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A morphology of Japanese and European corporate research networks

Diana M. Hicks ^{a,*}, Phoebe A. Isard ^b, Ben R. Martin ^a

^a *Science Policy Research Unit, University of Sussex, Brighton BN1 9RF, UK*

^b *Research Centre for Social Sciences, University of Edinburgh, Edinburgh EH8 9JU, UK*

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Abstract

Institutions performing research often collaborate with each other, and firms are no exception. In recent years, research laboratories have been collaborating more frequently; again, firms are no exception to this trend. In this paper, the extent of corporate research collaboration is measured by counting jointly authored papers published by 34 major European and Japanese firms in the pharmaceuticals, chemical-pharmaceuticals and electronics sectors.

In our analysis, we first examine the changing research output of the companies during the 1980s using scientific publications as an indicator of research capability. We then compare the patterns of research collaboration by the companies. We find that European firms collaborated on 52% of their papers in 1989, up from 31% in 1980. For Japanese firms, the figures are lower – 33% in 1989 compared with 22% in 1980. Thus, there is a gap and a growing divergence between the rates of collaboration for European and Japanese firms. The explanation seems to be the increasing intra-European collaboration by European firms, and a striking growth in collaboration with domestic universities by European electronics companies. These differing collaborative patterns give some indication of the sources of technical opportunities available to firms in Europe and Japan.

1. Introduction

An understanding of the links between a firm's research and the outside world is increasingly necessary in any attempt to understand the innovation process as technology becomes more complex and R&D budgets more constrained. A fruitful framework for conducting such an analysis is that based on the concept of national innovation systems. This approach focuses attention

on the links between firms and other institutions producing science and technology, and highlights the contribution that the public sector makes to innovation. According to Nelson and Rosenberg (1994), two proponents of this framework, universities should be incorporated in economists' models of growth because academic and other publicly funded research produces the new findings that offset the diminishing returns to R&D implied by conventional economic models. However, research links between firms and universities or other public sector laboratories vary widely, and analysing them has proved a considerable challenge. They can, however, be explored quan-

* Corresponding author.

titatively using bibliometric indicators. This involves examining papers published in scientific and technical journals which have been co-authored by corporate and public-sector researchers. This article analyses the jointly authored published research output of large Japanese and European firms to map their main research links.

The use made by various industries of university research was the subject of a survey by researchers at Yale University (Klevorick et al., 1995). The survey distinguished between 'old' science, or science acquired when firms hire graduates and used to solve more routine technical problems, and 'new' science, or the latest findings at the research frontier. Although many industries draw upon the scientific knowledge of their employees, only a few have strong links to current university research. Rosenberg and Nelson (1994) synthesised the results of several studies to arrive at the following conclusion:

“university research in the engineering and applied sciences is strongly servicing only a limited range of industries, specifically, those connected with electronics, chemical products, health and agriculture.” (1994, p. 346.)

These are the industries that publish the most papers in the open scientific literature, and they are therefore the ones examined here. More specifically, we have chosen to focus on the research output of large science-based firms in the electronics, pharmaceuticals, and chemical-pharmaceuticals¹ sectors. Besides carrying out a bibliometric analysis, we have also conducted interviews with research managers in most of the companies.

In previous examinations of industrial research, links with outside organisations featured prominently. Early studies of technological innovation demonstrated that successful innovations

are characterised by (amongst other things) links to external sources of scientific or technical information and advice. It has been argued that basic research facilitates successful innovation because it creates external links (Freeman, 1991; Rothwell, 1992). But why does 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 acquire the capability to recognise, assimilate and exploit knowledge created elsewhere (Cohen and Levinthal, 1989; Gambardella, 1992). Innovation studies bear out this assessment, suggesting that, when a firm needs to solve a technical problem, researchers, especially those with PhDs, are able to gather information from personal contacts in academe (Gibbons and Johnston 1974; Angell et al., 1985; Advisory Board for the Research Councils, 1986). Investing in basic research ensures that the firm has researchers in-house to make those links. The history of US corporate research laboratories also supports this point. Initially, the main purpose of corporate research laboratories was to identify and evaluate external technology. There was then a period when they concentrated more on internal technological development, but in recent years they have again been emphasising links with external sources of knowledge (Mowery, 1989; Freeman, 1991).

However, the links between scientific research and innovation are rather indirect, therefore it is not the task of this article to draw conclusions concerning success in product or process innovation, let alone industrial competitiveness. Instead, we have two rather more modest aims: to begin a detailed empirical comparison of national innovation systems and the links between the constituent institutions; and to examine the dynamics of the system, looking at how the patterns change over time. We see this as preliminary work in an area that will grow in importance as the technical state-of-the-art (e.g. access to databases) advances, allowing more complete data to be analysed and a fundamental understanding of the dynamics of national innovation systems to be obtained.

¹ These are companies traditionally classified as 'chemicals' but which are increasingly diversifying into pharmaceuticals as well, for example BASF and ICI (before its demerger into ICI and Zeneca).

2. Comparison of published research output

Before focusing on the research collaborations of companies, we need to look first at the output of scientific publications produced by European and Japanese companies. In particular, we will consider how similar their research capabilities are in three aspects: the volume of publications; the fields in which the companies have been publishing, and how basic their research has been.

We might expect differences between European and Japanese companies for several reasons:

(i) Japan has previously not been very strong in more basic technological research (Gamota and Frieman, 1988);

(ii) Japan's scientific capability as reflected in publications and citations, although strengthening, has been weaker than that of leading European nations (Hicks, 1993);

(iii) many Japanese believe that at present they are not creative enough nor contributing sufficiently to world science.

On the other hand, there are reasons why we might expect similarities. Major Japanese firms are often now at the technological frontier and feel that to advance further they must exploit opportunities created by more basic research. To remedy their perceived weakness, they have begun to invest more in basic research during the 1980s (e.g. Science and Technology Agency of the Japanese Government, 1991). Company research might also look similar in these advanced nations because science is, par excellence, an international pursuit, and so the scientific environment and its constraints are broadly similar in Japan and Europe.

The data examined here are bibliometric.² Companies in each sector were chosen because they publish large numbers of papers or have a reputation for performing more basic research. Table 1 lists the 34 companies that were included. The companies are 'unconsolidated', in other words, we have not included subsidiaries or

² The economic motives behind firm publishing are explained in Hicks (1995).

Table 1
European and Japanese companies included in study^a

Sector	Europe	Japan
Pharmaceuticals	Glaxo	Daiichi
	Roche	Eisai
	Sandoz	Fujisawa
	Smith Kline-Beecham ^b	Sankyo
	Wellcome	Shionogi Takeda
Chemical-pharmaceuticals	BASF	Asahi Chemical
	Bayer	Kyowa Hakko
	Ciba	Mitsubishi Kasei
	Hoechst ^c	Mitsui Toatsu
	ICI	Sumitomo Chemical
Electronics	GEC	Fujitsu
	Philips	Hitachi
	Plessey ^d	Matsushita
	Siemens	Mitsubishi Electric
	STC ^e	NEC
	Thomson	Sony Toshiba

^a The companies not interviewed were BASF, Daiichi, Eisai, Fujisawa, Plessey, Sankyo and Sandoz.

^b We included the laboratories of both Smith Kline French and Beecham. These two companies only merged at the end of the period considered here.

^c The Hoechst data include papers from Behringwerke, a wholly owned pharmaceutical subsidiary.

^d GEC and Plessey have since merged.

^e Now BNR Europe.

overseas laboratories. Data were compiled from the *Science Citation Index* (SCI) on articles and notes³ published in the years 1980, 1984 and 1989. The rationale here was that we wished to cover a reasonable period (e.g. 10 years) to identify significant trends. 1989 was the most recent year for which data were available before the fieldwork in Japan. Initially 1984 was the earliest year for which we had access to data, but subsequently statistics back to 1980 became available on CD-ROM. The limit of 3 years was largely dictated by technical constraints at the time the

³ In the SCI, publications are classified into a number of categories including 'articles', 'notes', 'reviews', 'letters', 'meetings abstracts' and so on. We chose to include only the first two of these categories because we are primarily interested in publications reporting substantial new research findings.

Table 2
Number of papers in journals scanned by *Science Citation Index* (SCI)

	Number of papers			Percentage change in number of papers since 1980	
	1980	1984	1989	1984	1989
<i>Pharmaceuticals</i>					
Europe	594	522	1028	-12	73
Japan	360	290	508	-19	41
<i>Chemical-pharmaceuticals</i>					
Europe	973	745	1094	-23	12
Japan	195	231	328	18	68
<i>Electronics</i>					
Europe	719	616	1064	-14	48
Japan	692	744	1273	8	84
<i>All sectors</i>					
Europe	2286	1883	3186	-18	39
Japan	1247	1265	2109	1	69
Entire SCI database				6	19

empirical work was performed. Comprehensive time-series data would obviously be superior, and technical advances should make this possible in future.⁴ For the present, we note that the trends reported here are broadly consistent with aggregate data in the US National Science Foundation's Science Indicators (National Science Board, 1993).

2.1. How much did the companies publish during the 1980s and what were the trends?

Table 2 shows the number of papers published by the companies in 1980, 1984 and 1989. In 1989, European and Japanese pharmaceuticals and chemical-pharmaceuticals groups differed substantially, with the European firms publishing between two and three times as many papers as the Japanese. This is perhaps not surprising since European pharmaceuticals and chemical-pharmaceuticals companies are larger than their Japanese counterparts. In electronics, the European and Japanese groups published fairly similar numbers of papers, though the Japanese corpora-

tions began the decade publishing 4% fewer papers than the Europeans and ended it publishing about 20% more.

The number of papers published by most companies increased substantially over the decade, though the number of publications often decreased between 1980 and 1984.⁵ The penultimate column in Table 2 show the percentage change in the output of papers between 1980 and 1984. All three groups of European companies together with the Japanese pharmaceutical companies published fewer papers in 1984 than in 1980. The most likely explanation is that more basic research in European companies was appreciably affected by the economic downturn at the start of the 1980s while that in most Japanese corporations was not so adversely affected.⁶

⁵ Informal checks which were made on paper counts in 1983 and 1985 indicated that this was not a statistical artefact but a significant trend over the first part of the 1980s.

⁶ Available evidence indicates that, in real terms, R&D expenditure in the UK electronics and chemical industries increased in the early 1980s (although other industries suffered decreases) (Central Statistical Office, 1989). One possible explanation is that R&D funding in the chemicals and electronics sectors in the UK may have been redirected away from more basic research.

⁴ Further details of the methodology can be found in Hicks et al. (1992).

Notwithstanding the drop between 1980 and 1984, most of the companies ended the decade publishing substantially more than at the beginning. The percentage increases between 1980 and 1989 are listed in the final column of Table 2. Over this period, the number of papers in the 3 500 leading scientific journals covered in the SCI database grew by 19%; of the various categories considered here, only European chemical-pharmaceuticals has a lower rate of growth (12%) (however, firms in this sector published more than any of the other groups in 1980, and in 1989 they were still in second place). Japanese chemical-pharmaceuticals publishing grew by 68% over the 9 years, European pharmaceuticals by 73% and Japanese electronics by 84%. These companies were dynamic members of the scientific community during the 1980s, increasing their scien-

tific output three to four times faster than the world average.

The above results suggest that these companies together make a significant contribution to publicly available scientific and technical knowledge although their research efforts appear vulnerable to firms' economic fortunes. Despite a drop in the early 1980s, companies in all sectors increased their publishing substantially over the decade. This increase does not seem to be solely a European or a Japanese phenomenon, nor is it specific to one technology or industrial sector.

2.2. In what fields do the companies publish?

To compare the fields in which companies publish, we classified papers on the basis of the journals in which they were published, using a

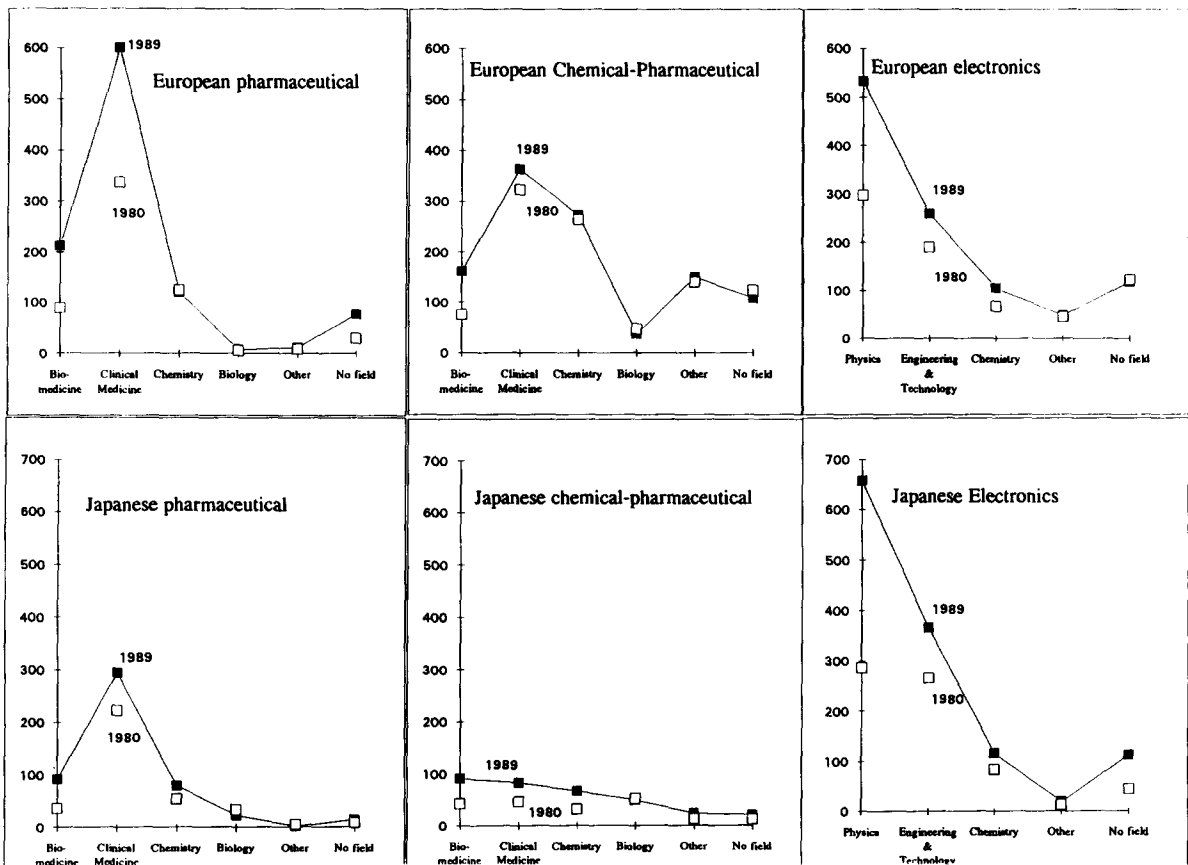


Fig. 1. In what fields do the companies publish?

scheme developed by CHI Research.⁷ Fig. 1 summarises the distribution of company papers across scientific disciplines. There are six graphs, each of which displays the number of papers in individual fields in 1980 and 1989 for each group of companies (for example, European pharmaceuticals or Japanese electronics).⁸ The graphs reveal that, unlike universities, companies tend to specialise in either physical sciences or biomedical sciences. The patterns are closely related to the technological base of the companies with pharmaceuticals companies specialising in clinical medicine and biomedicine and electronics companies in physics. The chemical-pharmaceuticals firms spread their publications rather more evenly across fields especially in Japan.

The degree of specialisation can be assessed by calculating the percentage of papers in the main field. In 1989, the pharmaceuticals companies published 58% of their papers in clinical medicine, and the electronics companies about 50% of their papers in physics. However, the

chemical-pharmaceuticals companies published no more than 1/3 of their papers in any single field. Over time, pharmaceuticals and electronics companies have become more specialised in their main fields while chemical-pharmaceutical companies have not.

Chemistry is the only scientific field in which all three industrial sectors publish. Nevertheless, it is not the main field even for chemical-pharmaceuticals companies, and publishing in chemistry did not increase appreciably between 1980 and 1989 at least for European companies. Chemistry would thus seem to be a pervasive research field in both physical and biomedical science-based companies. Yet it is not the focus, either in the sense of being the largest scientific field or the fastest growing.

2.3. *How basic is the research?*

The European and Japanese companies do not therefore differ greatly in the amount they publish nor in the fields they research. Conceivably, Japanese companies might be performing less basic research. The conventional way of measuring the level of effort in basic research is to look at expenditure. However, individual companies may interpret the definition of 'basic research' quite differently and therefore expenditure figures may not be comparable, especially across countries. Our data enable us to analyse 'basicness' in a different way. We used a classification (again constructed by CHI Research) of journals in the SCI into four levels according to how basic

⁷ This classification into broad disciplines was developed by CHI Research for use in the report, *Science and Engineering Indicators*, prepared by the US National Science Board. The journal classification was last revised in 1986. We are grateful to CHI Research for providing us with the journal categorisation list.

⁸ In almost all cases, the 1984 data point was located in the same place or lower than the 1980 point. Therefore, to enhance the legibility of the graphs, the 1984 data have not been plotted.

Table 3
Level definition and prototype journals
(a) Physical sciences

Level	Name	Prototype journal
1	Applied technology	Journal of the Iron and Steel Institute
2	Engineering sciences	Journal of Nuclear Science and Technology
3	Applied research	Journal of Applied Physics
4	Basic science	Physical Review
(b) Biomedical sciences		
1	Clinical observation	Journal of the American Medical Society
2	Clinical mix	New England Journal of Medicine
3	Clinical investigation	Cancer Research
4	Basic science	Journal of Biological Chemistry

is the research they report; Level 4 is the most basic and Level 1 the most applied. The scheme is illustrated in Table 3 which displays the names of the levels and prototype journals in each level

in both the physical and biomedical sciences. This approach to assessing whether the research is more or less basic is far from perfect. It involves assuming that all papers in a given journal are

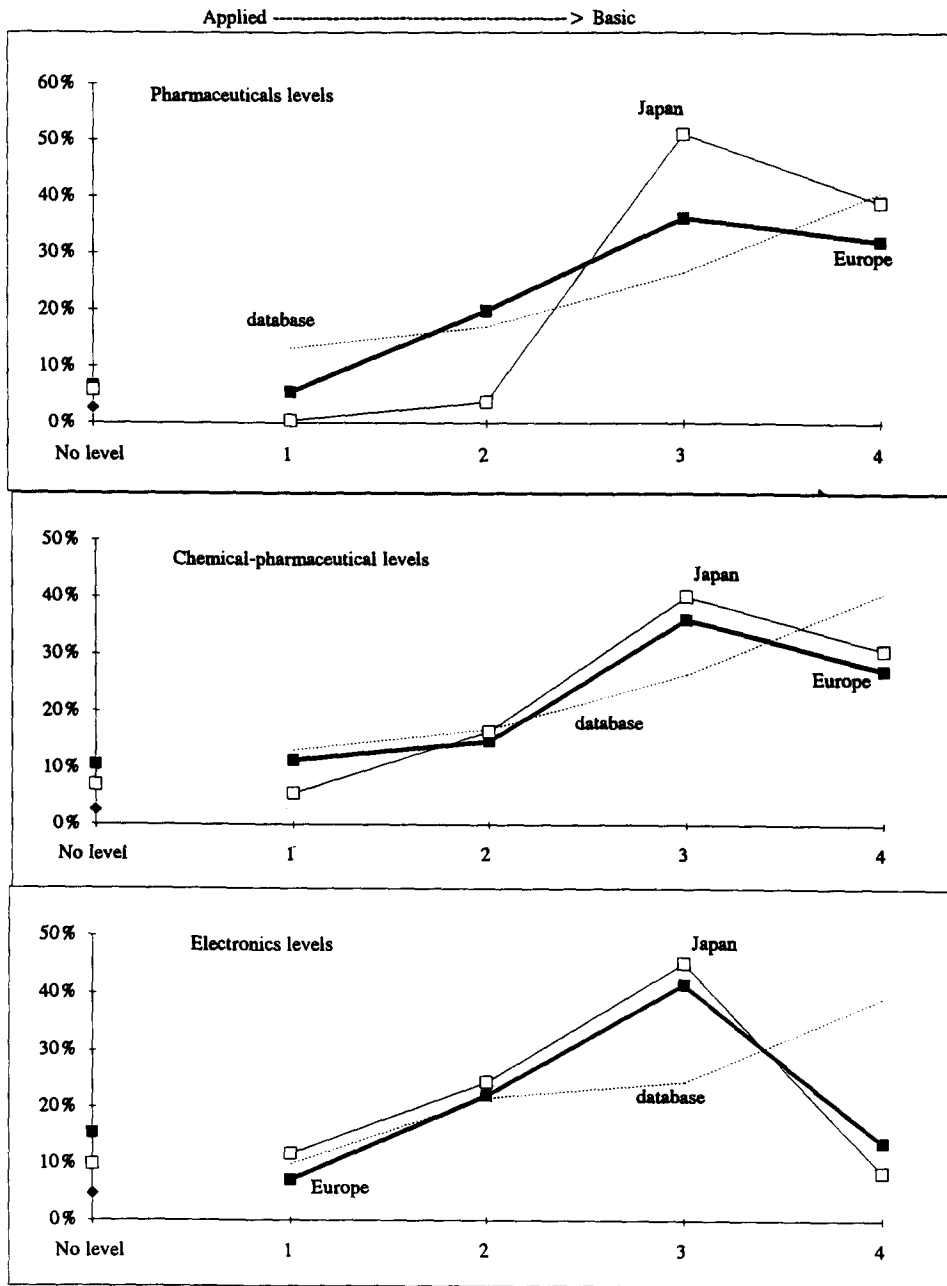


Fig. 2. How basic is the research?

equally basic. There is also an element of subjectivity in classifying a journal at a particular level on the four-point scale. Nevertheless, the advantages of this measure of 'basic-ness' are that it is independent of company definitions and can be applied consistently across countries.

Fig. 2 summarises the percentage of papers in each level. There is one graph for each industrial sector on which is plotted the Japanese and European company data for 1989 together with the overall distribution for SCI database in 1986 (the only year for which statistics exist) for comparative purposes. The latter shows that the largest proportion of papers fall in Level 4 (the most basic category). As the SCI database is dominated by publications from universities, and as these papers tend to be more basic, this is perhaps not surprising. Of the three industrial sectors, electronics companies produce the lowest percentage of the most basic (Level 4) papers. This is partly because pharmaceuticals (and to a lesser extent chemical-pharmaceuticals) are more closely linked to the science base than electronics technologies (Narin and Olivastro, 1992), and partly because several of the electronics companies carry out research related to heavy electrical equipment or power generation, neither of which is very closely linked to science.

European and Japanese corporations are broadly similar. The basic-applied profiles of pharmaceuticals companies differ the most, with the Japanese apparently emphasising basic research considerably more than the Europeans. This effect seems to be due to a dearth of more applied pharmaceuticals papers published by Japanese companies in the journals scanned in the SCI. There could be two reasons for this: first, if Japanese clinical medical research is of lower quality, that would prevent it being published in the international literature (Fukushima, 1989); secondly, from our interviews it would appear that there are differing co-authorship conventions in the two regions. In particular, Japanese companies may not co-author much of the clinical research that they fund to maintain the appearance of a separation between industry and medicine, a characteristic of the Japanese system.

3. Collaborative research

We now turn to an analysis of co-authored papers as indicators of collaboration. Before doing this, we ask the following questions: why do firms seek research partners? And what kind of collaboration underlies co-authored papers? We use the answers to these questions in interpreting the co-authorship data, a process we begin by examining rates of co-authorship and how these changed over time. In the final sections, we examine the data in more detail, describing trends in company co-authorship with other companies, with hospitals, government laboratories and other public sector laboratories, and with universities.

3.1. *Why do firms engage in research collaboration?*

Klevorick et al. (1995) have argued that, to understand the determinants of technical advance and R&D intensity in an industry, we must empirically investigate not only appropriability and patent protection but also technical opportunity. They observe that economic models of R&D imply diminishing returns. In these models, as applied research and development projects are completed, they draw upon and hence deplete the pool of technical opportunities available for future exploitation. However, since some industries have sustained high R&D intensities and rates of technical advance over time, they hypothesise that pools in such industries might be replenished in some fashion. Klevorick et al. point to three sources of new technical opportunities: advances in scientific understanding and technique; technological advances made by other industries or institutions; positive feedback from the industry's own technological advances. They believe that, of these three sources, advances in scientific knowledge constitute the most important. They point in particular to two types of scientific advance. First, there are the results of past research, embodied in the stock of knowledge and used in technical problem-solving. Secondly, there are new opportunities arising in the latest research.

We would argue that research collaboration is one mechanism through which companies access

technical opportunities arising from past and current research. R&D managers in the firms examined were asked about their motives for research collaboration. The managers gave two main types of reason:

1. Research efficiency: (a) the firm cannot do everything itself, (b) reducing costs and risks by sharing them with other partners, (c) taking advantage of cross fertilisation and synergy (more commonly expressed by Japanese than European companies).

2. Access to technical opportunities: (d) helping in the recruitment of high quality researchers, (e) acquiring skills in a new area, or gaining access to technology and knowledge. (f) entering a network and building relationships, (g) gaining early warning of where things are starting to happen (more common in European than Japanese firms).

The answers point to the concern of managers with R&D efficiency and with access to technical opportunities, both those from past research (through recruitment) and from the latest research. Other analyses have found a similar emphasis on accessing technical opportunities through links with the science base. For example, a UK government working party investigating industrial research found that both recruitment and the need to access current opportunities are important motives for firms to collaborate with universities:

1. For many companies, the primary purpose of sponsoring research in universities is to develop and maintain working relationships with individuals, teams or centres of recognised excellence or particular expertise, to keep in touch with developments in particular fields. In this way companies keep intellectually alert and are able to move quickly into new areas as and when potential for commercial development is perceived.

2. Recruitment: “Companies seeking to recruit a small number of first-class science graduates each year . . . [find] this to be an effective means of making contacts.” (Advisory Board for the Research Councils, 1986, pp. 33 and 36.)

Writing from a management perspective, Rubenstein (1989) relates university linkages to

the minimum viable size for a corporate research effort. He argues that companies tend to specialise in the primary discipline underlying their technology and

“have only token groups in the other fields to serve as scouts and early warning mechanisms. This means that, in order for a reasonable sized . . . [corporate research laboratory] to provide adequate coverage of fields of *potential* relevance to the company, as well as those of *obvious* importance, they must maintain strong contacts with the university community . . . Most frequently [the] payoff is not in the form of an identifiable new product or process but comes in more subtle forms, such as increased sophistication of the company’s total technology base, the avoidance of technical blunders, and early warning of opportunities or threats from new developments in science and technology.” (1989, pp 53–55 – original emphasis.)

These analyses suggest that firms need links such as collaborative research with universities and other public sector laboratories to access technical opportunities.

3.2. *What type of co-operation underlies joint papers?*

In the following analysis, institutionally co-authored papers, that is, those listing an address other than the company’s own laboratory, are taken to indicate some type of successful co-operation. However, precisely what is indicated by co-authored papers remains rather unclear.⁹ Therefore, the type of co-operation underlying the co-authored papers from companies was investigated by interviewing a sample of the papers’ authors. Company researchers listed among the authors of 1989 co-authored papers were asked to describe the contribution made by each

⁹ See Katz and Martin (1996) for a discussion of the extent to which co-authored papers represent an adequate indicator of collaboration.

Table 4
Nature of collaboration underlying co-authored papers from Japanese companies

	All collaborations		Foreign only	
	Number	%	Number	%
Person seconded	39	35	11	52
From company	26		10	
To company	13		1	
Joint research – i.e. work at both sites	32	29	5	24
Sample preparation/analysis division of labour mentioned	12		3	
Idea/experiment division of labour	22	20	0	0
Subcontract, money for experimental work	14		0	
Other	18	16	5	24
Co-ordinated by outside organisation	10		1	
Former employee, student or joint appointment	8		4	
Total	111	100	21	100

party.¹⁰ Information was obtained from nine laboratories on 156 co-authored papers published in 1989, from which usable accounts were obtained for 111 collaborations.

Several methodological points should be noted. First, exchange of money was not explicitly investigated as a factor affecting collaboration, but money may well have been transferred from the company to the co-authoring institution in many cases apart from those where the co-authoring institution was another company. Secondly, the company's perception of each collaboration has been examined and not collaboration per se. For example, when more than two co-authoring institutions were listed, often information was obtained on only one (the one with which the corporate researchers had links). In addition, our classification of the type of collaboration depends on which aspects of the work the respondent mentioned in their response to an open-ended question. Thirdly, one of the categories of collabora-

tion ('person seconded'¹¹) sometimes overlaps with the other categories. In several cases, joint work began at the university to which a corporate researcher was seconded and then continued in both the corporate and the university laboratories upon the researcher's return to the company. These situations have been classified under the heading of 'person seconded', even though they might also qualify as 'joint research'. In contrast, work co-ordinated by an outside organisation was always classified as such even if secondment of staff was involved.

Table 4 shows the results on the different forms of collaboration. Although not specifically mentioned in the table, discussions with academics accompanied most if not all research exchanges, including small research contracts, and indeed company scientists generally see this as a major benefit of collaborative research. This supports the hypothesis that collaborative research is one way to access new technical opportunities. Even if the results reported in the joint paper do not necessarily open up new technological opportunities, company scientists can often obtain help

¹⁰ Only Japanese companies were surveyed, and those included differ from those examined in the rest of the paper because the survey was conducted during a larger study. The companies included in this survey are Asahi Glass, Fuji, Kao, Mitsui Toatsu, Nippon Steel, NTT, Sagami Chemical Research Center, Takeda and Toshiba.

¹¹ In other words, collaborations where one or more researchers transferred temporarily from one laboratory to another.

Table 5
Trends in collaboration over the 1980s

	1980–1989 % increase in			% of papers that are collaborative	
	Total papers	Non-collaborative papers	Collaborative papers	1980	1989
<i>Pharmaceuticals</i>					
Europe	73	29	144	38	54
Japan	41	11	153	21	38
<i>Chemical-pharmaceuticals</i>					
Europe	12	-26	85	35	57
Japan	68	37	135	32	45
<i>Electronics</i>					
Europe	48	3	230	20	44
Japan	84	64	167	19	28
<i>All sectors</i>					
Europe	39	-3	133	31	52
Japan	69	45	156	22	33

with solving technical problems and gain some idea of what is happening in the field through open-ended discussion with their collaborators.

Table 4 highlights the importance of secondment, with more than one-third of the joint papers involving long-term (1 year or so) or short-term (several weeks to a few months) personnel exchanges. Some exchanges were not motivated by the desire to access technical opportunities, for example where a doctorate was obtained,¹² or where the instrumentation available at the host site was used (particularly when the company was the host). However, other exchanges were primarily for exploring new opportunities, for example where the company sought to learn about new areas (such as high-temperature superconductivity) in the laboratory of a leading professor, or where they needed to learn about specific pieces of instrumentation (in one or two cases with the aim of developing the technology in the company).

However, secondment of researchers was not the sole form of collaboration. Jointly performed research, in which experimental work took place at two (or more) sites without any mention of personnel exchange, was almost as frequent as secondment, accounting for 29% of the co-authored papers. In some of these, the desire for R&D efficiency seems to have been paramount, for example where researchers had met at professional society meetings, had several discussions on topics of mutual interest and collaborated because they shared interests and could complement each other's inadequate facilities. In other cases, the company's interest in technical opportunities was made explicit. One company wanted to make atomic level observations of their materials to investigate crystal dislocation. The company had a sophisticated instrument, while the professor did not have much instrumentation but was very knowledgeable about atomic structure. They therefore decided to collaborate.

In 20% of co-authored papers, one institution contributed the original idea or theoretical knowledge, and the other performed the experiment. Such a division of labour is not dissimilar in nature to a research contract. Concern with

¹² Most of the young researchers recruited by Japanese companies have a masters as their highest degree rather than a doctorate.

R&D efficiency was visible here too, for example when a university was asked to perform clinical tests on a dermatological product. In other cases, technical opportunities apparently motivated the work. For example, a company was interested in the initial picosecond or so of a particular process, and the university had invented a technology capable of recording the early stages of that process. The university thus had equipment and knowledge which the company wanted but lacked. In another example, a professor had developed a method for analysing flows of materials that the company considered useful in studying the behaviour of flows of molten material in a blast furnace. In yet another case, a company wanted to develop a new polymer structure; they asked a professor to determine the structure of their samples because the professor was an expert at using X-rays to determine crystal structure.

Overall, Table 4 indicates that collaborations in Japan take a wide variety of forms. This is a commonly recognised feature of industry–university links in the West, suggesting a certain similarity between Japanese and Western collaborative linkages. The collaborations can also be traced to a variety of motives, among which access to technical opportunities features prominently.

3.3. Trends in collaborative research

Let us now turn to consider the trends in co-authorship over the 1980s. Collaborative research increased sharply over the decade as is clear from Table 5. The first column shows the percentage increase in the total annual production of papers between 1980 and 1989 (discussed earlier and taken from Table 2). The next two columns address the question: which component increased most, collaborative or non-collaborative papers? In every case, the number of collaborative papers increased far more than non-collaborative papers. Only in the case of European chemical-pharmaceuticals companies did the number of collaborative publications fail to at least double between 1980 and 1989. European electronics companies exhibited the most rapid growth, with a tripling in the number of collaborative papers. In contrast, the number of non-col-

laborative papers published by European chemical-pharmaceuticals and electronics companies fell or remained approximately static. The largest increase in non-collaborative papers was 64%, recorded by Japanese electronics companies. Yet even this is less than the smallest percentage increase for collaborative papers.

What fraction of the companies' research efforts are devoted to collaborative research? The last two columns in Table 5 report the percentage of total papers that are collaborative. In both Japan and Europe, chemical-pharmaceuticals companies collaborate most, with electronics companies collaborating least. Japanese companies began the decade collaborating proportionally less than European companies (22% compared with 31%). By the end of the decade, the gap had widened (to 33% compared with 52%). Initially, the difference was largest in the pharmaceuticals sector while in the chemical-pharmaceuticals and electronics sectors Japanese and European companies collaborated at about the same rate. By the end of the decade, however, there was a substantial gap in all sectors, with European groups collaborating on between 44% and 57% of their papers and Japanese groups collaborating on 28% to 45% of their publications.

The difference between Japanese and European companies in the rate of collaboration can be labelled the 'collaboration gap'. This and the diverging rate of collaboration between Japanese and European companies over the 1980s characterise these data. In what follows, we examine why there is such a gap and why it has grown. Is it because Japanese companies collaborated less abroad? After all, Japan is geographically rather distant as well as being linguistically and culturally quite separate from other advanced scientific nations. Alternatively, is it because Japanese universities are weak, so the level of collaboration with domestic universities has been low? Or are there other causes? At the same time, we will examine in more detail the dramatic growth in collaboration during the 1980s. Does this reflect a strengthening of domestic or foreign networks? And in which sectors are most of the collaborative partners? Are companies forging research

links with other companies, with universities, or with other types of research institution such as government laboratories and hospitals?

3.4. *With whom do the companies collaborate?*

To answer these questions about collaboration, we have classified co-authoring institutions by sector and by country or region. Institutional addresses have been categorised first as university, industry or 'other' (e.g. government laboratories, hospitals, charities) and secondly as domestic or foreign. To look for any evidence of 'Europeanisation' in collaborative networks, in certain cases the foreign category was subdivided. To do this, the foreign institutions collaborating with European companies were classified as either inside or outside Europe (defined here to be the EU and Switzerland).¹³ Analysing patterns of collaborative research is by nature a complex task. Even if we exclude totals and averages, any interpretation involves 135 permutations of (a) European and Japanese companies in (b) three industrial sectors collaborating with (c) university, industry and 'other' institutions which may be (d) domestic, foreign or (in the case of the European companies) European in (e) 1980, 1984 and 1989.

The figures discussed below are for the percentage of the total number of papers that list at least one address from a particular category, such as universities, or domestic industry. When collaborations are classified in this way, a single paper with two or more institutional co-authors can be counted more than once. For example, a paper with co-authors from a domestic university and from a foreign university would be counted in both the domestic universities' percentage and the foreign universities' percentage. As a result, the two percentages for collaboration with foreign and domestic universities cannot be simply added together to obtain the total percentage of papers with an academic co-author, since there

will be double counting of those papers with both types of partner.

3.5. *Is there a theoretically predicted rate of collaboration?*

Although it is impossible to predict the rate at which companies should collaborate with other institutions, in larger countries a greater proportion of collaborators would normally be expected to be domestic. Scientists in countries that publish a higher percentage of the world's scientific literature should on average be more likely to collaborate with institutions in the same country, because a larger percentage of potential partners work there. As Japan has more scientists and engineers than individual European countries, we might expect Japanese companies to collaborate proportionally more with domestic institutions than European firms (although possibly offsetting this is the fact that Japanese companies collaborate less overall).

This assumes, of course, that all potential collaborators represent equally attractive partners. Since the Japanese share of the world total of scientific publications is somewhere between 8% and 13% (depending on which database is used), this model would predict that 8–13% of the Japanese collaborative papers would be with domestic collaborators and the remainder with foreign partners. In reality, the numbers are almost exactly the opposite; 88% of collaborative papers for Japanese companies have a domestic collaborator's address on them while 18% have a foreign address.¹⁴ In short, it would seem that not all potential partners are equally attractive. Other studies of the factors affecting collaboration confirm this conclusion. In particular, they suggest that the rate of collaboration falls off strongly with geographical distance and with differences

¹³ Switzerland is not a member of the European Community (EC) or the European Union, but the industrial systems are closely linked and for the purposes of this study we classified Swiss institutions as European.

¹⁴ Note that the percentages do not sum to 100% because for some papers there are both domestic and foreign collaborators. For European companies, the corresponding figures are 60% domestic and 49% foreign. If Europe is defined as the home 'country', then 88% of collaborative papers have a domestic collaborator and 20% have a foreign collaborator.

Table 6
Collaboration with domestic companies. Percentage of total papers averaged over 1980, 1984 and 1989

Sector	Europe (%)	Japan (%)
Pharmaceuticals	1	2
Chemical-pharmaceuticals	3	5
Electronics	2	8

in language, history and culture; closer and more similar partners are much more attractive to each other (Katz, 1994; Luukkonen et al., 1992). Unfortunately, at present we cannot calculate precisely how collaboration depends on distance and therefore what deviations from the norm, if any, we are seeing.

3.6. Collaboration with companies, hospitals, government laboratories and other public-sector organisations

We will first examine collaboration with companies, followed by 'other' institutions in the same country and finally 'other' institutions abroad. The next section will then analyse university collaboration.

Table 6 shows the percentages of papers listing another domestic company address. The percentages are mostly very small. This is no surprise; as we have seen, companies specialise in their research so the candidates for collaboration are restricted to a small number of firms doing similar types of research. These will often be direct competitors, thus ruling out collaboration. The results reveal that Japanese firms collaborate slightly more with each other than do their European equivalents. Hence, neither the overall collaboration gap nor the divergence that we noted above is explained by collaboration with other domestic companies – indeed, any gap here is in the opposite direction.

The largest difference between Japanese and European companies is in electronics, where Japanese corporations participate extensively in MITI programmes. However, upon inspection of the titles of the papers, the collaborations turn out to be primarily in the areas of power-generating equipment and nuclear energy. For exam-

Table 7
Collaboration between electronics companies and other domestic firms. Percentage of total papers

Sector	Europe (%)	Japan (%)
1980	1	6
1984	2	9
1989	3	10

ple, Toshiba and Tokyo Electric Power might collaborate on power systems research. Table 7 summarises how the collaboration data for electronics companies varied over time. The rate of collaboration with domestic companies increased steadily in both Europe and Japan. This is particularly noteworthy for the Japanese companies since, as we saw earlier, the number of non-collaborative papers increased appreciably (by 64%) over the same period. In absolute terms, the number of papers with a domestic company listed as a co-author increased from 44 to 122, i.e. almost tripling over the decade.

Collaboration with foreign companies is less frequent, corresponding to under 5% of the total number of papers, and in Japan the figure was zero in some cases. Drawing conclusions from such small numbers is therefore rather hazardous. Nevertheless, the European companies do seem to collaborate with foreign companies a little more than their Japanese counterparts, and this may have increased over time. Therefore, collaboration with foreign companies makes a minor contribution to the gap and to the divergence discussed earlier.

Figures on the percentage of papers that list the address of a domestic hospital, government laboratory or some other public-sector institution are listed in Table 8. Overall, there is more collaboration with these institutions than with

Table 8
Collaboration with domestic hospitals, governmental laboratories and other institutions. Percentage of total papers averaged over 1980, 1984 and 1989

Sector	Europe (%)	Japan (%)
Pharmaceuticals	10	3
Chemical/pharmaceuticals	7	7
Electronics	6	4

Table 9
Collaboration with foreign hospitals, government laboratories and other institutions. Percentage of total papers

Sector	1980 (%)	1984 (%)	1989 (%)
<i>Pharmaceuticals</i>			
Europe	5	8	15
Japan	0	0	3
<i>Chemical-pharmaceuticals</i>			
Europe	5	6	9
Japan	1	1	2
<i>Electronics</i>			
Europe	2	3	5
Japan	0	0	1

industry, except in the case of Japanese electronics companies. However, the only contribution to the collaboration gap evident in this table is for the pharmaceuticals sector where European firms collaborate quite frequently with domestic hospitals. The difference may in part reflect the difference in co-authoring conventions mentioned earlier, whereby Japanese companies tend not to appear as co-authors on clinical research that they fund in Japanese hospitals. There is no clear trend in these figures so this form of collaboration makes no contribution to the divergence noted above.

In contrast, collaboration with hospitals, government laboratories and other public-sector institutions in foreign countries does contribute to both the gap and the divergence, as can be seen from Table 9. In all three industrial sectors, European collaboration is higher and the difference between European and Japanese collaboration grew over the decade. Is this because European companies collaborate with institutions outside Europe? Or are they collaborating more inside Europe? In other words, is this an aspect of globalisation or of European regionalisation?

Table 10 displays the figures needed to address this question. The European data are split into two categories: institutions within the EU (together with Switzerland) and those outside. The table indicates that the companies collaborate with partners inside Europe at a slightly higher rate than they collaborate with those from outside Europe. Also, the rate of collaboration

with institutions outside Europe almost equals the Japanese rate of foreign collaboration. This means that intra-European collaboration almost entirely accounts for the gap between European and Japanese collaboration with foreign, 'other' institutions. Furthermore, intra-European collaboration increased over the decade, contributing to the divergence between European and Japanese rates of collaboration overall. We might say that European companies have an extra component to their foreign collaboration (intra-European collaboration) which is unavailable to the Japanese and which contributes to both the overall gap and the divergence between Europe and Japan.

To summarise, in our search for the origins of the gap and divergence between the rates of co-authorship of European and Japanese companies we have found contributing factors. Collaboration with other companies, however, is not one of those factors – indeed, the pattern runs counter to the general one, with Japanese companies collaborating a little more with other domestic companies than do European companies, particularly in the electronics sector. Collaboration with foreign companies contributes a small amount to the gap and divergence. Collaboration with hospitals, government laboratories and other organisa-

Table 10
Collaboration with foreign hospitals, government laboratories and other institutions. Percentage of total papers

Sector	1980 (%)	1984 (%)	1989 (%)
<i>Pharmaceuticals</i>			
Europe			
In Europe	3	5	11
Outside Europe	3	4	5
Japan	0	0	3
<i>Chemical-pharmaceuticals</i>			
Europe			
In Europe	3	4	6
Outside Europe	2	2	3
Japan	1	1	2
<i>Electronics</i>			
Europe			
In Europe	2	2	4
Outside Europe	0	1	1
Japan	0	0	1

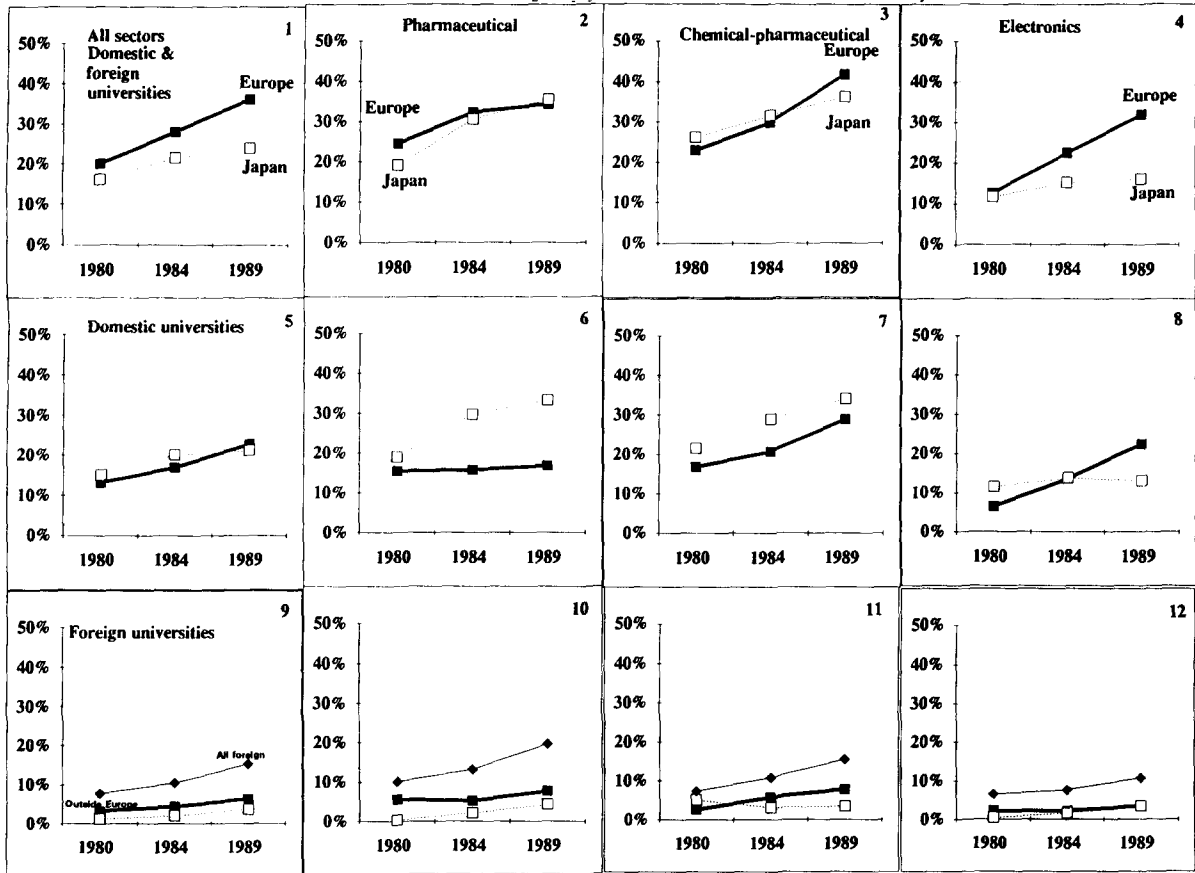


Fig. 3. Collaboration with universities – percentage of papers with at least one co-author from a university.

tions contributes more substantially. Domestically, the largest gap is in the pharmaceuticals sector and can be traced to more collaboration with hospitals by European companies. Collaboration with foreign hospitals, government laboratories and other institutions contributes noticeably to both the gap and the divergence, largely because of the extra component of intra-European collaboration by European companies. We now turn to the largest group of co-authored papers, those listing a university address.

3.7. Collaboration with universities

Fig. 3 shows the rate at which the companies collaborate with domestic and with foreign universities, and how this changed over the 1980s.¹⁵

The figure contains 12 graphs, each displaying the percentage of papers with a university collaborator for European and Japanese companies in 1980, 1984 and 1989. European data are plotted with a heavy continuous line and Japanese with a light dotted line. The first row of graphs gives the rate of collaboration with universities as a whole, the second that for domestic universities only, and the third that for foreign universities. For European companies, the rate of collaboration with universities outside Europe (and Switzerland) is plotted separately on the graphs in the

¹⁵ For comparison, *Science and Engineering Indicators – 1993* reports that articles co-authored with a university grew from 22% of industry articles in 1981 to 32% in 1989 (National Science Board, 1993, see Appendix table 5–26, p. 429).

third row as a heavy continuous line, while total foreign collaboration (whether with another EC country or further afield) is shown with a light continuous line. The graphs in the first column give the data for all sectors combined. The graphs in the other three columns display the data for each industrial sector separately. Thus graph number 7 (the numbers are in top right hand corner of each graph) indicates the rate at which companies in the chemical-pharmaceuticals sector collaborated with domestic universities.

Beginning with Graph 1, we can see that collaboration with universities contributes substantially to the gap and divergence between the overall rate of European and Japanese collaboration. The gap is not accounted for by the level of collaboration with domestic universities. Domestic and foreign collaboration are separated in the graphs immediately below (Graphs 5 and 9) revealing that rate of collaboration with domestic universities is approximately equal in Europe and Japan. Rather, European firms collaborate slightly more with partners outside Europe than Japanese companies do with foreign partners. However, overall foreign collaboration is substantially higher due to the intra-European component of foreign collaboration. As we saw in the previous section, this pattern also characterised collaboration with 'other' institutions (government laboratories, hospitals, etc.). This overall picture, however, obscures certain sector-specific patterns.

In the pharmaceuticals sector, there seems to be no gap or divergence (Graph 2). This is because Japanese companies collaborate with domestic universities at a substantially higher rate than do European companies. Foreign collaboration fits the pattern described above, in which collaboration outside Europe is similar but somewhat higher than the foreign collaboration of Japanese companies, and European overall foreign collaboration is much higher because of the intra-European component. Intra-European collaboration grew substantially over the decade increasing from 5% to 13% of total papers which corresponds to a jump from 28 to 131 papers.

In the chemical-pharmaceuticals sector, there appears to be little evidence of a gap, but some

support for divergence in the latter part of the 1980s (Graph 3). Japanese companies began the decade collaborating at a marginally higher rate with universities but ended it collaborating at a lower rate. Again, we see that collaboration with domestic universities was higher in Japan than in Europe. In addition, we see the now familiar pattern of foreign collaboration, though this time European and Japanese companies collaborated with foreign universities at about the same rate at the beginning of the decade. By the end, however, collaboration with universities outside Europe was a little higher than Japanese foreign collaboration, and the total foreign collaboration for European companies was noticeably higher. In this sector, each component of collaboration by European companies with universities increased: domestic, intra-European and outside Europe.

Electronics is perhaps the most unusual sector. Graph 4 shows a dramatic divergence between the European and Japanese data. At the beginning of the decade, the European and Japanese companies were collaborating with universities at approximately the same rate. By the end of the decade, there was a considerable gap. The European companies had reached a rate of collaboration comparable to that in the other sectors while for Japanese companies the rate of collaboration remained relatively low. If we look first at foreign collaboration, we see the same pattern as before, although in electronics the rate of collaboration outside Europe equals the rate of foreign collaboration of Japanese companies. If we then add in the additional component of intra-European collaboration, the rate of total foreign collaboration for European firms appreciably exceeds that in Japan. Although the rate of collaboration outside Europe has scarcely altered, the rate of intra-European collaboration has doubled from 4% to 8%.

The most striking trend, however, is in rate of collaboration with domestic universities. For Japanese companies, the rate remained level at about 12%, while for European electronics companies it increased from 6% to 22%. It is this increase in domestic university collaboration that accounts for much of the divergence seen in the

overall sectoral figures in Graph 4. It also accounts for a substantial component of the overall trend in Graph 1 because the Japanese electronics companies produced more than half of the Japanese papers.

This raises another question. What is more unusual: that the rate of collaboration with domestic universities increased so much for European companies or that it changed so little among Japanese companies? Inspection of the increase in absolute number of papers provides an answer. Japanese electronics companies doubled their output of papers that also had a domestic university address from 79 in 1980 to 165 in 1989. This is a little less than the approximately 250% increases in the other sectors, but not markedly so. The reason that the rate of collaboration did not change is that papers produced by the companies alone (i.e. with no collaborators) grew by 64%, the largest increase. On the other hand, European electronics companies published well over 400% more papers with a domestic university address in 1989 than 1980.¹⁶ This is substantially more than the increase of approximately 90% in the other sectors. Non-collaborative papers increased by just 3%, so the rate of collaboration increased substantially. Thus, Japanese companies substantially increased their non-collaborative work while European companies exhibited an enormous increase in collaboration with universities.

This striking increase in collaboration with *domestic* universities by European electronics companies is rather unexpected. During the 1980s, high-profile EC programmes were implemented with the aim of increasing intra-European collaboration. The bibliometric results raise the question of whether those programmes might have had a more local (i.e. national) effect. To check this hypothesis, funding acknowledgements were examined on all available 1989 papers produced by European electronics companies in collaboration with a domestic university. There were 240 papers in total of which 127 were available. Of

these, 50% acknowledged a funding source.¹⁷ Only 6% acknowledged EC funding. Previous work in the biotechnology area indicates that approximately 75% of EC-funded papers acknowledge EC funding.¹⁸ Even if EC support was completely absent in 1980, the subsequent increase in funding from EC programmes could not account for the sharp rise in collaboration with domestic universities by European electronics companies.

Another factor to take into account is that during the 1980s in Japan there were a number of 'third sector' research organisations in areas relevant to the electronics companies. These are co-operative research facilities such as the 'Key Tech Centres' to which companies send employees to work on frontier research. Research papers produced in these organisations tend not to list the company addresses. In European countries, such organisations either do not exist or are less common, and this structural difference may lower the measured rate of collaboration by Japanese companies in comparison to the European. In other words, Japanese companies may have less need to co-author papers because some of their joint research is undertaken in these 'third sector' organisations.

To summarise, collaboration with universities contributes to both the gap and divergence between the rates of co-authorship for European and Japanese industry. There are two main causes. First, intra-European collaboration by European companies forms an extra component in foreign collaboration that their Japanese counterparts lack. Intra-European collaboration grew particularly rapidly over the 1980s. Secondly, European electronics companies dramatically increased the number of papers co-authored with domestic universities during the 1980s while

¹⁶ The number of such papers was 46 in 1980 and 238 in 1989.

¹⁷ This is a slightly higher percentage giving such acknowledgements than general papers. The acknowledgements in papers immediately after the examined papers were also checked. Of 79 non-American papers, 24 or 30% acknowledged their funding sources. By contrast, 61% of the 28 American papers acknowledged their funding sources.

¹⁸ Grant Lewison (Policy Research in Science and Medicine, Wellcome Trust), personal communication (1994).

Japanese companies sharply increased the number of papers published without an institutional co-author. The net result is that the rate of collaboration with domestic universities diverged sharply for this sector.

4. Conclusions

These Japanese and European companies boast substantial research capabilities, publishing large numbers of papers in the international scientific literature. Although our data are limited to 3 years, there seems little doubt that the firms increased their published output over the 1980s, notwithstanding the recession's apparent effect in Europe early in the decade. They publish in similar scientific fields, and in both the pharmaceuticals and the electronics sectors firms have increased their degree of research specialisation. Even allowing for the shortcomings of our indicator of 'basic-ness', their research seems to be equally basic. The only exception is in the pharmaceuticals sector where co-authoring conventions may differ in Japan, thereby reducing the apparent presence of firms in more applied clinical research.

The implications of these results are two-fold. Firstly, they do not support the idea that the scientific research of Japanese companies is somehow different from that of European firms. The Japanese firms analysed here publish as much as equivalent European companies, their research appears to be as basic as that of their European counterparts and it seems to be concentrated in the same broad scientific fields. Secondly, at the level of scientific disciplines, pharmaceuticals and electronics companies apparently became more specialised in their research during the 1980s¹⁹ – despite the widely held impression of increasing interdisciplinarity and fusion.

Research collaboration increased dramatically

over the 1980s in both European and Japanese companies. However, there is a gap and divergence between the rates of collaboration of European and Japanese companies; that is, Japanese companies collaborate less than their European counterparts and this difference grew over the 1980s. European companies collaborate outside Europe more than Japanese companies do with foreign institutions (although only by a small amount). However, foreign collaboration for European companies contains an extra component (intra-European collaboration) and it is this which accounts for most of the gap between European and Japanese foreign collaboration. Intra-European collaboration increased over the decade, most notably in the pharmaceuticals sector. Although European electronics companies increased their rate of collaboration with European institutions over the decade, the more dramatic change in their collaborations was found elsewhere in that they sharply increased their rate of collaboration with domestic universities over the decade. Japanese electronics companies, in contrast, substantially increased the number of non-collaborative papers. This accounts for a large part of the overall gap and divergence in this sector.

If we interpret these results in light of corporate motives for research collaboration, we could say that during the 1980s European companies were more aggressive in their pursuit of R&D efficiency and/or technical opportunities through research links with outside organisations. In large part, this may reflect differing geographical circumstances. Japanese firms are more isolated which may explain why they collaborated less abroad, while European firms have been increasingly taking advantage of the 28% of world science produced on their doorsteps. However, the striking trends in papers jointly authored between electronics companies and universities lead to the tantalising question: were the European companies pursuing R&D efficiency as their fortunes fell while the level of research in Japanese companies was so advanced that they found fewer technical opportunities in public sector laboratories?

Comparing national research systems at the

¹⁹ Again, the reader is reminded of the limitations involved in our classification of papers into fields on the basis of the journals in which they are published, but none of these should affect the general conclusion drawn here about increasing specialisation.

institutional level using indicators is a complex task because institutional structures vary and cultural differences may also play a part. In this paper, we have made a first attempt by comparing the research output of Japanese and European companies and examining their research collaborations. Our results complement analyses of national systems obtained through other approaches, and our contribution lies in producing internationally comparative benchmarks of firm-level research activity (as opposed to institutional structures). As bibliometric analysis advances, more comprehensive analyses are becoming possible, enabling some of the ambiguities of this analysis to be resolved and a clearer comparison to be made between the differing sectoral structures of national research systems.

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