1995

Published papers, tacit competencies and corporate management of the public/private character of knowledge

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Industrial and Corporate Change 4: 401-424, 1995

Abstract

This paper focuses on the movement of scientific and technological knowledge. It explores companies' reasons for publishing in the scientific and technical literature, reasons that turn on the need to link with other research organisations. The analysis begins by establishing that firms do indeed publish. Such publishing mediates links with other organisations, serving to signal the presence of tacit knowledge and to build the technical reputation necessary to engage in the barter-governed exchange of scientific and technical knowledge. Similar processes are seen in other areas of technical knowledge exchange.

Introduction

This paper examines why companies publish papers in refereed scientific journals. Companies do publish quite extensively. But it is not immediately clear why they should publish especially given the traditional emphasis on appropriability and the distinction between basic (non-appropriable) and applied (appropriable) research. In practice, the distinction between science and technology is often very difficult to make. This intermingling characterises the published literature too. The paper argues that because there is no 'natural' distinction, academic and industrial researchers construct the distinction between public and private knowledge in such a way as to provide them maximum advantage. Firms are able to publish precisely because they can choose which information to make public.

Publications are produced from longer-term research, and firms perform such research not only to produce appropriable results, but also to access technical opportunities produced in the science base. Firms and universities are linked primarily through trained graduates, thus publication has often been credited with enhancing recruiting efforts. This emphasis accords with the view that to move technical knowledge, people must move because the important knowledge is tacit. In this view, publications are of little importance. However, this view is too simple.

This paper proposes that publications are intimately related to tacit and unpublishable knowledge. Although such resources cannot be conveyed in a paper, they can be described in a paper. So unpublishable resources can be found by searching the literature. As tacit and unpublishable knowledge is the foundation of scientific and technical credibility, authors use papers to build credibility. This is needed to participate in the barter governed exchange of scientific knowledge. Firms want to participate in barter exchange networks to further their aim of accessing technical opportunities produced in the science base. Such networks exist to move the tacit and unpublishable components of knowledge. The paper concludes by observing that credibility established through publication also serves more clearly commercial ends.

Companies publish

Basic, public and hence published research produced by companies is often represented by anecdotes of discoveries that won the Nobel Prize. The archetypal path-breaking discovery by a corporate researcher was the birth of radio astronomy at Bell Laboratories. While investigating sources of static in long distance communications, Bell's Jansky discovered radio static coming from the stars. Subsequently, astronomers designed radio telescopes to receive and interpret these signals and so better understand the stars. A more recent example would be the discovery of high temperature superconductivity by IBM researchers.

Although major discoveries are important, they alone do not advance knowledge. There are also the innumerable incremental contributions that compose the day-to-day business of researchers, the foundations on which the big breakthroughs are built and the bulk of scientific progress. In analogy with innovation, we must examine both radical and incremental advances. This paper examines research as a whole, encompassing both the major discoveries and incremental advances produced by researchers in companies.

Researchers cannot themselves decide whether advances are major or minor. Jansky's discovery was not awarded a Nobel Prize because he insisted on its worth; rather the use of Jansky's work by many other researchers made it into a path breaking discovery. The fate of a researcher's work is in the hands of later users because knowledge is advanced by a community of researchers (Latour, 1987; Kuhn, 1970). Therefore, a result must first be released to the community before it can attain the status of a new fact. Researchers do not produce experimental results only to smile and go on to the next experiment - they tell others about their work. Results are released in conference presentations, pre-prints, phone calls, and published articles, the published article becoming part of the archive, the permanent public record of advances in knowledge.

Companies publish papers. A study of research published by major European and Japanese pharmaceuticals, chemical-pharmaceuticals and electronics firms, demonstrates that large firms publish substantial numbers of papers[1]. A count of articles and notes indexed in the Science Citation Index showed that in 1989 certain large companies published upward of 200 papers per year, with one or two reaching 500. This means firms such as: Philips, Hitachi, ICI, Ciba, Siemens, Sandoz, Roche, Hoechst and Toshiba are contributing as much to the public literature as medium-sized universities such as Waseda or Keio in Japan or Sussex or Reading in the UK.[2] It should be noted that firms specialise in either physical sciences research or life sciences, whereas universities do both. Therefore, these firms with a more specialised publication profile are publishing as much as the more broadly based universities. To place company publishing in the broader context of national scientific output, we can examine statistics for the UK, Netherlands and US. In 1991, companies participated in 8% of UK papers (Hicks & Katz, 1994). On average, between 1980 and 1989, companies produced 6% of Dutch scientific output (De Bruin et al., 1992). In the US in 1991, companies produced 9% of science and engineering publications (NSB, 1993).

Some companies are among the most highly cited institutions, indicating that their work is of a high scientific standard. In the biological sciences nine corporations have citations per paper averages that rank them among the top 25 US universities, and two companies - Cetus and Genentech have average citations per paper that exceed that of the top 25 US universities.[3] In the physical sciences the situation is similar, with six companies ranking alongside the top 25 US universities and two companies - Bellcore and AT&T - exceeding the citations per paper figures of even the top ranked US university.[4] In a world ranking of institutions in electrical engineering 1986-1990, 9 companies have average citation scores that equal those of the top 25 universities and the scores of 2 of these - AT&T and Fujitsu - exceed those of any university.[5] Several unified institutional rankings (based upon average citations per paper 1981-91) are available and these are summarised in Table 1. The table reveals that when measured by average citations per paper, companies are

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[1] Data from Hicks, Isard and Martin, 1993, where methodological details may be found.

[2] Figures from J.S. Katz, unpublished research.

[3] However the top 10 "independent" institutions would all be ranked higher than universities on a unified list.

[4] Publications 1987-1990 collated. Science Watch, Vol. 2 No. 10, November 1990, pp. 1-2.

[5] Science Watch, Vol. 4 No. 2, October 1991, p. 7.

more likely to be among the best institutions in the world in the physical sciences than in the biological sciences.[6]

Table 1[7]

How many companies are in the top 10 (when institutions are ranked on average citations per paper, 1981-91)?

Country	Field	Years	"Publishing" size of institutions[8]	Number of companies in top 10
World	Molecular Biology	1981-91	>200	0
	Molecular Biology & Genetics	1988-92	>200	2
US	Chemistry	1988-92	>250	1
Non-US	Chemistry	1988-92	>250	0
Japan	Life sciences	1981-91	>3000	0
			1000-3000	0
			<1000	0
Japan	Physical, Chemical & Earth Sciences	1981-91	>3000	0
			1000-3000	1
			<1000	3
U.S.	Physical sciences	1981-91	no limit	3

What do these papers represent? Are their authors coddled in campus-like central research laboratories of major multinationals producing work so useless as to be basic? Papers are more likely to be produced from long-term research. Longer-term research is more likely to be found at corporate rather than divisional level. Corporate research laboratories perform a variety of functions: fire fighting, research to meet divisional needs, and research they initiate (Rubenstein), and the later is most likely to produce publications. However, these rules of thumb are each a matter of probability. Papers published by companies do list addresses of central laboratories

[6] The hint that industry is a more significant player in physical sciences research than in biomedical research is confirmed when numbers of publications are examined. As mentioned above, industry produced about 9% of US scientific publications in 1986. However, when this is broken down by field, there are substantial variations. Industry produced twenty-six percent of the engineering & technology papers, 17% of the physics papers and 17% of the chemistry papers. In contrast, companies published 4% of biomedical papers and 5% of clinical medical papers.

[7] Science Watch, Vol. 3 No. 3, May 1992, p. 7; February 1993, p. 8; and June 1993, p.p. 1-2, Institute for Scientific Information data generated for Science, fax, 1992.

[8] Number of papers per institution

much of the time, but by no means 100% of the papers are produced by central laboratories. Papers are also published by researchers in divisional labs, sometimes in collaboration with the central lab but also by themselves. Furthermore, examining a nation's entire scientific output would reveal papers published by small businesses.

Examining the content of papers finds results both remote from application and close to device developments. Representative of the first would be titles such as: "Possible Effect of 2-Dimensionality on the Superconducting Pairing Interaction" and "Regional Assignment of Nonspecific Crossreacting Antigen (Nca), One of CEA Gene Family, to Chromosome-19 at Band Q13.2". More applied papers carry titles like: "High-Speed and Compact CMOS Circuits with Multipillar Surrounding Gate Transistors", or "Dihydropyrimidines - Novel Calcium-Antagonists with Potent and Long-Lasting Vasodilative and Antihypertensive Activity". These basic and applied titles were probably published in different journals because most journals embody a specialist field. Taking advantage of their specialised character, scientific journals have been classified into four levels according to how basic is the research they report. Large European and Japanese firms in the pharmaceuticals, chemical-pharmaceuticals and electronics sectors published in 1980, 1984 and 1989, 23% of their papers in the most basic category, 41% in the second most basic category and 26% in the two most applied categories.[9] Thus, not all corporate publication is basic. Furthermore, presence in a database such as the Science Citation Index does not demarcate science and technology.

To what extent are science and technology separable?

Corporate scientific publishing would be inexplicable in a stylised country, where companies would innovate to enhance their competitive position and universities would produce scientific research on topics chosen because of their interest to the academic research community. In such a situation, companies would patent or keep secret any knowledge they produced while university researchers would scrupulously publish full accounts of their research in refereed journals. The government would fund university science believing it to be of long term benefit to industry and would be concerned that companies use university research so its investment be realised for the good of the nation. Companies and universities would play distinct and complementary roles.

[9] 10% were unclassified, Hicks, Isard & Martin.

The real world is not like this. Nevertheless when asked, large innovative companies consistently say that universities should do basic research, and concomitantly that only companies have the resources necessary to undertake the full scale development needed to transform research results into marketable products (see for example ABRC, 1986, p. 33, Uenohara, 1985, p. 141). Academics publish more and patent less than do industrial researchers (Rappa, 1992); while universities produce the bulk of the American published scientific and technical literature (71% in 1989), they produce only 1.4% of America's patents (NSB, 1993, p. 152 and appendix table 5-25). Thus this simple, even linear, model captures something fundamental and enduring about how labour is divided in the production of science and technology.

In this stylised world, basic research ⇨applied research ⇨ development: breakthroughs generated in basic research are passed through applied research and into development along the way becoming technology. The more robust, less linear, interpretation is technology⇔science; they coexist with the links between them going both ways (Barnes, 1982; Kline, 1990).[10] Either way, there appears to be an institutional gap: companies develop technology and universities perform science, but the knowledge universities produce needs to be transferred to the companies for use in technology. Diagrams illustrating both the linear and interactive models contain this link: science⇨technology, suggesting that analysts should ask how companies and universities might be connected so that the overall system may generate maximum industrial competitiveness.[11] Consequently, for at least 10 years there has been a great deal of analytical interest in university-industry links.[12]

The problem can be addressed from a slightly different perspective, in that the perceived institutional gap may be partly an analytical gap. The idea that two institutions generate two different things, science and technology, necessitates looking for linkage. However in many areas neither science and technology, nor corporate and academic research interests can be clearly distinguished.

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[10] The shift from the "bad old days" (Barnes, 1982, p. 167) of the linear model to the current interactive model seems to date from 1969. Barnes cites "W. Gruber and G. Marquis (eds), Factors in the Transfer of Technology (Cambridge, Mass.: MIT Press, 1969), as one marker of the point at which the interactive conception and its merits achieved clear visibility."

[11] The interactive diagrams also contain an arrow running from technology to science. But there does not seem to be such concern to create policies to facilitate this interaction.

[12] See for example the 120 item annotated bibliography in Kruybosch, 1982.

Shrum has argued that research cannot be unambiguously classified as science or technology in most cases. The distinction between science and technology is made in the everyday discourse of scientists and engineers, but it serves as an ideological resource, a resource acquisition strategy, claiming for engineers the prestige of science and for scientists the usefulness of technology. Shrum argues that all criteria used to classify research contain inherent ambiguities. 1) Motivation is sometimes used to categorise research activities, but it is impossible to ascertain a researcher's motives, and we would be wary of classifying quite practical results as science, regardless of how vehemently a researcher claimed to be doing basic research. 2) Distinguishing between production of knowledge and production of artefacts does not work because scientists build some instruments and engineers publish some papers. 3) Use of knowledge cannot classify research because information has multiple uses. 4) Organisational affiliation of researchers does not work, as my paper argues. 5) Finally, the social institutions of scientists - such as professional societies, university departments, research journals - do discriminate between physics, electrical engineering, etc. However, they cannot therefore be said to differentiate science and technology because the approaches evidenced by people in these different institutions will be broadly similar.

Science and technology then cannot always be distinguished clearly. Neither can many research activities in companies and universities because R&D in companies overlaps with that in universities. Although development is performed by companies while research without commercial relevance - such as high energy physics - is not, in between lies perhaps the bulk of modern natural science research.[13] In this region, academic and corporate researchers can pursue closely related research. Indeed we find that companies not only do development; they also perform and publish research.

That firms are part of the science base - publishing an appreciable fraction of scientific papers and turning up amongst the leading, high-impact institutions - points to the overlap between their role and that of the universities in creating the stock of public knowledge. Lenoir maintains the research community is an "extended community"; its culture and values shaped not just by academics but also by industrialists. Rappa uses the term "technological communities". Both refer to the mingling of academic and industrial research activity over large swathes of modern science and technology.

[13] At least in OECD countries. There may be little or no overlap in the rest of the world.

Disseminating research results, including more applied research, in refereed journals, seems paradoxical behaviour from organisations supposedly devoted to the creation, appropriation and strategic management of proprietary information. After all, releasing research results creates public knowledge. The categories "private" and "public" knowledge could be used to distinguish corporate and university activities. In this scheme, private property is created through corporate patenting while public knowledge is advanced through academic publishing. Here however, what seems private can be public and what seems public can have private components. Specifically, the methodology sections of published papers reveal procedure, but often not enough to replicate the experiment because researchers protect their competitive advantage by appropriating techniques through secrecy. Patents, in contrast, completely disclose procedure because failing to do so may invalidate the patent. Although patents appropriate knowledge, they also make it thoroughly public. Secrecy also appropriates but it is alternative to rather than compatible with patenting. In choosing between secrecy and patenting, companies manage the release of their knowledge. Similarly, academics manage the release of their knowledge by choosing how much they disclose.

Science and technology, public and private knowledge are often neither clearly distinguishable nor mutually exclusive. Therefore, researchers are often able to choose whether to label a result, device or substance, scientific or technological and to decide whether to publish, patent or hide it. In this respect, researchers can dynamically construct the boundaries between science and technology, public and private. This paper examines corporate scientific publishing as an example of managing the public/private distinction. Examining how companies manage the public/private boundary in their knowledge production clarifies how scientific and technological knowledge moves.

Why are companies able to publish?

Publication disseminates and so moves research results outside the laboratory. Companies, being companies, should attempt to appropriate as much as possible. The presumption that they appropriate everything may be responsible for a belief that companies publish little or nothing.[14] Nelson, however, points out that corporate R&D produces both proprietary and non-proprietary information (Nelson, 1982). I

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[14] Perhaps because companies seem to be just knowledge appropriators, the extent and nature of corporate publishing has been little studied, but see Halperin, Small & Greenlee, Frumau, Narin et al., Steck et al, Hicks et al., Godin.

would argue that the end product, proprietary or public information, results from a two stage process. Stage one is producing the information, and stage two is appropriating or releasing it. In other words, information newly minted in a corporate laboratory is not inherently public or private. Companies make it public or private. They construct the character of the knowledge, as opposed to reacting to something inherent in their new information. Publication is part of the process of making knowledge public or private and as such reveals the sometimes delicate management of the public/ private divide.

Companies are able to publish because they are able to control the public/private line. They screen material to be published with an eye to patent implications, and material is published once they satisfy themselves that sensitive information is protected (for example, by applying for a patent). Thus, they are not prohibited from publishing by some inherent, private property of their knowledge, nor do they appropriate everything. Rather they manage the process by establishing procedures to reconcile publication with appropriation.

Because companies place appropriation above release, publication depends on patenting. Interviews with R&D managers in Japan indicated that if things can be patented, they can be published; but if is not possible to patent, and the knowledge must be protected through secrecy; publication is difficult if not impossible. Because publication depends on patenting, papers are not leading indicators of a company's technical direction. In addition, not every research result produced in a corporate laboratory is published. To a non-specialist, publications will not be a comprehensive indicator of a corporate research portfolio; though to those working in similar areas in other firms, they might provide useful clues to competitors' research directions.

One might hypothesise that because they are screened, company papers must be different from other scientific papers - somehow lacking in properly scientific content. Certainly publication is somewhat delayed by screening. However, as scientific publication is hardly instantaneous, this is a difference in degree not in kind. As seen above, industrial papers can be among the most highly cited. At the minimum then, the characteristics of company and university papers overlap.

When screening papers, companies pay attention to the public-private divide and decide where to draw the line. They manipulate the relationship between public and private knowledge. Other strategic moves on the public/private divide will be explored in succeeding sections which will answer the question: why do companies publish? In examining what motivates corporate publishing we will begin to see how public and private knowledge are related and how manipulating their boundary facilitates moving knowledge. Before examining motives for publication, we must take a step back and look at why firms perform the underlying research.

Why do companies perform longer-term research?

Prerequisite to releasing research results in scientific papers is producing results. As we have seen, not all corporate results are applied. This is not surprising, considering that in 1993, companies performed 18% of US basic research (NSB, 1993). It is sometimes difficult to understand why firms would support this type of research. Of course, they might hope to obtain the seeds of new technologies from their longer-term research. Unfortunately for firms, investment in such research has an unpredictable payoff because the results might not be useful or they might be useful to someone else. Hence industrial long-term research efforts are modelled by economists using the metaphor of drawing balls from an urn. The probability that a firm will draw a ball that will make them money is quite low because economically useful research results are produced erratically (Gambardella, 1992).[15]

This means that most companies do not perform longer-term research - for example, financial services, retailers and almost all types of small firms. Companies that do must use a science-based technology. In addition, as Rosenberg argues, they tend to have "fairly strong and well-entrenched positions of market power" and thus to believe they will be there in the longer-term to benefit from the research. They also tend to have "a diverse range of products and strong marketing and distribution networks that increase their confidence that they will eventually be able to put the findings of basic research to some good commercial use" (Rosenberg [1990], p. 167-68). In other words, firms that believe they will be able to appropriate the unpredictable payoff from longer-term research will perform it. Only a few companies fit this description, for example larger companies in electronics, pharmaceuticals and chemicals.

From the economists' perspective therefore, companies' longer-term research produces results unpredictably. That would not be so bad if a firm knew that when it produced results it had a good chance of appropriating them. However, some firms perform longer-term research but seemingly have no chance of appropriating its uncertain results - for example small instrument makers and small biotechnology firms (Lenoir, 1994). Either they are aberrations, economically insignificant

[15] Therefore attempts to measure the payoff from basic research are unsuccessful, inconclusive or unconvincing.

exceptions, or else they indicate that companies may have sound, economically rational reasons for performing longer-term research beyond the desire to generate and appropriate intellectual property.

The reasons firms perform longer-term research have been described from both the economics and the management perspectives. Both lists can be divided into two parts, namely performing research to produce: a) research results and b) other, less tangible benefits. Rosenberg offers the following reasons for performing basic research from an economist's perspective (Rosenberg, pp. 170-171).

To produce research results:

1. basic research results are often produced unintentionally
2. in order to understand better how and where to conduct research of a more applied nature
3. essential for evaluating the outcome of much applied research and for perceiving its possible implications

Other reasons:

4. as a ticket to an information network
5. to monitor and evaluate research being conducted elsewhere

Rubenstein lists managers reasons for performing basic research.

To produce research results:

1. because, who knows, we might come up with a fundamental breakthrough of proprietary value
2. because it is not too expensive on a modest scale and the efforts of one or a few scientists can provide a big payoff in terms of entry into new fields or even possibly a new product
3. to improve our basic understanding of the materials, processes, and phenomena with which we deal

Other reasons:

4. to improve our image in the academic and scientific community
5. to give us a window into new areas of technology before they become widely disseminated
6. to help in recruiting high-grade technical people. Having some opportunity for doing "their own work" helps to keep basic-oriented scientists happy; it's a fringe benefit

Firms do use the results of longer-term research. However, there are reasons for performing research beyond the desire to produce appropriable knowledge.[16] The other reasons seem to concern linkage with the outside world in some way, whether providing a window on what others are doing, help in recruiting or entry into others' networks. Research is performed to link with the outside world.

Why is it important for innovating firms to link with the outside world? The answer is found in innovation studies, economics and economic history. Studies of technological innovation demonstrate that successful innovations are characterised by (amongst other things) links to external sources of scientific and technical information and advice. Basic research facilitates successful innovation because it enables linkage (Freeman, 1991; Rothwell; 1992). Why should basic research enable links to be established between corporations and other researchers? Economists argue that acquiring external knowledge costs money. Even if the "supplier" does not charge, companies must invest in basic research to create the capability to recognise, assimilate and exploit knowledge created elsewhere (Cohen & Levinthal, 1989, Gambardella, 1992). Innovation studies bear out this assessment, showing that when a firm needs to solve a technical problem, researchers, especially those with PhD's, are able to gather information from academic contacts (Gibbons & Johnston, 1974; Angell, 1985; ABRC, 1986). Investing in basic research ensures the firm has researchers on board to make those links. The history of US corporate research laboratories also supports this point. Initially corporate research laboratories identified and evaluated external technology. After emphasising internal technological development for a time, corporate R&D laboratories have in recent years again come to emphasise links with external sources of knowledge (Mowery, 1989; Freeman 1991).

Why do companies publish, to recruit?

Companies perform research, and the impediments to their publishing the results are more illusory than real, but these are necessary and not sufficient conditions to explain corporate publishing. In science policy terms, companies augment the science base by releasing their knowledge, but this is a social good, not an economic motive for companies to publish. After all, writing papers makes no

[16] Therefore, the success or failure of research cannot be easily evaluated nor can theoretical urn model faithfully encompass these motivations. Moreover, since the contribution to the bottom line cannot be demonstrated, the place of basic research in corporations is often uncertain and is vulnerable in recession.

money and consumes time. Presumably, companies could obtain all the benefits of research in Rubenstein and Rosenberg's lists solely from performing the research and without risking the release of any information. For example, they could develop and patent seeds of innovations in-house without releasing any information. They should be able to build the capacity to absorb outside information by performing research, without disseminating it. Teams performing experiments for in-house consumption should be able to assess the experiments of others without writing papers.

Perhaps the explanation is that publication does not benefit the firm or management and but is initiated entirely by individual research staff. Interviews with R&D managers indicated that companies do not offer rewards for scientific publications as they often do for patents, though they may take into account publication records in staff review. Thus companies do not compel publication. Certainly, publication benefits individuals, especially those who find it intrinsically rewarding. Also, in Europe and the US, though less so in Japan, researchers with publication records are able to change jobs more easily. In Japan, researchers can obtain PhD's through publishing. At one extreme then, it is possible that publication is simply an indulgence granted scientific staff; some might argue therefore that it does not benefit the company.

However when questioned, companies, especially pharmaceutical companies, also say that their publishing aids in recruiting and retaining top quality researchers. Apparently, good salaries, excellent equipment and freedom from teaching, administrative duties, and all the hassle of university research are not enough to entice top scientists into corporate work; the opportunity to publish proves a further necessary inducement. Enhanced competitiveness in recruiting might be the only benefit companies derive from publishing by their scientists. It certainly seems sufficient to explain why companies allow publication.

The argument that knowledge is conveyed orally, not in papers

The idea that publishing benefits firms' recruitment but has little or no effect on the substance of its research (producing results or linking with the outside world) accords with a traditional view in science studies that although papers ostensibly transmit knowledge, in fact they are almost irrelevant. Sociologists have argued that informal communication is extremely important in transmitting knowledge, more so than the literature. Edge quotes Garvey and Griffith to substantiate this point:

> *In a study of over 200 research efforts in psychology, we found that ideas for less than one out of seven originated from sources such as journal articles, presentations at national meetings, etc. Instead, the scientist relies heavily on*

informal networks of information exchange to keep abreast of current activities and of the current views of the community on the value and relevance of specific research problems.[17]

The argument is that scientific papers as explicit, formalised representations of knowledge exclude two types of information that are more important. The first type is unpublished information. This information could in principle be published, and may already be found in pre-prints or released in a conference presentation. Eventually it will be published, but by then its use will be limited. Thus, in fast moving areas of science to be aware of current work one must be in contact with leading researchers in the field because by the time research results are published they are no longer current.

The second type of knowledge not found in journal articles is tacit. Assessing the value and relevance of research questions would seem to be a quintessentially tacit process - precisely fitting Polanyi's classic description of the structure of knowledge. One's conscious thought focuses on assessing the value and relevance of a research problem; the answer is obtained by integrating a number of clues in subsidiary awareness in a process akin to a Gestalt shift. Since a sort of Gestalt shift is involved, it is a personal judgement, embodied and hence tacit (Gelwick).

The role of researcher-to-researcher contact in transferring tacit knowledge was investigated in a study of researchers attempting to construct a new type of laser. Collins found that nobody could build the laser after reading published accounts; rather researchers had to talk to other, successful researchers. Collins attributes the need for personal contact, and the consequent existence of a network, to the tacit nature of the knowledge being transferred. Because the knowledge was tacit, it was by definition person-embodied and inexpressible in a journal article and so could only be transferred in person.

As publications ostensibly transmit knowledge and firms perform research to link with the outside world, we might have expected to find publishing firms benefiting from facilitated movement of knowledge. However, it appears that the real work in moving knowledge is talking to other researchers to obtain unpublished and unpublishable material. This reinforces the view that firms' substantive aims in performing research are not furthered through publishing, but rather publishing enhances recruiting.

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[17] Garvey and Griffith quoted in Edge who also lists other studies drawing the same conclusions.

Publishing signals possession of unpublishable resources

Interviews with Japanese and European R&D managers support a more moderate interpretation indicating that in their science-based industries, **firms** encourage publication.[18] The managers affirmed that publishing helps in recruiting and retaining the best staff. They also listed other benefits.

1. Regulatory agencies require or encourage publication in areas like pharmaceuticals, agrochemicals and veterinary products. Here publications are needed to obtain approval to sell products.
2. Publication is the hallmark of quality in scientific work. It stimulates researchers' creativity, helping to generate new ideas and helping to raise quality.
3. Some Japanese firms want their engineers to obtain PhD's through publishing.
4. Pharmaceutical companies can use publication to generate interest in a substance they have discovered. The firms benefit when academics are attracted into conducting collateral research on the biological action of these substances.
4\. Publication raises corporate image.
5\. Publication aids networking and facilitates collaboration.

Firms benefit from publication in a variety of ways. Regulatory requirements need little comment except to say that these may well vary between countries and will affect a company's propensity to publish. The connection between publication, research quality and staff quality is more intangible but no less important.

The rest of the paper will concentrate on the last three reasons, that is it will explore the connections between publication, networking and corporate image. It will argue that firm publishing facilitates the movement of knowledge. The first component of this argument is that journal articles do in fact count. The aforementioned idea that formal knowledge is irrelevant while unpublished and tacit knowledge is terribly important is rather too simple.

First, publications do communicate useful knowledge to firms. Senker's study of US and UK ceramics firms found that in both countries firms obtained scientific and technical information from universities and national laboratories via the research literature. Personal contacts were used somewhat more, but often the two were used together (Senker, 1994, p.19). Nelson and Levin's survey of firm knowledge

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[18] The interviews were performed as part of a study comparing the basic research outputs of Japanese and European firms. R&D managers in large chemical, pharmaceutical and electronics firms were interviewed in 1991-1992. Phoebe Isard interviewed the European managers.

protection and acquisition also found that publications were rated effective sources of information in a wide range of industries (Nelson, 1992, p. 64). Godin surveyed industrial authors and found that they too rated the published literature highly as a source of useful information (Godin, 1994, p.130). Other studies have indicated that the literature makes an appreciable contribution to technical problem solving in firms (Gibbons & Jonston; Angel).

Second, an anthropologist's observations in a laboratory established the centrality of documents in scientific life. The anthropologist was able to portray laboratory activity as "the organisation of persuasion through literary inscription" (Latour & Woolgar, p. 88) - and to understand scientists as readers and writers of documents. 'Documents' here has a wide interpretation that includes inscriptions written on tags on bottles; the output of instruments, whether printed or electronic; charts and graphs derived from the instruments' output; and reports or published papers. The emphasis on documentation contrasts with the aforementioned tendency to emphasise informal communications in information transfer.

> *Observations of the present laboratory, however, indicate that some care needs to be exercised in interpreting the relative importance of different communications channels. We take formal communication to refer to highly structured and stylised reports epitomised by the published journal article. Almost without exception, every discussion and brief exchange observed in the laboratory centred around one or more items in the published literature. In other words, informal exchanges invariably focused on the substance of formal communication. . . much informal communication in fact establishes its legitimacy by referring or pointing to published literature.*
>
> *Every presentation and discussion of results entailed the manipulation either of slides, protocol sheets, papers, pre-prints, labels, or articles. Even the most informal exchanges constantly focused either directly or indirectly on documents. Participants also indicated that their telephone conversations nearly always focused on the discussion of documents; either on a possible collaboration in the writing of a paper, or on a paper which had been sent but which contained some ambiguity, or on some technique presented at a recent meeting. When there was no direct reference to a paper, the purpose of the call was often to announce or push a result due to be included in a paper currently being prepared. (Latour & Woolgar, pp. 52-3)*

We begin to see that scientific work connects heterogeneous elements such as formal and informal communication. Papers are useful precisely because in scientific work they are part of such heterogeneous assemblages.

The heterogeneous assemblages found in research are the focus of Hilgartner and Brandt-Rauf's analysis of data streams. "Data" in their scheme, are "not the end-products of research or even . . . isolated objects, but . . . part of an evolving data stream". For consistency across fields, they:

> *use the word* <u>*data*</u> *as a technical term, encompassing both inputs and outputs of research, as a shorthand for 'information and other resources produced by or needed for scientific work.' This definition is meant to include not only experimental results, but also instrumentation, biological materials and other samples, laboratory techniques, craft skills and knowledge, and a wide range of other information and know-how. (Hilgartner & Brandt-Rauf, p. 7)*

Data streams are thus seen as "chains of products", and papers are part of the chain. A data stream comprises objects and information, and the information can be tacit, unpublished or published. Neither the objects nor the tacit knowledge can be communicated in a publication. However, a paper describing research points to other elements of the data stream and thus indicates that the authors possess certain tacit knowledge and materials. Readers learn the area in which the researchers work, the names of the materials used, the techniques used to manipulate them, and the astute reader assesses the technical quality of the work. Readers are alerted to the existence of underlying tacit knowledge, skills, substances and so on possessed by the authors. Published papers thus point to unpublishable resources.

Papers help move knowledge in two ways, the first being the obvious one of conveying useful information and the second being signalling. Papers signal the presence of other elements in the data stream. So papers help researchers in firms track science outside the firm by conveying information and by helping the researchers search, select and evaluate tacit knowledge.

The need for credibility in active information gathering

This suggests that readers can benefit from publication. What of authors? Or more specifically, firms employing able readers of scientific and technical literature benefit through the information imported into the firm, but do firms employing authors benefit except from enhanced recruiting? Why should firms want to signal to others the tacit knowledge and resources they hold?

The answer is that knowing resources exist is not enough to obtain them because they are not for sale. Publishing builds credibility, and credibility liberates knowledge. This section explains this by exploring how firms link with the academic research community. We have seen corporate researchers as producers of knowledge, as publishers and as readers of others' papers. This does not exhaust their role in the research system however. To obtain knowledge, researchers must actively engage other researchers.

Earlier I noted that firms perform longer-term research in order to produce research results and to link with the research world. This argument is corroborated by a past Group Vice President for Corporate Research at Xerox who has said:

> *In order for industrial research organisations to be in close contact with new advances in basic science, it is important for the industrial group to be an active **participant** at the leading edge of world science. Effective technical interchange requires that the industrial organisation have its own basic research results in the relevant scientific area to use as the currency of exchange. Participation in world scientific and technical conferences is perhaps the most important way for an industrial research organisation to place itself in intimate contact with the advances in world science. (Pake, 1986, p. 36, emphasis original)*

This statement has brought into the discussion a new, active element. If companies use basic research to recognise, assimilate and exploit outside knowledge, then within the firm their researchers presumably are active "assimilating" and "exploiting". In the outside world, they "recognise" - a relatively passive affair, implying perhaps intelligent scanning of the scientific literature. Pake suggests that corporate researchers actually take a more active approach in the outside world - less recognising than bartering. Researchers exchange technical information, a prerequisite being basic research results to use as "currency".

Earlier in the paper I argued that companies manage the public-private nature of their knowledge and manipulate these categories. Hilgartner and Brandt-Rauf point out that academics do the same. Academics obtain competitive advantage by developing novel data or resources in the lab. Therefore the decision to release information from the data stream, how much and in what form, is strategic.

> *There are many ways to exploit the comparative advantage that stems from unique data or resources. One approach is to limit access while using the data to develop <u>more</u> data. Another method is to disseminate the data widely with the hope that one's scientific credibility will grow as others use and cite the data . . . Data often become "bargaining chips" in negotiations with potential collaborators, and there are a variety of negotiations that take the general form: I've got these clones, you've got expertise with this technique, let's pool our resources and do the following project. (Hilgartner & Brandt-Rauf, pp. 13-14)*

Thus, obtaining knowledge and resources from academics is not simply a matter of discovering their existence by reading the literature. Academics have many options in providing access, and although they may write a paper to signal that certain resources exist, they do not thereby promise access to all who read the paper. Obtaining access requires personal contact and negotiation. Senker found that a company researcher visiting a national laboratory "made a point of providing 'juicy' results from in-house research so as to elicit the time and interest of the expert and get advice on company problems" (Senker, p. 19). In a study of university-industry networking in Danish biotechnology, Kreiner and Schultz investigated barter relationships. They found that company scientists enter into the fluid, loosely coupled, networking activities of academic researchers, networking driven more by accidental opportunity than strategy. The relationships formed tend to be long-term, evolving friendships that involve information sharing and maybe collaboration, characterised by trust and reciprocity. Because scientists barter information, they enter into and maintain these relationships with people whom they believe can and will reciprocate (Kreiner, 1990).

Reciprocity then has two aspects - trust and technical assessment. As barter relationships tend to be ongoing, a researcher who takes advantage in one round, by withholding information for example, can be shut out of future exchanges. Thus, there is a strong incentive to establish a trustworthy reputation. However, even exceedingly honourable researchers may not be ideal partners in information exchange if they do not hold interesting information. Therefore, researchers who wish to obtain information through the informal networks must also establish technical reputations.

The importance of technical reputation in scientific life was emphasised by Latour and Woolgar, whose observations indicated that in the laboratory the reliability of data was frequently conflated with the evaluation of individuals. To explain how judgements based on such seemingly different bases could be combined, Latour and Woolgar theorised that credibility was the unifying, underlying factor. To them, credibility "concerns scientists' abilities actually to do science" (p. 198). They proposed that credibility is converted from one form to another during scientific work. Scientists use <u>data</u> to generate <u>arguments</u> used to write <u>articles</u>. These are read, generating a certain amount of <u>recognition</u> that aids grant raising, generating <u>money</u> to buy new <u>equipment</u> and <u>materials</u> that are used to generate more <u>data</u>, and so on. Each of the underlined resources can notionally be valued in terms of credibility; thus the process converts credibility from one form to another, hopefully increasing the amount of credibility. Note the presence of published articles. When articles are published, recognition and increased credibility can follow.[19] Westney and Sakakibara found that Japanese managers well understood this. More than American managers, they encouraged their engineers to publish to enhance prestige and visibility because they valued the opportunity to build networks (Westney [1985]).

The need to establish a reputation for technical knowledge, or credibility has also been seen in another area of technical information exchange. Von Hippel's studies of informal know-how trading amongst engineers have confirmed the importance of being seen to possess technical knowledge for those wishing to engage in information trading. Schrader studied informal information trading among technical managers of steel mills and found that, amongst other factors, technological knowledge of the person making an inquiry significantly affected the chances of information being given (Schrader, 1991, p. 164). De Meyer finds that credibility governs movement of knowledge within a firm's international network of laboratories (De Meyer, 1993, p. 113).

De Meyer also suggests that a credible researcher is one who is perceived to be able to produce high-quality work in a subject of interest. My own interviews with R&D managers indicated another credibility-governed process, the choice of university researchers to collaborate with, is also framed by the need to find people producing high-quality work in an area of interest.

Credibility governs the movement of scientific and technical knowledge in informal networks, and credibility amounts to a reputation for possessing useful tacit knowledge. It has two components: technical quality and subject area. Both can be

[19] Presumably, reputations could also be built through conference presentations. Conference talks serve many of the same functions as journal articles. Most published papers began as conference talks and some conference talks never are published. Therefore, more information should be available in conference papers than journal articles. In addition, conference talks are given soon after the research is completed, in contrast to journal publication. The advantages of journal articles over conference presentations lie partly in quality. Journal articles, being refereed, are subject to a certain amount of quality control. Also, because they can be read and assessed in depth, the reader can better judge the quality of the underlying work. From the point of view of the reader, journal articles should be the superior means of assessing the quality component of credibility. For the author, conference talks are easier.

Journal articles are also superior to conference talks in enabling broad access to the information. They disseminate results beyond the narrowly focused intellectual communities and partially geographically restricted groups that attend each conference. Thus they can build credibility among broader constituencies.

established through publication, which in pointing to the tacit and unpublishable parts of the data stream signals the area in which a researcher works and the quality of that work. Companies need to have technically knowledgeable people; therefore they must perform research. They must also be seen to have technically knowledgeable people; therefore they must publish research.

Credibility established through publication is used in wider circles

Imai has argued that information transmitted in the market is not transmitted by price alone, although traditionally all relevant information is supposed to be compressed into a price signal.

> *Rather, technological and other information also moves between actors in the market. Especially as the strategic importance of technology increases, information which is not directly reflected in prices has become essential. . . What is important is to determine precisely what kinds of information other than prices are transmitted among economic actors. To understand the workings of today's market economy and of corporate behaviour within it, it is crucial to give explicit consideration to how various economic actors are interconnected in the economy, and how information flows between them. (Imai, p. 243)*

Technological information flows between actors in markets in part through publications.

In complex systems manufacturing such as the flight simulator industry, the "marketplace" is a variety of professional committees, industry association meetings special working groups etc. Because firms manage very large budgets for their clients, technical credibility is crucial to winning orders. Publications and patents both serve to build up credibility and demonstrate the 'credentials' needed to be invited to participate on the committees and to win orders.[20]

In other industries, companies that sell products to firms who are themselves technically sophisticated, benefit from being seen by engineers and medical professionals as technically sophisticated. Companies attempting to recruit the best engineers also benefit from a sophisticated image, even though the engineers may not want to publish themselves. Journal articles send messages to stockholders in pharmaceutical companies that things are in the pipeline and so bolster a company's

[20] M. Hobday, personal communication on flight simulator industry.

share price. Similarly they can help a small firm attract capital. Thus papers, because they are part of data streams, can send signals that are useful in many markets - labour, product, capital, stock and most fundamentally in the barter-governed markets in which knowledge is exchanged.

Conclusion

Between 1984 and 1989, researchers in the corporate laboratory of one Japanese chemical company increased the number of papers they published by 300%. When asked why this was so, the manager explained that during the 1980's the company decided to shift its central business from bulk chemicals to areas requiring advanced academic-type research which often had to be done within the company. These areas were: pharmaceuticals (including biotechnology), information and electronic materials and new materials. Publication increased because in pharmaceuticals publication is required for regulatory approval, but even in the other areas, the research required is often quite basic and therefore is easier to publish than the more applied-type research on which the company previously concentrated. In addition, as they moved into more basic-type research, the importance of access to internationally exchanged scientific knowledge increased tremendously. In order to obtain access, it was critical to enter into the give and take relationships which characterise the scientific community. Thus management enforced a more open policy towards the release of scientific information. One concrete result of this policy was that the budget for attendance at international conferences was increased, and employees were required to present a paper at any conference attended.

This story encapsulates the analysis presented here. Firms in science-based industries do publish journal articles. They are able to do so in part because they perform longer-term research. They are also able to manage the release of their knowledge - deciding whether to keep information to themselves or to enforce a more open policy. They release information in publications for a variety of reasons. Important among these are their need to participate in the barter-governed exchange of scientific and technical knowledge and their need to send market signals beyond that reflected in prices. Publications signal the existence of tacit knowledge and other unpublishable resources, thus building credibility needed to find partners in knowledge exchange. By signalling the existence of unpublishable resources, papers also allow researchers to search, select and evaluate tacit knowledge. Thus papers are integral to moving knowledge: not only do they convey formalised information; they point to the unpublishable.

Acknowledgements

Phoebe Isard interviewed European R&D managers. This paper draws on a project comparing EC and Japanese corporate basic research funded by the Japanese Science and Technology Agency through their fellowship program and by the UK Economic and Social Research Council through the Science Policy Support Group. The paper was written at University of California, Berkeley with support from the Air Force Office of Scientific Research, Air Force Systems Command, USAF, under AOFSR Grant # F49620-92-J-0539.

I would like to thank Margaret Sharp, Keith Pavitt, Ben Martin and Phoebe Isard for comments on previous drafts.

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