they published 4.0 journal articles, or 10 times more than reported by ISI figure. There are of course various systematic differences between the two

TABLE 2. Parameters for status groups.

	Social communication			Information retrieval			Information dissemination	
	E-mail communicators	Communicators	CMC index	Online 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	+	+**	+	+	+	+	+*	−

Note. CMC = computer-mediated communication. Reference groups: junior researchers, females, for "e-mail communicators" and "communicators," also the "silent scientists."
+ Positive coefficient; − negative coefficient.
Significance levels: ** $p < .01$. * $p < .05$. ‡ $p < .1$.

DOI: 10.1002/asi

TABLE 3. Parameters for research productivity.

	Social communication			Information retrieval			Information dissemination	
	e-mail communicators	Communicators	CMC index	Online 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 squared	−	−	−	.	−**	.	−‡	+
Book chapters	+	+	.	.	.	.	+*	.
Monographs	−	−	.	.	.	.	.	.
Conference presentations	+*	+	.	.	+*	+*	+	+**
Conference presentations squared	−	−	.	.	−*	−	.	.
Reports	−	+	.	.	.	.	.	.

Note. CMC = computer-mediated communication. Reference group for "e-mail communicators" and "communicators," also the "silent scientists." + Positive coefficient; − negative coefficient.

Significance levels: ** $p < .01$. * $p < .05$. ‡ $p < .1$.

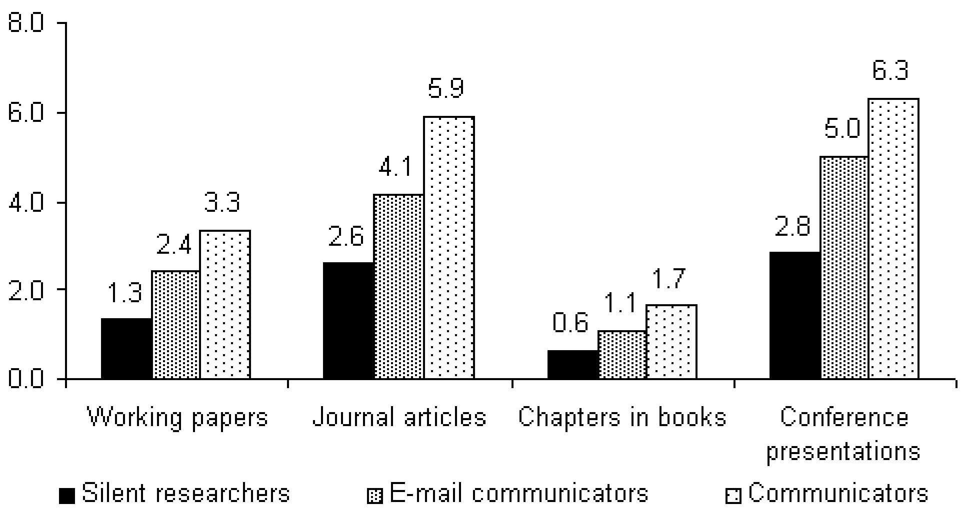

FIG. 1. Mean number of publications in 2001 and 2002 by type and communication group.

data series,[4] but we cannot exclude the possibility of an overestimation by the SIBIS respondents.

The above-listed Hypothesis 2a is confirmed: The relationship between productivity and computer network use is positive (see Table 3, Figures 1 and 2), as in most previous analyses (Cohen, 1996; Hesse et al., 1993; Kaminer & Braunstein, 1998; Walsh et al., 2000). 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 Web site and the use of e-journals to obtain information. In addition, evidence of a weak but significant nonlinear effect was found (the squared variables confirm Hypothesis 2b). This could be due to three reasons: (a) decreasing returns on Internet use may be responsible for less-pronounced differences in Internet use than would be expected from productivity differences alone; (b) an alternative explanation would be a certain upper limit of time that scientists are willing to invest for communication and information obligations, and therefore for the use of computer networks to achieve these; and (c) the result could be an artifact of the measurement of publications: the publications of researchers with many co-authored articles are overestimated because of the full-counting method. Their Internet use, however, is measured correctly. Given the available information, it is not possible to determine clearly,

[4]These systematic differences are due to different sets of disciplines (only five in SIBIS vs. 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 total counting in SIBIS).

DOI: 10.1002/asi

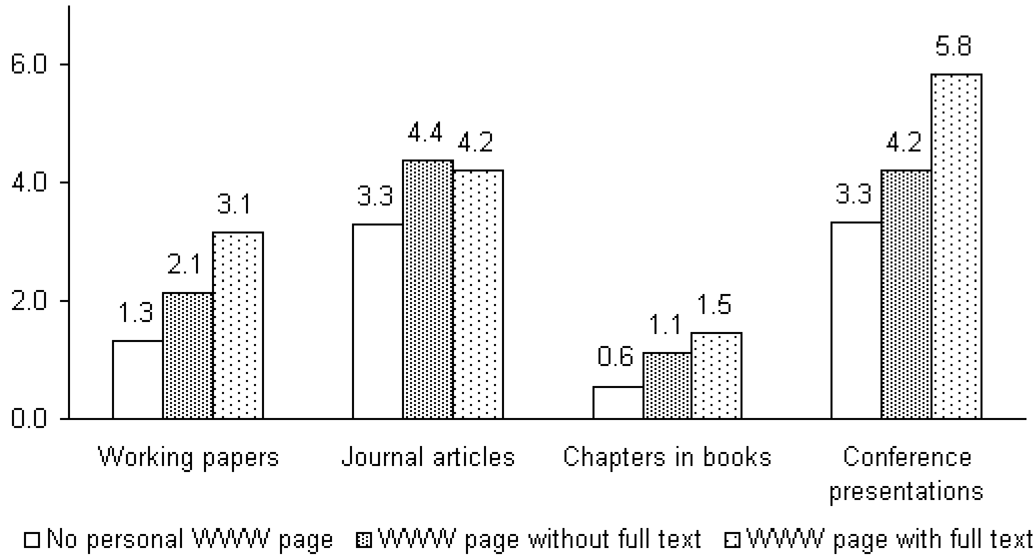

FIG. 2. Mean number of publications in 2001 and 2002 by type and use of a personal homepage.

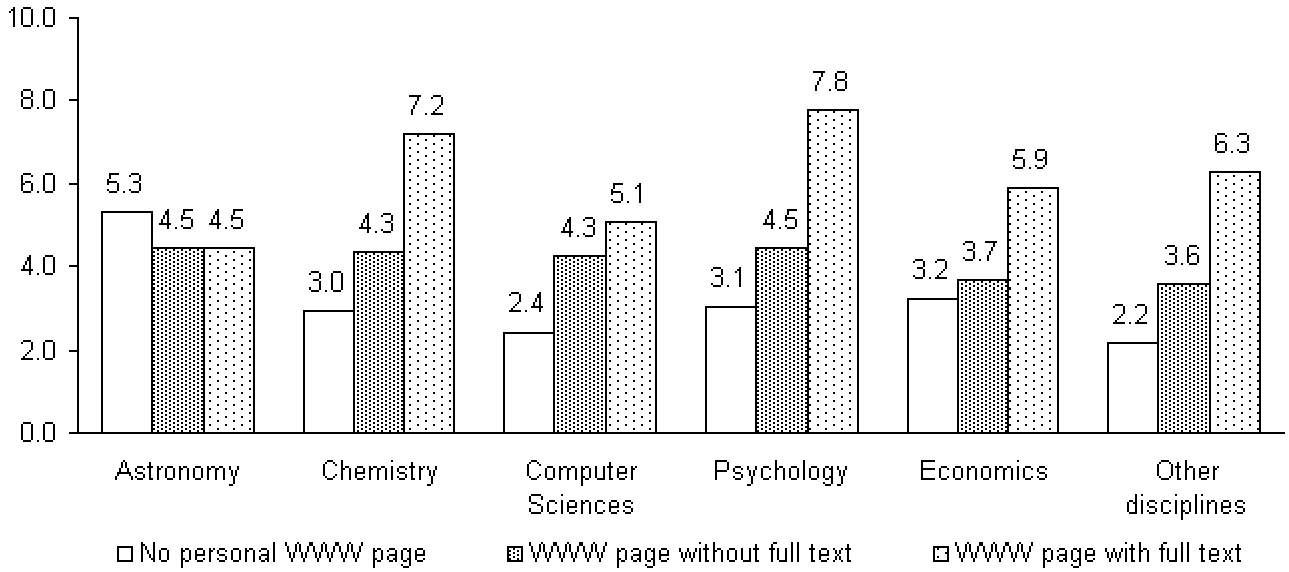

FIG. 3. Mean number of conference presentations in 2001 and 2002 by academic discipline and use of a personal homepage.

which explanation is valid; but the productivity result is stable, even when collaboration variables are included in the estimations—this casts doubt on any bias due to the overestimation of publications. Unfortunately, the data does not permit any conclusions to be drawn regarding the form of the relationship between Internet use and productivity.

Another very interesting finding is that the use of personal homepages is strongly correlated with the number of conference presentations (see Table 3 and Figure 2). Scientists who make their research findings available on their homepages and who retrieve the work of their colleagues from the Web attend significantly more conferences than their peers, who do not use the Web for these purposes. However, they do not publish more in academic journals. This leads one to an electronically enhanced informal communication model with greater importance of self-publishing that co-exists with the traditional formal communication system. This relationship can be found in most academic disciplines in the dataset, but it is particularly pronounced in chemistry and psychology (see Figure 3).[5] Rob Kling (Kling, 2004; Kling & McKim, 2000) identified these disciplines as "restricted flow fields" in which the particular constellation of working arrangements inhibited the

[5]The relationship was also investigated for each discipline by means of variance analyses and non-parametric Kruskal-Wallis tests, which produced significant results for all disciplines except for astronomy.

DOI: 10.1002/asi

diffusion of manuscripts via electronic repositories. These results could indicate that scholars in these disciplines are less concerned of being plagiarized or denied credit, and that the insecurity concerning the quality and trustworthiness of unrefereed manuscripts is lowered, if these have been presented at conferences. Moreover, a conference presentation also raises the publicity of the manuscript and reduces another weakness of this type of self-publishing (Kling & McKim, 1999). This would explain the correlation between conference presentations and the inclusion of manuscripts on homepages.

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 organizations. On average, every respondent had two co-authors per scientific publication and—overall, not per publication—seven collaborators (median values).[6] 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. Therefore, they are omitted from the following discussion. The collaboration variable and the network size variables, however, exhibited a consistent trend (see Table 4): Collaborating scientists communicate more over the Internet and use it more for sourcing and disseminating information than noncollaborating scientists (Hypothesis 3a, confirmed). This is consistent with previous findings (Walsh et al., 2000). The size of the collaboration network exhibits a U-shaped effect, as hypothesized (Hypotheses 3b and 3c, both confirmed): The larger the collaboration network, the more often the Internet is used for informal communication. However, scientists with very large collaboration networks did not use computer networks more often than scientists with moderately sized collaboration networks did. This could be due to an upper time limit for computer network use, which is not exceeded even if a scientist has many collaborators. Scientists' time is a scarce commodity and spending time on the Internet actually "competes" with many other activities. It is also interesting to note that the larger the collaboration network, the smaller the volume of information obtained from general electronic sources, with a correspondingly lower importance of the WWW for disseminating research findings. Well-connected scientists use more targeted ways of exchanging information, for instance e-mail attachments.

Further Control Variables

The results for the further control variables will be presented only briefly (tables can be obtained from the author upon request).

Academic disciplines. The use of computer networks varies across the academic disciplines. No general difference between scientists and social scientists was evident, but 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. Economists use all types of electronic sources. 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). This probably reflects the fact that in astronomy (and physics) in particular, large-scale databases and archives were established at a very early stage. Psychologists and chemists source less information from the Internet than scientists from other disciplines do, probably because they have obtained their primary information in traditional ways through experiments in laboratory environments. The migration of these environments to the Internet is still at an early stage. However, psychologists are the most active communicators and use Internet-based tools (e-mail) to a considerable extent.

[6]The distribution of R&D collaborators is notably skewed to the right. The arithmetic mean is 14.8 collaborators per respondent (see Table A2 in the Appendix). The difference between co-author and collaborator figures is due to different wording in the questions: Co-authors were assessed for a typical publication and collaborators in general. So the number of collaborators has to be higher, as collaborators do not necessarily co-author all the respondent's papers.

TABLE 4. Parameters for the collaboration variables.

	Social communication			Information retrieval			Information dissemination	
	E-mail communicators	Communicators	CMC index	Online 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 squared	−*	−**	−	+	+*	−	−‡	+

Note. CMC = computer-mediated communication. Reference group for "e-mail communicators" and "communicators," also the "silent scientists."
+ Positive coefficient; − negative coefficient.
Significance levels: ** $p < .01$. * $p < .05$. ‡ $p < .1$.

DOI: 10.1002/asi

Country differences. The country differences with regard to Internet use are somewhat unclear. Overall, only scientists in Germany show a markedly 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 Word Wide Web is more important than in the other countries for disseminating scientific information: An above-average proportion of Danish scientists have homepages and include full-text documents on them. These country differences are still hard to explain. They may stem from different national communication conventions, the integration of a national scientific community into the international scientific community, or the availability of resources on the Web. Further cross-country analyses would be necessary to shed more light on this issue.

Network-related infrastructure. The network-related infrastructure variables are only important for information retrieval and dissemination. 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 subscriptions and licenses for journals, databases, and other electronic sources.

Attitude. 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, the previously established relationship between attitudes and use schemes still holds (see e.g., Day & Bartle, 1998; Holmquist, 1997; Lenares, 1999; Mitra et al., 1999).

Summary and Conclusions

The empirical analysis showed that the Internet has become a ubiquitous tool in European science. Some of the results that were based on previous, mainly U.S.-based research were corroborated and others were not. This might be attributable to country idiosyncrasies: The intensity of Internet use differs somewhat across the countries of the dataset. However, it may well be that the widespread diffusion of the Internet in industrialized countries has also changed its role in scientific R&D in some respects. Therefore, some of the older results have to be reviewed.

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: The more productive scientists are, the more they use the Internet for all the investigated purposes (social communication, information retrieval and dissemination). Clearly, the benefits of Internet utilization exceed the costs. Above all, journal articles and conference presentations are significant predictors of Internet use. A small nonlinear effect was also obtained that indicates that highly productive scientists do not utilize the Internet as often as their publication activities would suggest. This is a new finding. This is interpreted as a consequence of decreasing returns on Internet use and a trade-off between communication and information-related activities and other research work.

Another finding backs some of the early expectations that the Internet might facilitate a significant change of the scholarly communication system (Ginsparg, 1994; Harnad, 1991, 1997; Odlyzko, 2001) and that the difference between formal and informal communication is becoming increasingly blurred (Meadows, 1998; Russel, 2001). The data show that the number of conference presentations (but not the number of journal articles) correlates significantly with the practice of including manuscripts on homepages. The correlation is particularly notable in academic disciplines that were found to be rather hesitant in adopting electronic manuscript repositories, like chemistry and psychology. Personal homepages might be a useful platform for disseminating manuscripts that have been reviewed and publicized on other occasions. However, further investigation is still required regarding which circumstances and for what kind of scientists this type of self-publishing constitutes a viable alternative and how the work that gets posted on the web can be characterized.

The analysis also sheds new light on the relationship between Internet use and collaboration activities. Scientists who collaborate use the Internet more often than scientists who do not. This is not astonishing. However, it not only applies to Internet-based communication tools, but also to applications that are mainly employed for obtaining or disseminating information. The more collaborators scientists have, the more intensively they utilize the Internet. However, the relationship is U-shaped: Scientists with very large collaboration networks do not use computer networks more often than do scientists with moderately sized collaboration networks. Again, as for the Internet-productivity relationship, this may be a trade-off between communicating and performing other research work. To be able to carry out their core research activities, highly networked scientists either have to restrict their communication activities or delegate (some of) them to assistants and co-workers.

Finally yet importantly, the results support the assumption that invisible colleges have integrated the Internet into their communication practices. Hence, anyone 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 therefore cannot be corroborated. The concept that

DOI: 10.1002/asi

equality of access to online sources improves the situation for researchers at the bottom of the hierarchy is also not supported: The analysis shows that the quality of the infrastructure (computers, network access) does affect the use of Internet applications. Moreover, it can be assumed that established academics tend to have better computer equipment and network access than their less-established co-workers.

The analysis was based on a cross-section of nearly 1,500 scientists from seven European countries and five academic disciplines. There are some weaknesses in the data because of the survey-based methodology. First, the publication figures are notably higher than are figures from more-reliable sources, and single- and multiple-author publications had to be given the same weight. However, as explained above, this does not change the basic validity of the results. There is no reason to expect that frequent Internet users particularly exaggerated their publication figures and the relationship between Internet use and research productivity holds if we control for collaboration activities. A second weakness of the analysis is due to the lack of information on the overall research population: The sample was drawn randomly from scientists in five disciplines and seven countries, but there is not sufficient information to check the extent to which the responses to the survey are really representative of this sample. The topic of the survey may have produced an overrepresentation of Internet users, and some questions may have favored responses from active researchers. However, there is a notable variance in the dataset about both Internet use and research productivity and so a general bias in the data is not expected. In the future, to understand the use of Internet applications in science better, it is worth broadening the scope, both in terms of countries and disciplines. Moreover, it would also be beneficial to carry out time series and panel analyses. These are necessary to reliably determine the effects of Internet use, which are often—as is also in the present analysis—beyond the scope of the available empirical data.

Acknowledgments

The present study draws on the evidence collected within the SIBIS (Statistical Indicators for Benchmarking the Information Society) project and is indebted to the European Commission and the Swiss Federal Office for Education and Science who funded the project under the IST programme (IST-2000-26276). This contribution benefited from comments on the SIBIS reports made by Najib Harabi and other members of the SIBIS project team. Moreover, the author is indebted to two anonymous reviewers for their thoughtful and clear comments.

References

Abels, E.G., Liebscher, P., & Denman, D.W. (1996). Factors that influence the use of electronic networks by science and engineering faculty at small institutions. Part I: Queries. Journal of the American Society for Information Science, 47, 146–158.

Barjak, F., & Harabi, N. (2004). Internet for research. SIBIS topic report no. 2 to the European Commission, DG Information Society. Solothurn, Switzerland: University of Applied Sciences at Solothurn Northwestern Switzerland. Retrieved January 28, 2005, from http://www.fhso.ch/pdf/unternehmer/sibis_final.pdf

Brockman, W.S., Neumann, L., Palmer, C.L., & Tidline, T.J. (2001). Scholarly Work in the Humanities and the Evolving Information Environment. Washington DC: Digital Library Federation, Council on Library and Information Resources. Retrieved October 17, 2002, from http://www.clir.org/pubs/reports/pub104/contents.html

Brown, C.D. (2001). The role of computer-mediated communication in the research process of music scholars: An exploratory investigation. Information Research, 6(2). Retrieved October 1, 2002, from http://informationr.net/ir/6-2/paper99a.html

Budd, J.M., & Connaway, L.S. (1997). University faculty and networked information: Results of a survey. Journal of the American Society for Information Science, 48, 834–852.

Butterworth, I. (Ed.). (1998). The impact of electronic publishing on the academic community: An international workshop by the Academia Europaea and the Wenner-Gren Foundation. London: Portland Press.

Callon, M. (1995). Four models for the dynamics of science. In S. Jasanoff, G.E. Markle, J.C. Petersen, & T. Pinch (Eds.), Handbook of science and technology studies (2nd ed., pp. 29–63). Thousand Oaks/London/New Delhi: Sage.

Carley, K., & Wendt, K. (1991). Electronic mail and scientific communication. A study of the SOAR extended research group. Knowledge: Creation, Diffusion, Utilization, 12, 406–440.

Clark, B.R. (1995). Places of inquiry: Research and advanced education in modern universities. Berkeley: University of California Press.

Cohen, J. (1996). Computer mediated communication and publication productivity among faculty. Internet Research: Electronic Networking Applications and Policy, 6(2/3), 41–63.

Cole, J.R., & Cole, S. (1973). Social stratification in science. Chicago/London: University of Chicago Press.

Crane, D. (1972). Invisible colleges. Diffusion of knowledge in scientific communities. Chicago/London: University of Chicago Press.

Cronin, B. (1982). Invisible colleges and information transfer. A review and commentary with particular reference to the social sciences. Journal of Documentation, 38, 212–236.

Cronin, B. (1995). The scholar's courtesy. London: Taylor Graham.

Cronin, B. (2001). Bibliometrics and beyond: Some thoughts on web-based citation analysis. Journal of Information Science, 27, 1–7.

Cronin, B. (2003, October). Scholarly communication and epistemic cultures. Paper presented at the ARL Conference Scholarly Tribes and Tribulations: How Tradition and Technology Are Driving Disciplinary Change, Washington, DC. Retrieved May 12, 2005, from http://www.arl.org/scomm/disciplines/Cronin.pdf

Day, J., & Bartle, C. (1998, March). The internet as an electronic information service: Its impact on academic staff in higher education. Paper presented at the IRISS '98 International Conference, Bristol, UK. Retrieved June 29, 2001, from http://sosig.ac.uk/iriss/papers/paper06.htm

Dubrovsky, V., Kiesler, S., & Sethna, B. (1991). The equalization phenomenon: Status effects in computer-mediated and face-to-face decision making groups. Human–Computer Interaction, 6, 119–146.

Econometric Software Inc. (2002). LIMDEP (Version 8.0) [Computer software]. Plainview, NY: Author.

European Commission. (2003). Third European Report on Science & Technology Indicators 2003—Towards a knowledge-based economy. Brussels: European Commission.

Finholt, T.A. (2002). Collaboratories. Annual Review of Information Science and Technology, 36, 74–107.

Finholt, T.A., & Olson, G.M. (1997). From laboratories to collaboratories: A new organizational form for scientific collaboration. Psychological Science, 8, 28–36.

Finholt, T.A., Rocco, E., Bree, D., Jain, N., & Herbsleb, J.D. (1998). NotMeeting: A field trial of netmeeting in a geographically distributed organization. SIGGROUP Bulletin, 20, 66–69.

Fjordback Søndergaard, T., Andersen, J., & Hjørland, B. (2003). Documents and the communication of scientific and scholarly information: Revising and updating the UNISIST model. Journal of Documentation, 59, 278–320.

Frank, S. (2003). R&D expenditure and personnel in Europe: 1999–2001. Statistics in focus. Theme 9—3/2003 [Electronic version]. Retrieved September 5, 2003, from http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-NS-03-003/EN/KS-NS-03-003-EN.PDF

Fry, J. (2004). The cultural shaping of ICTs within academic fields: Corpus-based linguistics as a case study. Literary and Linguistic Computing, 19, 303–319.

Fulk, J., Schmitz, J., & Steinfield, C.W. (1990). A social influence model of technology use. In J. Fulk & C. Steinfield (Eds.), Organizations and communication technology (pp. 117–140). Newbury Park/London/New Delhi: Sage.

Garvey, W.D. (1979). Communication: The essence of science. Facilitating information exchange among librarians, scientists, engineers and students. Oxford: Pergamon Press.

Garvey, W.D., & Griffith, B.C. (1972). Communication and information processing within scientific disciplines: Empirical findings for psychology. Information Storage and Retrieval, 8, 123–136.

Ginsparg, P. (1994). First steps towards electronic research communication [Electronic version]. Computers in Physics, 8, 390–396.

Gläser, J. (2003). What internet use does and does not change in scientific communities. Science Studies, 16, 38–51.

Glasner, P. (1996). From community to ‘collaboratory’? The Human Genome Project and the changing culture of science. Science and Public Policy, 23, 109–116.

Hagstrom, W.O. (1965). The scientific community. New York: Basic Books.

Harnad, S. (1991). Post-Gutenberg galaxy: The fourth revolution in the means of production of knowledge [Electronic version]. Public-Access Computer Systems Review, 2, 39–53.

Harnad, S. (1997). The paper house of cards (and why it is taking so long to collapse) [Electronic version]. Ariadne, 8, 6–7.

Herbsleb, J.D., Mockus, A., Finholt, T.A., & Grinter, R.E. (2000, December). Distance, dependencies, and delay in a global collaboration. Paper presented at the CSCW 2000 Conference, Philadelphia, PA. Retrieved April 1, 2002, from http://www-2.cs.cmu.edu/~jdh/collaboratory/research_papers/cscw_delay.pdf

Hesse, B.W., Sproull, L.S., Kiesler, S.B., & Walsh, J.P. (1993). Returns to science: Computer networks in oceanography. Communications of the ACM, 36(8), 90–101.

Hilgartner, S. (1995). Biomolecular database—New communication regimes for biology? Science Communication, 17, 240–263.

Hiltz, S.R. (1984). Online communities. A case study of the office of the future. Norwood, NJ: Alex Publishing Corp.

Holmquist, J.E. (1997). Survey on the use of electronic journals at Princeton. In U. Grothkopf, H. Andernach, S. Stevens-Rayburn, & M. Gomez (Eds.), Library and information services in astronomy III (ASP Conference Series, 153) [Electronic version]. Retrieved November 24, 2001, from http://www.eso.org/gen-fac/libraries/lisa3/holmquistj.html

Hurd, J.M. (1996). Models of scientific communication systems. In S.Y. Crawford, J.M. Hurd, & A.C. Weller (Eds.), From print to electronic: The transformation of scientific communication (pp. 9–33). Medford, NJ: Information Today Inc.

Kaminer, N., & Braunstein, Y.M. (1998). Bibliometric analysis of the impact of Internet use on scholarly productivity. Journal of the American Society for Information Science, 49, 720–730.

Kircz, J.G. (1998, March). Changing presentations! changing science? Paper presented at the Colloquium L’écrit de la Science [Writing Science], Nice, France. Retrieved October 12, 2003, from http://www.science.uva.nl/projects/commphys/papers/nicem.htm

Kling, R. (2004). The internet and unrefereed scholarly publishing. In B. Cronin (Ed.), Annual review of information science and technology (Vol. 38, pp. 591–631). Medford, NJ: Information Today.

Kling, R., & Callahan, E. (2001). Electronic journals, the internet, and scholarly communication. In B. Cronin (Ed.), Annual review of information science and technology (Vol. 37, pp. 127–177). Medford, NJ: Information Today.

Kling, R., Kraemer, K.L., Allen, J.P., Bakos, Y., Gurbaxani, V., & Elliott, M. (1996). Transforming coordination: The promise and problems of information technology in coordination. [Electronic version] In T. Malone, G. Olson, & J. Smith (Eds.), Coordination theory and collaboration technology. Mahwah, NJ: Lawrence Erlbaum.

Kling, R., & McKim, G. (1999). Scholarly communication and the continuum of electronic publishing. Journal of the American Society for Information Science, 50, 890–906.

Kling, R., & McKim, G. (2000). Not just a matter of time: Field differences and the Shaping of electronic media in supporting scientific communication. Journal of the American Society for Information Science, 51, 1306–1320.

Knorr-Cetina, K. (1981). The manufacture of knowledge. An essay on the constructivist and contextual nature of science. Oxford: Pergamon Press.

Knorr-Cetina, K. (1983). The ethnographic study of scientific work: Towards a constructivistic interpretation of science. In K. Knorr-Cetina, & M. Mulkay (Eds.), Science observed. Perspectives on the Social Studies of Science (pp. 115–140). London: Sage.

Koku, E., Nazer, N., & Wellman, B. (2001). Netting scholars: Online and offline [Electronic version]. American Behavioral Scientist, 44, 1752–1774.

Kraut, R.E., Egido, C., & Galegher, J. (1990). Patterns of contact and communication in scientific research collaboration. In Intellectual teamwork. In R.E. Kraut, C. Egido, & J. Galegher. (Eds.), Social and technological foundations of cooperative work (pp. 149–171). Hillsdale, NJ: Erlbaum.

Kuhn, T.S. (1996). The structure of scientific revolutions (3rd ed.). Chicago/London: University of Chicago Press.

Latour, B., & Woolgar, S. (1979). Laboratory life. The social construction of scientific facts. Beverly Hills/London/New Delhi: Sage.

Laudel, G. (2001). Collaboration, creativity and rewards: Why and how scientists collaborate. International Journal of Technology Management, 22, 762–781.

Lazinger, S.S., Bar-Ilan, J., & Peritz, B.C. (1997). Internet use by faculty members in various disciplines: A comparative case study. Journal of the American Society for Information Science, 48, 508–518.

Lenares, D. (1999, April). Faculty use of electronic journals at research institutions. Proceedings of the ACRL Ninth National Conference, Detroit, MI. Retrieved October 12, 2003, from http://www.ala.org/ala/acrl/acrlevents/lenares99.pdf

Lievrouw, L. (1988). Four programs of research in scientific communication. Knowledge in Society, 1, 6–22.

Lievrouw, L. (1990). Reconciling structure and process in the study of scholarly communication. In C.L. Borgman (Ed.), Scholarly communication and bibliometrics (pp. 59–69). Newbury Park/London/New Delhi: Sage.

Lievrouw, L.A., & Carley, K. (1990). Changing patterns of communication among scientists in an era of “telescience.” Technology in Society, 12, 457–477.

Luukkonen, T., Persson, O., & Sivertsen, G. (1992). Understanding patterns of international scientific collaboration. Science, Technology, & Human Values, 17, 101–126.

Mark, G., Grudin, J., & Poltrock, S.E. (1999, September). Meeting at the desktop: An empirical study of virtually collocated teams. Paper presented at ECSCW’99, The 6th European Conference on Computer Supported Cooperative Work, Copenhagen, Denmark. Retrieved May 16, 2006, from http://www.research.microsoft.com/research/coet/VirtualTeams/ECSCW99/paper.pdf

Merton, R. (1942). Social theory and social structure. New York: Free Press.

Meadows, A.J. (1998). Communicating research. San Diego: Academic Press.

Merz, M. (1998). ‘Nobody Can Force You When You Are Across the Ocean’—Face to Face and E-Mail Exchanges between Theoretical Physicists. In C. Smith & J. Agar (Eds.), Making space for science: Territorial themes in the shaping of knowledge (pp. 313–329). London: Macmillan.

Mitra, A., Hazen, M.D., LaFrance, B., & Rogan, R.G. (1999). Faculty use and non-use of electronic mail: Attitudes, expectations and profiles. Journal of Computer-Mediated Communication, 4(3). Retrieved May 16, 2006, from http://jcmc.indiana.edu/vol4/issue3/mitra.html

Mulkay, M. (1977). Sociology of the scientific research community. In I. Spiegel-Rösing, & D. de Solla Price (Eds.), Science, technology and society. A cross-disciplinary perspective (pp. 93–148). London: Sage.

DOI: 10.1002/asi

National Science Board. (2002). Science & engineering indicators 2002. Arlington, VA: Author. Retrieved May 16, 2006, from http://www.nsf.gov/statistics/seind02/pdfstart.htm

Nentwich, M. (2003). Cyberscience—Research in the age of the internet. Vienna: Austrian Academy of Sciences Press.

Noam, E.M. (1995). Electronics and the dim future of the university. Science, 270, 247–249.

Odlyzko, A. (2001). The rapid evolution of scholarly communication. Retrieved December 3, 2002, from http://www.dtc.umn.edu/~odlyzko/doc/rapid.evolution.pdf

Organization for Economic Co-operation and Development [OECD]. (1998). The global research village: How information and communication technologies affect the science system. Paris: Author.

Olson, G.M., & Olson, J.S. (2002). Distance matters. In J.M. Carroll (Ed.), Human–computer interaction in the new millennium (pp. 139–179). New York: ACM Press.

Price, D.J. de Solla, & Beaver, D. (1965). Collaboration in an invisible college. American Psychologist, 21, 1011–1018.

Rusch-Feja, D., & Siebeky, U. (1999). Evaluation of usage and acceptance of electronic journals: Results of an electronic survey of Max Planck society researchers including usage statistics from Elsevier, Springer and Academic Press (full report). D-Lib Magazine, 5(10). Retrieved January 28, 2005, from http://www.dlib.org/dlib/october99/rusch-feja/10rusch-feja-full-report.html

Russel, J.M. (2001). Scientific communication at the beginning of the twenty-first century. International Social Science Journal, 168, 271–282.

Sanderson, D. (1996). Cooperative and collaborative mediated research. In T.M. Harrison & T.D. Stephen (Eds.), Computer networking and scholarly communication in the 21st century university (pp. 95–114). Albany, NY: State University of New York Press.

Steinmueller, W.E. (2000). Will information and communication technology improve the 'codification' of knowledge? Industrial and Corporate Change, 9, 361–376.

Stevens-Rayburn, S., & Bouton, E.N. (1998). "If it's not on the Web, it doesn't exist at all": Electronic information resources—Myth and reality. In U. Grothkopf, H. Andernach, S. Stevens-Rayburn, & M. Gomez (Eds.), Library and information services in astronomy III. ASP Conference Series, 153. Retrieved October 18, 2003, from http://www.eso.org/gen-fac/libraries/lisa3/stevens-rayburns.html

Talja, S., & Maula, H. (2003). Reasons for the use and non-use of electronic journals and databases—A domain analytic study in four scholarly disciplines. Journal of Documentation, 59, 673–691.

Tenopir, C., & King, D.W. (2000). Towards electronic journals: Realities for scientists, librarians, and publishers. Washington, DC: Special Libraries Association.

Trevino, L.K., Daft, R.L., & Lengel, R.H. (1990). Understanding manager's media choices: A symbolic interactionist perspective. In J. Fulk, & C. Steinfield (Eds.), Organizations and communication technology (pp. 71–94). Newbury Park: Sage.

Van Alstyne, M., & Brynjolfsson, E. (1996). Could the Internet Balkanize science? Science, 274(5292), 1479–1480.

Van Leeuwen, T.N., Moed, H.F., Tijssen, R.J.W., Visser, M.S., & van Raan, A.F.J. (2001). Language biases in the coverage of the Science Citation Index and its consequences for international comparisons of national research performance. Scientometrics, 51, 335–346.

Walsh, J.P., & Bayma, T. (1996a). The virtual college: Computer-mediated communication and scientific work. The Information Society, 12, 343–363.

Walsh, J.P., & Bayma, T. (1996b). Computer networks and scientific work. Social Studies of Science, 26, 661–703.

Walsh, J.P., & Roselle, A. (1999). Computer networks and the virtual college. STI Review, 24, 49–77.

Walsh, J.P., Kucker, S., Maloney, N., & Gabbay, S. (2000). Connecting minds: CMC and scientific work. Journal of the American Society for Information Science, 51, 1295–1305.

Zhang, Y. (2001). Scholarly use of Internet-based electronic resources. Journal of the American Society for Information Science and Technology, 52, 628–654.

Zuckerman, H. (1988). The sociology of science. In N.J. Smelser (Ed.), Handbook of sociology (pp. 511–574). Newbury Park, CA: Sage.

Appendix

TABLE A1. Nominal variables of the analysis.

Variable	*n*	Total valid *N*	%
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 organization			
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
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

Note. Country and discipline excluded (see Table 1 in the text).

DOI: 10.1002/asi

TABLE A2. Variables of the analysis with ordinal and ratio scales.

Variable	Total valid *N*	Arithmetic *M*	*SE*
Computer-mediated communication (CMC) index (range 0–100)	1428	32.01	0.27
Index of usage of online information sources (range 0–100)	1268	46.71	0.17
Internet access to the important information sources (range 1–4)	1462	3.70	0.01
Age	1473	42.88	0.31
Total number of collaboration partners	1406	14.83	0.81
Number of co-authors	1369	1.96	0.09
Percentage of coauthored journal articles (range 0–100)	1029	82.78	0.99
Publications			
Working papers total	1413	2.23	0.11
Journal articles, total	1432	4.02	0.14
Chapters in books	1436	1.06	0.06
Monographs	1435	0.25	0.02
Presentations at scientific conferences	1430	4.49	0.14
Reports	1425	1.26	0.09
New ideas for new research through browsing the WWW (range 1–5)	1470	2.59	0.04
Considers whether the Internet supports realization of R&D (range 1–5)	1462	2.54	0.04
Internet used to stay up-to-date and focus the R&D (range 1–5)	1470	3.73	0.03
New ideas for R&D through e-mail communication (range 1–5)	1467	3.05	0.03
Use of electronic journals for obtaining scientific information (range 0–3)	1459	2.18	0.02
Use of peers' Web sites for obtaining scientific information (range 0–3)	1380	1.48	0.02
Computer quality index (range 0–5)	1453	2.49	0.02
Scientific recognition (range 0–4)	1473	1.04	0.03

TABLE A3. 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				
Online 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

Note. CMC = computer-mediated communication. Log-L(0): Restricted log likelihood, Log-L: log likelihood.

DOI: 10.1002/asi