Policy Sciences **26**: 361–395, 1993.

University-industry research links in Japan

DIANA HICKS
Science Policy Research Unit, University of Sussex, Falmer, Brighton, BN1 9RF, UK

Abstract. Some analysts have argued that research links between universities and industry in Japan must be weak because Japanese universities do not produce high quality science and because regulations restrict links. This article begins by examining the structure and funding of universities and indicators of the performance of Japanese science. The results do not lend support to the view that the universities do not produce research useful to industry. In addition, the system is evolving in directions more favorable for university research excellence. Examining the regulations governing university-industry interaction, and their observance, reveals no insuperable barriers. Thus, it is not surprising that bibliometric indicators suggest Japanese companies collaborate with Japanese academics more than with foreign institutions. R&D managers describe long-lasting relationships with academics, perhaps originating in college days, which continue with mutual benefits and obligations on both sides and provide valuable access to the wider network of the scientific community–access that money alone cannot buy. The stories of individual research collaborations establish the substantive nature of the underlying work, the importance of experimentation performed on university instrumentation, and the crucial role of personnel exchange.

> Question: Japanese firms show great interest in supporting foreign research and apparently only a modest interest in supporting research in the academic institutions at home. Does this indicate some continuing lack of confidence in Japanese research capabilities?
>
> Dr. Kondo: I think that sometimes Japan is criticized for 'buying brains' outside of our country. However, we do this because Japanese universities are not so cooperative with industry. As I said before, faculty have not been permitted to accept outside funds. But the situation is now changing. I believe that, in future, Japanese industry will distribute funds not only outside our country but also inside our country. (Kondo, 1992)

How strong are university-industry relations? This question recurs in policy-relevant analyses of the Japanese science and technology system and seems to be a source of international tension. Most often, the answer supplements a larger argument; no empirical study seems to have focused on this issue. Perhaps for this reason, assessments vary from the rather rare: 'standard image of close co-operation' to the more common: 'unexpected lack of university-industry research co-operation' (NRC, 1989b: p. 9; Okamura, 'Keynote Address,' in NRC, 1989c). Relationships between universities and industry in Japan are generally considered to be more distant than in the U.S. or Europe, in part because Japanese universities are thought to be weaker in research than their Western counterparts (e.g., Fransman and Tanaka, n.d.: pp. 29–31; OTA, 1984). Awareness of possible problems in Japanese university-industry

relations is coupled with the visibility, if not hyperbole, surrounding research relationships between Japanese companies and US universities, particularly MIT with 19 Japanese-endowed chairs and an office in Tokyo (Thrasher, 1991; NSF, 1986b; NRC, 1989c: p. 19). There is a danger that without a thorough understanding of the nature and extent of university-industry relations in Japan, the extent to which Japanese companies depend on foreign universities may be exaggerated. This paper draws evidence from a range of sources to describe the context for, extent and nature of university-industry research relationships in Japan.

The analysis begins by examining received wisdom about university-industry links in Japan. Some authors have traced problems to the low quality university research caused by restrictive organization of universities and their historically low level of funding, along with restrictive Monbusho (Ministry of Eduction) regulations governing university-industry interaction. In this article, countervailing evidence about the current situation and the direction of future changes is brought to bear. Then, the extent of collaborative linkage is discussed using the results of a bibliometric analysis. After this, Japanese R&D managers' perceptions of the nature of university-industry relationships at home and abroad are explored. Finally, short descriptions of the research work underlying collaborative papers are analysed to determine the nature of the exchange between university and company.

1. The current state of university-industry relations in Japan: A literature review

In the early 1980's, university-industry interaction was apparently of some concern in Japan. The American National Science Foundation (NSF) reported: 'a MITI official estimated that Japanese industry in 1983 spent twice as much for research at universities outside Japan as it did at universities in Japan.' Although specific expenditure figures obtained by NSF through personal communication were of dubious quality, many similar comments were subsequently made by Japanese observers.[1] This created general concern that companies found foreign universities to be much more attractive partners for research than Japanese universities. Stenberg believes that Monbusho responded to this by loosening restrictions on university-industry relations in 1983 (Stenberg, 1992: p. 48). It also prompted the NSF in Tokyo to survey Japanese firms about their involvement with U.S. universities. They found that support for research in U.S. universities comes from a small fraction of Japanese companies. They also found that the amounts involved were far below MITI estimates, and an insignificant part of total support for university research in the U.S. In 1984 the NSF found that surveyed companies spent $5.3 million in American universities. This contrasted with the $93.6 million estimate of MITI and the $9.6 billion of academic research expenditure in the U.S. in 1985. Although the NSF noted that Japanese corporate support for research in American universities was 'increasing at a prodigious rate' the Japanese concern would seem to have been somewhat overstated.[2]

If the MITI claim was not entirely well founded, it was certainly plausible. Japanese universities have a reputation for low quality research, and this would seem to make them unattractive research partners for companies. The problems are long-standing, and the Japanese 'have talked and talked about reorganizing for 10 years now' (Professor Fumio Kodama, question in Sun, 1989; NSF, 1985b; Hoshi, 1984). Recently change has begun; substantial new money has appeared and small organizational changes have been made. Reform is in the early stages, and so the following description of the current situation is offered with the caveat that it could become obsolete soon. Problems in the Japanese university system will be described in two categories: operational and financial. Organizational innovations and other changes will be pointed out where appropriate.

Are there organizational barriers to performing high quality research in a Japanese university?

In universities, research staff are organized into *koza*: groups headed by a professor who has substantial control and authority over its members, typically an associate professor, one or two research assistants and graduate students. There may be a shortage of Ph.D. students, partly because industry prefers to hire those with masters level degrees and partly because there are few graduate student fellowships. Post-doctoral positions, short-term appointments for young researchers, are rare. Promotion is based on seniority, and therefore young researchers face a very long, if not permanent, period in a subordinate post with little or no autonomy to pursue their new ideas.[3] The professor applies for and receives research grants. On the other hand, junior faculty do not spend time trying to raise money, and the size of the unit is sufficient to provide personnel for several projects (Yamamoto, 1989).[4]

The complexity of the Japanese university system is not conveyed by such a brief description. Firstly, not every university researcher is in a *koza*. Private universities and the newer national university at Tsukuba are organized differently, and engineering schools tend to be more flexible (National Research Council, 1989b: p. 5). Mention should also be made of four types of research institutes attached to universities. There are eight national inter-university research institutes in natural science fields that require large, expensive facilities or large teams of researchers (Monbusho, 1988: p. 10). Facilities in these institutes are far superior to those in regular university laboratories, and faculty receive as much as five times the funding of regular university faculty (National Research Council, 1989a: p. 8). There are 56 research institutes in the natural sciences attached to national universities. These promote cooperative research and joint use of research facilities by all university researchers. There are 341 'research centres, research facilities of university departments, etc.' located in national universities, an unknown number of which are in the natural sciences. These are small-scale facilities working in specialized areas such as molecular beam epitaxy that need expensive equip-

ment. Finally there are approximately 80 research institutes in the natural sciences attached to private and public universities (Monbusho, 1988: pp. 9–11). These various types of centers encourage co-operative or inter-departmental research and the sharing of costly research facilities and therefore are a more flexible element in the system. RCAST, a research center at Tokyo University established in 1987, extended this flexibility by introducing fixed-term appointments and by establishing industry-endowed chairs (Stenberg, 1992).

Japanese observers report additional obstacles to producing high quality research, including the limited mobility and resulting 'inbreeding' of researchers[5] and inflexible, bureaucratic rules governing research expenditure. For example, it is virtually impossible to hire staff on a research grant, including full-time secretaries and technicians. The ratio of technical staff to researchers decreased from 0.85 in 1965 to 0.31 in 1985. Young researchers and students thus are spending more time on chores that could be done by less qualified people (Yamamoto, 1989). Apparently so do professors. K. Matsubara, director of Osaka University's Institute for Molecular and Cellular Biology and one of Japan's leading biologists, must answer his own telephone and do much of the mundane lab work (Sun, 1989). On the other hand, Japanese professors may find it easier to travel abroad than their American counterparts; despite the lack of a sabbatical system in Japan they may draw two salaries and do not compromise their tenure while abroad (National Research Council, 1989a: pp. 8–9).

The severity of the financial regulations, and the manoeuvres used to circumvent them can be illustrated with two examples reported in *Nature*. The first is delay in disbursement of the Science and Technology Agency's (STA) 'special promotion funds' such that, in an extreme case, two researchers at the Fermentation Research Institute were forced into a manic spending spree to dispose of one year's grant money in less than two months (Swinbanks, 1991a).[6] They received their grant very late, but had to abide by the rule that the money be spent before the end of the fiscal year. University researchers must endure extra bureaucratic delays to obtain these funds because they cannot receive special promotion funds directly but must feed them into a national laboratory first.[7]

A second example concerns K. Kawano, a researcher at a national laboratory, who in 1991 was awarded a grant by the Human Frontiers Program (Swinbanks, 1991b). He had 'the dubious privilege of being the first person from a Japanese national laboratory to get a Frontier grant. As such, he [had] to blaze a trail through bureaucratic red tape to get his award.' The problem is that funds for national laboratories come from one pool into which Kawano's grant would be credited, thus losing its identity and association with Kawano. Furthermore, Ministry of Finance procedures mean that funds would have to be displaced and eliminated to make room.[8] The MITI-devised solution is for Kawano to place the funds in his personal bank account, buy supplies, fill in more forms and bring the supplies to the laboratory. MITI even devised a way

round the limitation on hiring technicians. One key reason this plan will work is that the Ministry of Finance has already issued a special exemption from personal income tax for such funds. This exemption was won by MITI and STA for a university researcher who received Human Frontier funding in 1990. Monbusho regulations prohibit universities receiving 'foreign funds' directly.[9] Again, the solution was to place the money in the researchers' bank account but this made them liable to 40–50 per cent personal income tax. STA and MITI first tried to get Monbusho to change its regulations; Monbusho refused, but 'extensive efforts' and 'vigorous persuasion' did prevail with the Ministry of Finance (Swinbanks, 1990a).

A final obstacle to producing top class research in a Japanese university is the peer review system which according to senior scientists is seriously flawed. It is reported that a small number of referees grade hundreds of applications by mail, in more fields than they can possibly know in detail. Reviewers are generally older people, less likely to be in touch with new science and not active in bench research. There is also a conservative tendency to discard work that has not been done before abroad (Sun, 1989). A report of the review procedure for Monbusho's 'special distinguished' and 'priority' research grants describes a 'depressing' interview process that was no more satisfactory. Committee members seemed not to understand the proposed research, and the applicant suspected he was successful because he had met two of the committee members before and because he produced an article from a foreign journal that praised his work. In the Human Frontiers program, foreign applicants, used to the American system, were furious that they were not told why their applications were rejected (Swinbanks, 1989b).

Japanese universities, then, suffer from an excessively hierarchical departmental structure, too much bureaucracy and a flawed peer review system. This probably hobbles Japanese researchers in the public sector, handicapping them in comparison to Americans and Europeans in the race to produce new scientific results, and thus making them less attractive partners for industrial research collaboration. Innovations are being introduced into the system, however. Competitive grant schemes targeted at younger and foreign researchers and short-term posts have been introduced. (These include ERATO and the International Frontier Research system at the STA Institute of Physical and Chemical Research (RIKEN).) In addition, the national laboratories have created their own graduate school to award PhD's for work done in the national laboratories (Swinbanks, 1988a; Maddox, 1991). Tokyo University leads the reform of the universities, having introduced a graduate school of sciences. The school aims to enhance research by concentrating power and funds in the graduate, as opposed to undergraduate, schools. *Koza* are also being redesigned to become multidisciplinary groups of 15 to 20 researchers with only four permanent members (Swinbanks, 1991d). Tohoku University's president developed and publicly admitted plans to bring STA and MITI money into the university, thus chipping away at a major impediment to university research (Swinbanks, 1990c). These as yet localized and

limited reforms indicate that over time, probably over a generation, the system may evolve into a form more conducive to research excellence.

Is the level of research funding low?

Operational impediments are not the only obstacles faced by a bright young Japanese scientist with a good idea for a research project. The chronically low level of expenditure on university research in Japan means that adequate resources might not be available.

Although many operational factors relate to the distribution of money, the level of expenditure on Japanese university research merits separate attention as a possible cause of low quality research. Analysts have argued that Japanese university-industry links are weak in part because of the quality of research. They tend to make statements similar to the following: Monbusho distributes to each *koza* a roughly equal amount of money.[10] The egalitarian nature of the *koza* funding may be problematic in that it does not reward excellence. On the other hand, group leaders do not have to spend all their time writing grant proposals. The sum is small and generally insufficient to support a high level of research. Competitive grants are available, but the amount of money devoted to these is low (see for example: Sun, 1989; Stenberg, 1992; Dibner, 1989: p. 51).

In this type of argument, the Japanese university system is, implicitly or explicitly, being compared with the American system to arrive at the judgment of expenditure being 'small' or 'low.' However, the Japanese system is funded differently than the American and is in this respect similar to European university systems. In this section, I will first clarify the nature of government support to Japanese universities and then discuss the overall level of support.

In the American system, core funding (called general university funds, or GUF, and distributed relatively evenly among faculty) plays a much smaller role than it does, for example, in German or British universities. Correspondingly, competitively awarded grants play a much larger role in the American system. Table 1 reports the percentage of government funding for academic research that comes from core funds, or GUF, in six countries. The table indicates that the Japanese and American university systems are of fundamentally different types. Therefore, comparison with the American system is not a sound basis from which to conclude that the amount of money available for grants in Japan is 'low.'

The core funding of U.K. universities traditionally paid for staff salaries and office expenses, providing a 'well-found laboratory' in which it was possible to conduct research. Competitively awarded grants were to pay for a post-doctoral positions and particularly expensive pieces of equipment. During the 1980's, the percentage of total university funding accounted for by core funding decreased, and the percentage accounted for by competitive

Table 1. Percentage of government funding for universities in the form of general university funds – 1987.

United States	**24%**
France	49%
United Kingdom	72%
Japan	**74%**
Federal Republic of Germany	74%
Netherlands	76%

Source: Irvine et al., 1990: table 8.2.

grants increased. The result is that GUF no longer provides enough for a 'well-found laboratory,' and research must be funded by acquiring grants. The trend was similar in Japan. As a result, GUF in the U.K. decreased from 80 percent of academic research funding in 1975 to 72 percent in 1987, and in Japan decreased from 77 percent in 1975 to 74 percent in 1987. In both countries academics are critical of these changes (Yamamoto, 1989).

These differences between funding systems and the recent changes mean that the only legitimate international comparison is of *total* funding for academic research. The figures provided by Irvine, Martin and Isard indicate that government funding of the university system in Japan is low by the standards of industrialized countries. Although expenditure increased in the 1970's, it did not increase much subsequently. Table 2 reports the expenditure on academic research in six countries in absolute terms, as a percentage of GDP and per capita.[11] The table indicates that the Japanese government spends less on its universities, relative to the size of the country, than any of the other five countries listed (except on expenditure per capita converted to common currency using official exchange rates, where the U.K. falls below Japan). The key observation is that, although the level of funding in Japan is low, it is not orders of magnitude below that in other countries as comparisons with competitive grants in the U.S. might suggest.

These funding figures should not be taken as the last word. Years of complaints, committee discussions, White Papers, and publicity at last seem to

Table 2. Expenditure on academic research – 1987.

	As percentage of GDP	Per capita - PPP exchange rates	Per capita - official exchange rates
Netherlands	0.44	53	64
FRG	0.35	47	62
United Kingdom	0.30	36	34
United States	0.29	53	50
France	0.27	35	44
Japan	**0.21**	**28**	**38**

Source: Irvine et al., 1990: tables 8.4, 8.5, 8.6.

have had an effect. In the April 1992 revision of the General Guidelines for Science and Technology Policy, the government committed itself to doubling 'its R&D investment as early as possible' (NSF, 1992). The Ministry of Finance awarded Monbusho substantial new money in the 1993 budget. As reported in *Nature*, the budget included $800 million to renovate the universities over the next five years, exceeding Monbusho's $600 million request. There was a 10 percent increase in the budget for competitive grants, extra funds for scholarships and fellowships for graduate students, and a new program of teaching asistantships for young researchers.[12]

Is the level of funding for Japanese research low? Comparing the amount of money available for competitive grants in the U.S. and Japan is invalid; comparing the total university funding in various countries is far better. Even on this measure, Japan is low in international terms, though not by an order of magnitude as the standard analysis would suggest. Furthermore, this may be changing.

Do the Japanese produce low quality science?

The organizational problems and the relatively low level of expenditure are said to be the cause of a low level of scientific performance by Japanese universities. This in turn supposedly makes them unattractive partners for industrial collaboration. Before turning to a discussion of the other cause of distant university-industry relations in Japan – restrictive regulations governing university industry collaboration – I will examine evidence about Japanese scientific performance to see if it is really as weak as is believed.

The evidence discussed here are indicators compiled from the *Science Citation Index* (SCI) database. This is a fairly standard source for bibliometric indicators, used by the U.S. National Science Foundation in its *Science and Engineering Indicators* series and by the Observatoire des Sciences et des Techniques in its *Science & Technologie Indicateurs.*[13] One caveat is attached to the following analysis. The number of papers from Japanese universities in the SCI is unknown. What is measured is the output of Japanese science as a whole, including contributions from companies, hospitals and non-profit organizations. These other contributions to national scientific output are substantial, and may have exhibited different trends than Japanese university output. One study of four databases (excluding the SCI) reported percentages of papers published by Japanese universities in 1985. The four values ranged between 58 and 77 percent. Unfortunately the sectors were identified using the rather unreliable method of counting keywords on-line (Negishi, 1990).

The Japanese are increasing their contributions to the international scientific literature, and their work is having an increasing impact on international science. From 1973 to 1986, the Japanese share of the world's scientific literature increased steadily from 5.3 percent to 7.7 percent, overtaking France,

West Germany and the Soviet Union to come third behind the United States and United Kingdom. From 1973 to 1984 the number of Japanese-authored papers increased by 53 percent (NSF, 1991: p. 91; Narin and Frame, 1989). A bibliometric study by Monbusho based on four different databases, which used the slightly unreliable method of on-line searching for country names in addresses, found that in certain subfields the volume of Japanese publishing had overtaken that of the U.K. by 1986, so that Japan ranked second behind the United States (Monbusho, n.d.).

The Japanese contribution to the world's scientific literature may be increasing, but some question the quality of this work (Swinbanks, 1987b). One indication of quality may be obtained by restricting the counts of publications to the most prestigious journals. Papers with at least one author from Japan and published in 24 of the world's leading scientific journals increased in number by 'over 50 percent during the 1980's – from a 3.3 percent share at the beginning of the decade to a 5.1 percent share by the end of the decade.' Chemistry and physics were the strongest subjects and medicine, the weakest. Japan's share of papers in *Nature, Science* and *Cell*, the three leading journals in biology, did not increase significantly, perhaps because Japan is not especially active in subjects, like developmental biology and molecular genetics, most often covered by those journals (*Science Watch*, 1990). The message obtained from counts of papers in prestigious journals is mixed – improvement overall, but not in the most prestigious (or fashionable) areas of biology.

A similarly mixed message is obtained from citation indicator data. During the 1980's, Japan's mean citations per paper placed it 15th among nations publishing more than 10,000 papers. This ranking is rather low in part because Japan publishes a relatively large fraction of its papers in physical, chemical and earth sciences. These fields tend to have lower average rates of citation than the biological sciences. The Japanese citation ratio (0.88) for all fields in 1984 was lower than that for France, West Germany, the U.K. and the U.S. Japan's strongest fields were engineering and technology (1.16), chemistry (1.12) and earth and space sciences (1.06). Only in engineering and technology did Japan rank as high as second.[14]

When measured by citations per paper relative to the world average, the impact of Japanese science did improve during the 1980's. Overall, Japan showed a 2.2 percent improvement in this indicator over the decade though West Germany (+3.6 percent) and the U.S. (+6.9 pecent) did rather better. At a more detailed level, Japan's improvement in citation impact in the physical, chemical and earth sciences (+12.4 percent) surpassed that of other leading nations. In engineering, technology and applied sciences, the relative citation impact fell (−5.1 percent) while that of most other nations increased. This is still Japan's strongest area, since its papers collected between 11 percent and 17 percent more citations than the world average. In the life sciences (+1.4 percent), agricultural and environmental science (+1.1 percent) and clinical medicine (+8.1 percent) relative impact increased, though not as much as that of France, Italy, and West Germany. Only the U.K. did worse in each area.

Japan also has more extremely highly cited papers in the life sciences than expected. This goes against the general pattern of stronger Japanese citation performance in engineering, technology and applied science (*Science Watch*, 1991a, 1991b, 1991c, 1991d, 1992).

Overall, citation indicators point to relatively stronger Japanese performance in engineering, technology and applied science than in other areas. Although Japan improved somewhat over the past decade in citations per paper relative to the world average, so did other advanced industrial countries. Looking at all fields combined, there was no change in the relative ranking of Japan. At the field level, in the physical sciences Japan is now ranked above Italy and is gaining on Canada. In clinical medicine Italy now ranks slightly above Japan on this indicator. In engineering, technology and applied sciences, the U.K. overtook Japan during the decade, while in life and agricultural and environmental sciences there was no change in the relative ranking of Japan.

It should be noted that although Japan's citation impact and its improvement is not unequivocally first class, on each indicator Japan's performance is comparable to that of Canada, Italy, France, West Germany and the U.K. Universities in these countries are not accused of being too poor to have anything to offer companies. Indeed, Japan is strongest in engineering and technology–subjects that would be most useful to Japan's strongest companies, those in electronics and automobiles. No doubt publishing from these companies contributed to Japan's relatively high citation impact in these areas. Internationally comparable information on corporate publishing is available for electrical engineering, one area of Japanese strength. Citations to papers published from 1986 to 1990 in 70 journals were counted. When institutions are ranked by citations per paper, Fujitsu (at 5.4 citations per paper over the period) is secondly only to AT & T (with 7.1) and has a higher score than any university (Stanford being the top university at 5.3). Other firms such as NTT, Hitachi, and Toshiba, fall below GTE, Bellcore, IBM, Rockwell, Hughes, Plessey, British Telecom, Hewlett Packard and GEC, and below the top 25 universities world-wide (*Science Watch,* October 1991: p. 7). Although these companies are well-cited, perhaps their performance is not good enough to account entirely for Japanese strength in engineering and technology. The data, although weakly related to universities per se, do not support the view that university research has little or nothing to offer companies.

Do the regulations governing collaboration prevent it?

The argument that Japanese university research has little to offer Japanese companies is only part of the explanation given for the supposed low level of university-industry collaboration in Japan. Restrictive regulations are said to govern such links. In 1983 Monbusho relaxed its rules and created four mechanisms through which national university faculty could cooperate with

industry: joint research, contract research, secondment of industrial researchers to the university, and donations. The problem with these mechanisms is that much red tape is involved. 'To obtain a small grant of [$8,000] from a company, [a researcher] first had to apply to the company for the grant and then "donate" it to the university. Only after it was "officially" recognized by the university and [Monbusho] could he use the money for research, six months later' (Swinbanks, 1990b). However, these regulations apply only to the 54 most prestigious national universities and not to the 142 public and private universities.[15]

Despite the bureaucracy, Monbusho figures show that since 1983, joint research, secondment and donations have increased rapidly. Table 3 indicates that even as late as 1990, the numbers of joint research projects and secondment, and the amount of money donated were each increasing by 10–25 per cent per year. In 1991 the funds provided by external sources were almost equal to the amount Monbusho provided in research grants (Swinbanks, 1990b). New mechanisms for interaction are appearing; Monbusho has established University-Industry Joint Research Centers in several national universities, and companies can now endow chairs at universities (NSF, 1987; Swinbanks, 1989a).

The effect of the regulations on the level of joint research between industry and universities seems prone to misinterpretation for several reasons. The first is simply that rapid changes have occurred. Interpretations can be easily out of date. For example, the oft-cited 1984, report, *Commercial Biotechnology*, produced by the American Office of Technology Assessment refers to the pre-1983 system (OTA, 1984; quoted in, e.g., Fransman and Tanaka, n.d.: p. 29; Dibner, 1989). Other interpretive problems seem to stem from the imposition of a Western or American framework which leads to an overemphasis on elements of the American system not found in Japan and a deemphasis on elements found only in Japan. In addition, qualitative differences between the Japanese and American systems are not systematically taken into account.

Table 3. Joint research projects and researchers accepted from industry.

Year	Joint Research projects	Researchers accepted from industry	Donations in billion yen
1983	60	70	15
1984	160	180	18
1985	220	250	22
1986	270	320	25
1987	400	460	29
1988	580	700	35
1989	700	840	38
1990	870	1030	43

Rounded to nearest 10. *Source:* Monbusho, 1988; 1992.

Japanese regulations do not allow faculty of national universities to work or consult for companies. This feature is often adduced in support of the thesis that university-industry links are weaker in Japan. In America, all companies having links with universities employ consultants, and one survey found that even at teaching-oriented state colleges, 80 percent of faculty had consulted for industry (Peters, 1982: p. 89; Darknell, 1982: p. 172). Rarely is the lack of consulting in Japan balanced against secondment of staff from industry to university – a formally available mechanism. In 1990, there were 1,031 cases sanctioned by Monbusho. In the U.S., secondment of company staff to perform research at universities (as opposed to adjunct professors who are usually limited to teaching) is in its infancy (Bloeden and Stokes, 1991; Peters, 1982: p. 86). Secondments there seem to last several months while, in Japan, one year may be more typical. Secondment of bench-level scientists is likely to be particularly effective in transferring tacit knowledge and skills from university to company. Such transfer would seem to be more difficult to obtain than the advice of consultants. In Japan, companies can probably obtain advice through informal links and under-the-table payments. There are many opportunities to do so: through donations, payments for seminars and advice, or simply retainers. Such payments are informal, and not reported, either by the companies or by universities. As long ago as 1972, lack of interaction between industry and university was labelled a 'myth' due to the 'long winked-at, underground interaction between professor and industry' supposedly given legitimacy by a revised interpretation of the law in 1971 (Findeis, 1972). In addition, it is reported that there are

> a plethora of professional societies and other information exchange organizations through which university and industry researchers can informally exchange views and research results. Professors have often received small sums of money from industry when their research was of interest, and Japanese professors can work for industry under the auspices of nonprofit agencies, such as the Industrial Research Institute in Tokyo (National Research Council, 1989b: p. 9).

The Monbusho-affiliated Japan Society for the Promotion of Science (JSPS) 'provides a forum for promoting co-operation by organizing Industry-University Co-operative Research Committees on specific themes of technological importance.' In 1988, 39 such committees were active (Monbusho, 1988: p. 22). Undocumented, informal co-operative research interaction without exchange of money also occurs in both America and Japan (Peters, 1982: p. 85). Obtaining precise information about these mechanisms is extremely difficult.

Highly visible in the American system, but even today virtually absent in the Japanese, are large programs of university-industry interaction formalized at the institutional level. Examples include industry-funded co-operative research programs, like the Harvard-Monsanto agreement; jointly owned

facilities, like the University of Rochester Laboratory for Laser Energetics; and co-operative research centers, like the Case Western Reserve Polymer Program (Peters, 1982: p. 16). Consulting is seen as important in the American system, partly because of its prevalence, but also because it is a critical element in initiating these formal programs (p. 59). Analyses of university-industry interaction in America place emphasis on formal programs, although to my knowledge, they have not been proved more effective than informal mechanisms, nor more prevalent. Indeed, analyses of formal mechanisms emphasize the role informal interaction plays in their initiation and success. The emphasis on formal mechanisms can probably be traced to their visibility. Named, publicized and based on negotiated contracts, such arrangements are likely to be familiar to the policy makers, R&D managers and university administrators interviewed by analysts. Identifying formalized arrangements, then, is easier than finding and counting the underlying informal arrangements and far easier than counting informal, even non-monetary, exchange which does not result in a large, formal program.

In Japan, formal institutional interactions are largely precluded. When co-operative research centers are needed – as, for example, with the International Superconductivity Technology Center – they must be established outside universities in the 'hybrid' sector where freestanding organizations enjoy both government support and corporate direction. In the U.S., such a center would probably be located in a university (Lastres, 1993). Not only are large formal programs not permitted in Japan, they may be less necessary. Universities have less need of large amounts of industrial funding because, as in Europe, they receive core funding or GUF (see above). For these reasons, informal, difficult to measure mechanisms will be more significant in Japan, and may be facilitated and more prevalent than in America.[16] Thus Japanese policy makers, R&D managers and university administrators are less likely to be aware of the extent of interaction, making interview-based comparative analysis problematic. However, because assessing the efficacy of university-industry interactions is difficult, and because informal interaction plays a role even in formal programs, the absence of formal programs in Japan should not be equated with distant and ineffective university-industry interaction.

The strength of collaboration between the two sectors is also affected by the attitude of Japanese university staff toward working with industry. University people have objected to working with industry since World War II, and the sentiment was quite strong in the 1960s. That it is still strong today is indicated by student demonstrations at Tokyo University in 1988 against engineering school plans to strengthen links with industry (Swinbanks, 1988b). Faculty objections to working with industry seem to come from the basic sciences. Engineering faculties are known to have a long tradition of working closely with industry. This is interpreted by Western observers to mean that the links between applied science and industry are comparable to those in the West; often it is the links between basic science and industry that are said to be weak. However, this interpretation overlooks the possibility that the work

conducted in applied science or engineering faculties in Japan might be found in a physics department in the United States, making comparison much trickier. In the physical sciences at least, this may be the case, with Japanese physics departments limited to esoteric areas such as high energy physics while engineering departments, for example, work on semiconductor physics, which is generally found in American university physics departments.[17] A more inclusive definition of 'engineering' research coupled with a restricted definition of 'physics' research is consonant with the unusual university funding priorities found in Japan. Physical sciences are usually better endowed than engineering sciences, but in Japan the reverse is found (Irvine et al., 1990: p. 195). The use of departmental names in international comparisons as a proxy measure of how applied the research is may well have to be re-examined empirically.

This section has questioned the extent to which regulations inhibit university-industry interaction in Japan. Assessments should pay greater attention not only to the current situation, but also to subtle yet significant differences between Western and Japanese systems. These differences include the definition of engineering, the use of secondment, and the role of informal mechanisms.

How much money do Japanese corporations contribute to Japanese universities?

In the previous section, Table 3 displayed the growth of the four permitted modes of co-operation with a university, and the figures were assumed to reflect industrial co-operation, but this is not strictly true. This section illustrates the point using available expenditure figures. Ideally, the figures would reveal how much is spent by companies in universities and what percentage of university research expenditure is accounted for by corporate funding. Unfortunately, this goal can only be approximated. In Table 4 available expenditure data are displayed. The data include: (1) expenditure under the four co-operative mechanisms in 1988; (2) amount budgeted for Monbusho grants in 1988; (3) amount of purely corporate funding for universities (as reported in the *Report on the Survey of Research and Development* or RSRD); (4) Irvine et al. figures for 1987 total national university expenditure, both separately budgeted (grants and institute funding) and general university funds (core funding).

In 1988, co-operative funding amounted to almost 70 percent of Monbusho grant funding. Co-operative funding in 1988 was 6 percent of 1987 total funding.[18] Interestingly, the total spent under Monbusho co-operative mechanisms exceeds that for purely corporate funding reported by universities.

That corporate funding of national universities is less than funding under the official co-operative mechanisms indicates that these figures should be

Table 4. 1988 expenditure under Monbusho university-industry co-operation mechanisms (Monbusho, 1988).

Mechanism	Billion yen	Percentage of total
Seconded researchers	0.3	0.9%
Joint research	3	8%
Contract research	6	17%
Donations	25	74%
Total	34	100%
Monbusho research grants	49	
Corporate funding of national universities	22[19]	
Academic separately budgeted – 1987	176[20]	
General University Funds – 1987	402	

(Figures have been rounded and therefore percentages do not add to 100.)

interpreted with caution. University co-operative research mechanisms do not equate with industrial funding of university research, firstly, because non-corporate contributions are included and, secondly, because corporations find other ways to contribute to universities. Corporations are not the only users of co-operative research mechansims; others, including local government and special corporations, also contribute to universities this way, though corporate contributions dominate the figures. For example, in 1987 there were 396 joint research projects, of which 41 (10 percent) did not include a corporation. Co-operating institutions included prefectural or municipal governments, national laboratories like RIKEN or the National Space Development Agency (NASDA), co-operatives, foundations and 'third-sector' institutes such as key-technology centers or the Japan Atomic Energy Research Institute (JAERI) (NSF, 1989). In addition, co-operation with Monbusho institutes such as KEK (high-energy physics laboratory) takes place under these mechanisms. This explains why the 22 billion yen corporations spent in national universities (as listed in the *Report on the Survey of Research and Development*) is smaller than the 34 billion yen expended under the formal co-operative mechanisms in 1988. Total extramural finance in national universities was substantially larger at 60 billion yen.

Money is also exchanged outside the four official channels, in part because many universities are not subject to the rules on account of not being national universities. The RSRD survey of universities reports that in 1989 companies provided 36 billion yen to Japanese universities. Seventy-three percent of this went to national universities, and thus companies do rely primarily on national universities, despite the somewhat burdensome regulations. University expenditure, which includes teaching expenses, is divided into extramurally and intramurally financed, and corporations accounted for 27 percent of the extramural finance at all Japanese universities; at national universities they accounted for 39 percent of extramural finance (Statistics Bureau, 1989: Table 3). At national universities, this amounted to 4 percent of university

research and teaching expenditure. In the United States in 1989, companies accounted for 6 percent of total university R&D (not including teaching) expenditure (National Science Board, 1991: appendix table 5.3). The figures are remarkably similar considering that the Japanese total expenditure includes teaching. One might also expect a larger difference because Japanese academics, like Europeans, can rely on general university funds to a far greater extent. It is impossible to know what percentage of the corporate contribution to universities is accounted for in these figures. Gifts of equipment or samples will not be recorded, nor will money passed 'under-the-table' – for example, large payments to professors for lectures at a company in lieu of consultancy.

Use of Monbusho co-operative research mechanisms has been growing quickly. This does not, however, accurately reflect university-industry interaction, as much interaction takes place outside these channels and because links with government institutes are included in the figures. Internationally comparable figures for percentage of university research financed by industry are not available at present. There seems to be little difference between Japan and the U.S., however, if available figures are examined and the differences between the two systems and the two statistics are kept in mind. One of these differences is that unreported, informal interaction could well be more significant in Japan than in other countries.

Summary

This description of the environment for university-industry collaboration in Japan indicates that certain common assumptions may be inaccurate. The university organizational structure may be restrictive, but it is changing. Funding may have been low, but substantial increases have been awarded. Neither of these problems seems to have prevented Japan overcoming linguistic, geographical and cultural isolation to increase its profile in the international scientific literature and attain size-adjusted citation rates at least comparable to those of Canada, Italy and France. Hence, there is no quantitative evidence that Japanese university research is so bad as to be of no interest to companies. After Monbusho relaxed its regulations, use of formal mechanisms of interaction grew dramatically, though informal mechanisms probably remain more significant. Although the strongest links may be with departments of applied science, one should avoid the easy assumption that the research in question is more applied than that of American university physics research done in collaboration with industry. Funding figures are not at present internationally comparable. Available, incommensurable data indicate that the level of corporate funding in Japan and the U.S. does not differ dramatically. Thus, in assessing the contribution of Japanese universities to corporate research, anecdotes about badly equipped laboratories need to be supplemented with more systematic evidence. In the remainder of this article, I will

discuss and interpret one such piece of evidence: the number of industrial papers co-authored with university researchers. I will first describe how the quantitative and interview data were collected, then present the results, which will be interpreted using information about the conduct of the joint experiments.

2. Empirical evidence

Bibliometric method

The quantitative data to be discussed in this paper concern the published scientific output of 28 Japanese companies. The firms in no way represent the entire population of Japanese companies, the vast majority of which publish few or no scientific papers. A company that performs science must have extra money, must use one of the more science-based technologies, must believe long-range research can result in profit, and must be open enough to allow publication of its discoveries. Few companies fit this description. Thus, these companies differ from those studied by researchers focusing on innovation or industrial policy who tend to frame studies around industrial sectors – in Japan often automobiles or electronics. The companies include the top ten R&D spenders during the late 1980s, companies that published more than 100 papers in journals covered by the *Science Citation Index* (see below), and others with a reputation for performing basic research. They are: Ajinomoto, Asahi Chemical, Asahi Glass, Fuji Photo Film, Fujitsu, Hayashibara Biochemical, Hitachi, Kao, Kirin, Kobe Steel, Kyowa Hakko, Matsushita Electric Industries, Mitsubishi Electric, Mitsubishi Kasei, Mitsui Toatsu, NEC, Nippon Steel, Nissan, NTT, Sagami Chemical Research Center, Shionogi, Sony, Sumitomo Chemical, Sumitomo Electric Industries, Suntory, Takeda Chemical Industries, Toshiba and Toyota.

The scientific papers published by these companies and listed in the *Science Citation Index* (SCI) were counted in the years 1980, 1984, and 1989.[21] This database aims to include the addresses of all co-authoring institutions; thus co-authored scientific papers could be analyzed. Co-authored papers were counted whole – that is, the numbers and percentages reported are the numbers and percentages of papers with a co-author from, say, a Japanese university. For example, a paper listing the addresses of Toshiba, Ricoh, Tokyo University and MIT, adds one paper to seven different totals, namely counts of collaborations with companies, universities, Japanese institutions, foreign institutions, Japanese companies, Japanese universities and foreign universities. The counting method generates figures for the percentage of papers co-authored with various sectors, for example Japanese universities. These should be interpreted as reflecting the rate of successful research collaboration between the companies and other institutions.[22]

Bibliometric analysis of international and domestic co-authorship

Earlier I argued that formal, institutional-level interactions are largely precluded in Japan. Permitted interactions and informal, under-the-table mechanisms link researchers in universities and companies. Such personal interactions are impossible to measure in their entirety even within one country; international comparison is extremely tricky. The measure investigated here – jointly authored scientific papers published in the international scientific literature – does capture informal, even non-monetary, research exchanges and permits international comparison. The interactions captured are a sample from across the entire company, rather than those prominent in the memory of one or two informants. The indicator reflects successful, substantive interactions that produced published, refereed papers.

Of course, the indicator is imperfect. Published papers do not capture all types of research interaction. Relationships may produce proprietary, unpublishable results, or they may fail to produce a paper yet aid the company's research effort in the longer term. Fleeting, day-to-day interaction such as advice given over the phone or at conferences is also important but not necessarily captured by the indicator. The indicator is an imperfect reflection of even successful publishable research interaction for several reasons. An ongoing relationship may not have produced papers in the particular years examined here. English-language publication practice differs between countries (Hicks et al., 1992), and publication and co-authoring practice varies. Six percent of British papers with more than one university address list more institutions than authors (Katz, 1992). Such papers reflect something other than simple joint research and reveal clearly that complex and varied phenomena underlie co-authored papers. Therefore, the publication indicators are partial, and interview material is also brought to bear. It should be noted that none of the data reveal whether a company's technological development benefitted from its researcher's links with academics.

In spite of their weaknesses, the quantitative data are particularly interesting because they contradict the idea that Japanese companies have abandoned Japanese universities and rely on links with American universities, particularly MIT, to supplement their in-house research. Table 5 reveals that

Table 5. Percentage of papers produced collaboratively.

Year	Number of papers published	Percentage of paper co-authored with:		
		Any type of institution	Japanese universities	All foreign institutions
1980	1727	20	12	1
1984	1873	25	16	2
1989	2942	33	21	6

in each of the three years examined, the companies co-authored a substantially larger portion of their papers with Japanese universities than with all types of foreign institutions from any country. In 1989, for example, 21 percent of the papers were co-authored with a Japanese university and 6 percent were co-authored with a foreign institution.

These percentages are calculated from the total number of papers published by the 28 companies. However, this total is dominated by the two largest companies which between them produced approximately one-third of the papers in 1989. Therefore, in Figure 1 the percentages of papers co-authored with a Japanese university and foreign institutions are displayed for each company individually. In this graph, 'U' marks the percentage of papers produced in collaboration with all Japanese universities, and 'F' marks the percentage of papers produced in collaboration with all foreign institutions. The number along the x-axis is the number of papers the company produced in 1989, and companies are ordered by this number. In each case, more papers were co-authored with Japanese universities than with foreign institutions. The unweighted average rate of collaboration across all companies was: 29 percent of papers co-authored with a Japanese university and 5 percent co-authored with a foreign institution.[23]

The prominence of national universities among the collaborative partners indicates the regulations governing national universities do not block links with industry. Seventy-six percent of the Japanese universities with which the companies co-authored papers were national, and national universities get 73 percent of corporate funding of universities (Statistics Bureau, 1989: Table 3, Summary). In part, this is because they are more research oriented than the public or private universities. Although the 96 national universities comprise 20 percent of the 475 Japanese universities, they are 28 percent of the more research-oriented universities which grant Ph.D. degrees, and they employ

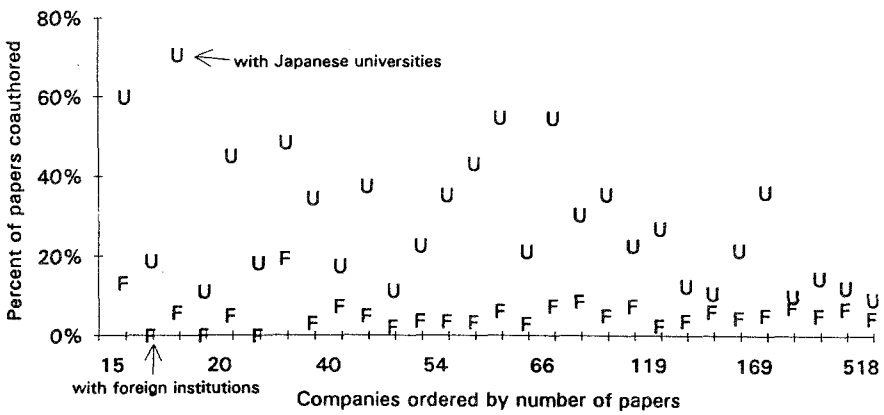

Fig. 1. Do the companies work more with Japanese universities than with foreign insitutions? 1989.

55 percent of the university staff engaged in R&D (Monbusho, 1988; Statistics Bureau, 1989: Table 1, Universities and Colleges). However, corporate research links are even more concentrated in national universities than are R&D personnel. When collaborating universities are ranked by number of companies with which they have links, the top 10 are national universities. University of Tokyo (24 companies) is number one followed by Osaka (23) then Kyoto and Tohoku (16).[24] This evidence suggests that Japanese firms rely on the domestic publicly funded research infrastructure much more heavily than they do on foreign research infrastructures.

Recent research into co-operative relationships in Japan's superconductivity industry confirms the hypothesis of strong university-industry relations. Hane found that Japanese universities helped firms diversifying into high temperature superconductivity. Firms new to superconductivity tended to file joint patent applications, while those in the traditional superconductivity industry tended to file independent applications. When examined, 58 percent of high temperature superconductor (HTS) joint patent applications were found to list a university partner; this contrasted with 14 percent in the traditional low temperature superconductors. Hane also surveyed the 60 professors involved in Monbusho's superconductivity research program about their research links. All 30 respondents reported some form of collaboration with another organization. Of all the collaborating institutions reported, a little over half were firms or private laboratories. Hane concludes: 'the large university presence in HTS collaborations reflects their often underestimated role as sources of frontier research from which the industry can learn' (Hane, 1991: pp. 228–241).

The different rate of university-industry collaboration in high and low temperature superconductivity is significant because high temperature superconductivity presumably is more science-linked than the older low temperature superconductivity. Biotechnology is another science linked technology, and analysts of biotechnology have concluded that Japanese industry will be disadvantaged in world competition by weak university-industry relations because such links characterize research in other countries. However, Fransman et al. surveyed six Japanese biotechnology companies on the importance of six 'external channels of technology transfer' and found that four companies ranked Japanese universities first (Fransman and Tanaka, n.d.: Table 8).

In brief, university-industry research links in Japan are extensive and significant. In particular, Japanese companies perform a substantial amount of their non-proprietary research in collaboration with Japanese universities and research collaboration with foreign institutions is much less frequent. However, this tells us nothing about the scale, form and content of the research relationships, and there may be a qualitative difference between the domestic and foreign collaborations. The remainder of this paper will explore the nature of university-industry relations in Japan and the histories of co-authored papers.

R&D managers' perceptions of university-industry relations

This section describes university-industry relations in Japan as perceived by corporate R&D managers. It is based primarily upon two sources of information: A survey of 149 Japanese firms conducted by the Japan Productivity Center (JPC) and St. Paul (Rikkyo) University in 1990[25] and exploratory interviews with R&D managers at 25 of the 28 firms in the bibliometric study.[26] The interviews explored motives for, nature of, and benefits from research links with universities; the use of official co-operative mechanisms; and the difference between working with a Japanese university and a foreign university.

Although university research is not directly relevant to technological development in many industries, the basic scientific principles and techniques which science and engineering graduates master are relevant in almost all industries (Nelson and Levin, 1986). Therefore, recruiting is central to university-industry relations. In one study of American university-industry relations, interviews were conducted with over 100 top level administrators and 400 scientists, in companies and universities, during the early 1980's. The authors state that: 'The most prevalent motivation for industry co-operation with university is based on the need for qualified science and engineering graduates. This need exists not only for Ph.D.s, but also at the baccalaureate level where the numbers required are much greater' (Peters, 1982: p. 93). In Japan, top quality science and technology graduates are needed not only as researchers and engineers, but as future managers, and the JPC survey indicates that similar motivations exist. Sixty percent of the surveyed companies said that recruiting was the most important type of relationship with domestic universities (Table 6).

The interviews support this. One manager said that his company has asked professors to recommend excellent graduates; the professors asked are those with whom the company has links, official and private – sometimes the pro-

Table 6. Most important type of relationship with domestic and foreign universities.

	Domestic (%)	Foreign (%)
Recruiting		
Source of talent	60	6
Research		
Partner in joint, basic research	18	30
Subcontractor for basic reesearch	13	39
Outside adviser for R&D	6	19
Other	2	6
Total	100	100
Number of responses	149	149

(Figures have been rounded and therefore percentages do not add to 100.)

fessor asks for a contribution to support a meeting he is organizing etc. – so it is a mutually beneficial relationship. Traditionally, professors have had a large say in where their students go after graduation. This, coupled with a shortage of skilled scientific and technical workers, is a key reason why companies establish and maintain relationships with university professors. Some companies never observed the system, relying instead on their reputations to attract recruits. In addition, these days the system is looser, many companies recruit, and graduates do not need to follow the professor's recommendation. Nevertheless, many companies maintain an extensive network of links with professors because there is some benefit in having their name known to students and enabling easy access to company information.

Although recruiting may motivate linkage, research rather than teaching is often the focus. Companies maintaining relationships to bolster recruiting will give small amounts of research money to many professors.[27] Correspondingly, a professor will receive little bits of money from several companies. From the company's point of view, the resources are small, so they do not expect research results. From the professor's point of view, the money adds up and materially aids the research, but without obligation. Companies may instead, or in addition, send staff on secondment – accompanied by necessary equipment and money. One manager emphasized that what occurs in any particular research collaboration is less important than the network, the connections with universities. Students come to the company from professors who are friends of the company. Most of the company's executives graduated from good universities; so professors there ask to use company equipment or people and the executives find it difficult to say no when '*sensei*' makes a request.[28]

Note here that companies do indeed see themselves as maintaining relationships, non-contractual to be sure but nevertheless long term, mutually beneficial bonds that also entail mutual obligations. Relationships between students and their former professors and between university classmates are maintained and help shape the institutional nexus. Therefore, although companies have the money, they cannot simply dictate the terms of the relationship. The more eminent a professor, the more he can extract from the company. For example, one company wanted to enter high temperature superconductivity and asked to place a person in a professor's laboratory to learn about the area. The professor said, in essence: 'Fine, as long as you send me back my former student.' In another case, a company was supplying sensitive sensors to an observatory when the professor asked for the employee who had made the sensors. So now the former company employee works for the university and will ask the company for free sensors. Given the bureaucratic restrictions on hiring staff in universities and the lack of post-docs (noted above), it is not surprising that professors request staff secondments from companies. As indicated above, requests are not limited to staff or use of equipment; money for organizing meetings or for travel can also be extracted.

Not all secondments to Japanese universities are at the request of profes-

sors, however. As the superconductivity case above indicated, companies initiate secondments when management decides to do research in an area but does not have the skills. Firms send people to universities to learn through undertaking research. This can be the main reason some companies send people to universities and perform joint research. The relative importance of secondment in Japan can probably be traced to three causes. First, companies staff their laboratories primarily with bachelors and masters degree recipients, not PhD's; so further training is often useful. Second, companies can afford to pay for time at a university because they benefit; seconded employees generally return to their company and remain there. Third, if a company is trying to diversify through R&D (merger and acquisition being frowned upon in Japan) it needs to acquire competence in new areas, and sending staff to do research at a university is one way of achieving this. Companies also initiate joint research to get access to technology, reduce risk, and stretch limited resources, both people and money. They even, in fact, obtain research results from Japanese universities (see below). But we must keep in mind the statement of one manager who noted that Japanese companies do not always look at the benefits in such 'hard terms,' because research collaboration provides 'seeds' at the personal and organizational level, and research needs a lot of communication and relationships, both of which benefit from the type of university-industry links maintained in Japan.

Accordingly we cannot dismiss research relationships with universities as unproductive and solely based on recruiting needs. Recruiting is not the sole motivation in all cases. The JPC survey confirms this; for 40 percent of the firms, research relations with universities are the most important type of relations (Table 6).

Are all transactions between companies and national universities conducted under the terms of the Monbusho regulations described above? This question is crucial for any analysis that compares the strength of university-industry relations in Japan and other countries because many Western assessments are based on describing the limits of these mechanisms. The most obvious limit – that professors, as civil servants, are not allowed to serve the interests of specific companies – precludes consulting. However, these regulations may be the *tatemae*[29] of university-industry relations, as one R&D manager described them. I argued earlier that informal links are likely to be more important than elsewhere. The interviews support this assessment. When R&D managers were asked whether other mechanisms existed to pass money to universities, it seemed that there were, though people were vague, probably for political reasons. The managers certainly did not like the regulations governing university-industry relations. They were queried in particular about the mechanism most obviously related to co-authored papers – 'joint research with industry' or *minkan-tono kyodo kenkyu seido*. This seemed to be universally disliked. One manager said that they rarely used it; individual universities apparently have their own schemes for accepting money from companies; Monbusho did not know that companies did not like to prepare compli-

cated documents, but universities did. Another said that they typically work outside the Monbusho system; if a very good professor was in the system, then they used it; but overall the system was not so important for their company.

It is not surprising the system is disliked; the procedures seem particularly tortuous and bureaucratic. Each project must be approved by the host university's president on the recommendation of a faculty council, after which the university asks Monbusho to provide funds; and if the project lasts more than one year, new requests must be submitted each year. The corporate funds are paid into the national treasury, with an equivalent amount provided to the university by the government.

Quantitative evidence confirms the dislike of this mechanism. Joint research accounted for only 8 percent of the co-operative research expenditure in 1988 (see Table 4). Although it is the co-operative mechanism most obviously related to co-authored papers, in fact joint research bears little relation to co-authored papers. List of joint research projects funded in 1987 and 1988 were compared with lists of co-authored papers. In the two years preceding publication, the companies had joint research projects at only 15 percent of the national universities with which they co-authored papers in 1989.[30] By far the most popular mechanism is donations. Donating money may be a less bureaucratic process and may therefore be used to support collaborative research, but lists of donations were not available (nor were lists of secondments or contracts), so this could not be checked.

Earlier I noted that university-industry relations played a substantial role in the high-temperature superconductivity research of Japanese firms. Did these firms use the joint research mechanism to cooperate with universities? Hane found that only one of the 60 professors in Monbusho's superconductivity research program had hosted a joint research project. When asked about the possible mechanisms for collaboration, industrialists and academics said joint research was:

> the most troublesome because of the need to define boundaries and negotiate the division of proprietary rights. Co-operative R&D also means that the industry must make a contribution. As many firms diversifying into HTS were new to superconductivity and had relatively small programs, they were not in a good position to participate through this form of collaboration.
>
> Rather than engage in a [joint research project], most firms prefer to dispatch researchers for general training or to set up a contract research agreement with the professor and his students for specific research to be done. This latter option was also seen as an important scheme for recruiting good graduates to the firms. Both of these routes were considered more straightforward (Hane, 1991: p. 238).

The impossibility of a company having an exclusive relationship with a professor (again due to their status as civil servants) is thought to hamper university-industry relations. Interestingly, two managers interviewed in this study mentioned this, and they expressed opposite views. One was dissatisfied that faculty could not work for one company only, that they also work for competitors; this precluded 'deep' relationships. The other explained that networks of contacts were very important in Japan. Good professors had a great deal of information about academic societies, government ministries (like MITI or STA), companies and foreign universities. They therefore developed broadly based insights into, for example, the future direction of a technology. Managers who cultivated friendships with such professors could benefit from their knowledge, though attempting to obtain information on specific companies would destroy the friendship and break the linkage. Professors could also bring together companies that would profit from doing joint work, like arranging a marriage. For example, with graduates in two companies working on converging research projects, a professor could suggest to the former students that their companies might like to get together. In addition, key professors received new equipment donations from manufacturers, who used the university's name in advertising. Other companies seconded people into the laboratories of famous professors and they watched how the equipment was used and told their company to buy it. So the laboratories of good professors get the newest machines; the professor is very important. Clearly, the effects of the regulations are not straightforward.

The JPC survey indicated that research relations with foreign universities are rather different, primarily because recruiting plays a very small role (Table 6). The interviews pointed to further differences. Collaborating with foreign universities seemed easier than collaborating with Japanese universities. Managers said they search out excellence abroad, and were aware that there was more of it abroad than at home. Collaborating with foreign universities was more expensive (in Japan companies do not pay for salary costs but in America they do) and foreign universities were more business-like, the collaboration being based on a contract. Connections with MIT were often mentioned in this regard. The companies therefore had higher expectations of useful research results from foreign universities.

As mentioned earlier, companies second researchers to Japanese universities. Similarly, every company visited seemed to have a formal program to send researchers to a foreign university for a year or so. In the JPC survey, companies were asked to indicate which mechanisms they used to cooperate with foreign universities and research institutes. The report did not tell us how many companies second employees. What we do know is that of 467 responses, 67 percent involved dispatch of employees, including some joint and subcontracted research. The remaining mechanisms were participation in 'open' university programs, and subcontracting and joint research without dispatch.

The survey also asked for the most important goal in establishing links with

foreign universities or research institutes. Table 7 lists the results and reveals that companies indeed expected research results from their foreign linkages. That was not the sole expectation, however; 16 percent of respondents placed priority on strengthening personal relations. One R&D manager believed that Americans often do not recognize that Japanese companies have such a goal in their relations with foreign institutions, and here lies a potential misunderstanding between Americans and Japanese. The American system is contract based, and universities deliver results. So there is a tendency to assume that Japanese companies are simply extracting research results from American universities at an ever-increasing rate. The Japanese, however, are willing to spend money on activities with more diffuse benefits, such as providing international experience and networking. The two motives no doubt coexist. Another R&D manager said that the company sends people abroad to get the most advanced technology; the goal is the same in all their research collaborations. Shortly afterward he said that with research overseas there is the language problem, and the main result tends to be developing a human network. In Japan, the network is important, but more important is obtaining quick results.

Table 7. Most important goal for co-operative relations with foreign research institutes.

Goal	Percentage (N = 140)
Implementing joint research	26
Obtaining technical information/research results	26
Subcontracting R&D	21
Strengthening personal relations	16
Obtaining information about overseas R&D	6
Other	4
Total	100

Source: JPC survey.

Origins and conduct of collaborative research underlying joint papers

The histories of collaborative papers can be analysed to examine more closely two issues raised above. The following section asks: what are the benefits accruing to companies from research relationships with Japanese universities? And how different are their relations with foreign universities? The answers are derived from data on the origins, motives and conduct of research underlying papers co-authored in 1989. Data were obtained from 9 laboratories that produced 156 collaborative papers in 1989, yielding 111 usable stories.[31] The brief descriptions of the collaborations were used to classify each project into four broad categories. These are listed in Table 8.

Several methodological points should be noted. Firstly, exchange of money per se was not examined; but it is probably safe to assume that money was

Table 8. Nature of collaboration.

	Total		Foreign	
	Number	%	Number	%
Person dispatched	**39**	**35**	**11**	**52**
– from company	26		10	
– to company	13		1	
Joint research (work at both sites)	**32**	**29**	**5**	**24**
– Sample preparation/analysis division of labour mentioned	12		3	
Idea/experiment division of labor	**22**	**20**	**0**	**0**
– Subcontract, money for experimental work	14		0	
Other	**18**	**16**	**5**	**24**
– Coordinated by outside organization	10		1	
– Former employee, student or joint appointment	8		4	
Total	**111**	**100**	**21**	**100**

transferred from the company to the co-authoring institution unless it was also a company. Secondly, the information collected is not about collaborations as much as the company view of collaborations. So, for example, when more than two co-authoring institutions were listed, often information on one only was obtained. This would be the one with which the corporate researchers had links. In addition, classification depends to a large extent on which aspects of the work the respondent mentioned. Thirdly, the category 'person dispatched' overlaps with the others. For example, joint work often began at a university to which a corporate researcher was seconded and continued upon the researcher's return to the company in the corporate and university laboratories. These situations were classified under dispatch, even though they might also qualify as joint research. In contrast, work coordinated by an outside organization was always classified as such even if dispatch was involved. Finally, although not mentioned in the table, discussion with academics accompanied most if not all research exchanges, including simple research contracts, and company scientists see this as a major benefit of collaborative research.

Table 8 confirms that Japanese companies perform joint research with Japanese universities. The importance of secondment is obvious, with more than one-third of the joint papers involving long term (one year or so) or short term (several weeks or months) personnel exchange. Motivations included: learning about new areas, such as high temperature superconductivity in the laboratory of a famous professor; obtaining a doctorate; learning about specific pieces of instrumentation, in one or two cases with the aim of developing the technology in the company; and using the instrumentation available at the host site, particularly when the company was the host. However, secondment was not the sole mode of collaboration, even with foreign institutions.

True joint research, in which experimental work took place at both sites without mention of personnel exchange, was almost as frequent as secondment, accounting for 29 percent of the joint papers. Sometimes, one institution used the instruments of the other to analyze its samples. In 12 cases this was explicitly mentioned, and this figure is probably low as some respondents noted only that work occurred at both sites. Most often (10 of 12 cases) the company used the co-author's instrumentation to probe its samples.

In 20 percent of the papers, one institution contributed the idea or theoretical knowledge and the other performed the experiment. In 22 cases the company provided the idea and the university performed the experiment; this was classified as subcontracting. On seven papers the company did the experimental work, and the university provided theoretical work – conceptualization, computations, molecular design, etc. In one case the university professor supervised a PhD, though apparently without any secondment. There were two wholly theoretical collaborative papers; these were classified as joint research.

The remaining 16 percent (18 papers) were either co-ordinated by an outside organization, or were the result of a joint appointment or job change. Ten papers were produced under the auspices of an outside organization – for example, an international standardization body, industrial association or MITI-type collaborative research project. Three papers produced by one company resulted from a unique institutional arrangement in which a laboratory director was also a professor at MIT. Five reported experiments performed while the researcher was either a student or at the researcher's previous place of employment.

Foreign collaborations were not dramatically different, although there was no subcontracting. This might result from differing co-authorship conventions. For example, if the company funds university research, a Japanese academic might list a company employee as a co-author, but an American would not. There was a greater percentage of secondments, 52 percent versus 35 percent for all papers. Secondment does not account for all foreign collaborations, though the answers to general questions about links indicated that this was almost the only mode of interaction between the companies and foreign institutions.

These data thus complement more general questions about links: more variety exists than indicated by managers' descriptions of the circumstances surrounding linkage. Variety is a commonly recognized feature of industry-university links in the West, hence Japanese and Western industry-university linkages are similar in this respect. Perhaps it is more important that companies often used instrumentation developed by or at least located in the partner's laboratory. Sometimes these were government laboratories, but they were also, predominantly, Japanese universities. Japanese companies do obtain publishable research results using instrumentation in Japanese universities. That Japanese universities and government laboratories offer a useful, functioning research environment is indicated by the 16 papers resulting from

secondment of a company employee to a Japanese institution, the 10 papers on which the partner performed analysis of samples, the 14 on which the company paid for experimental work at a Japanese institution – and the 16 on which at least some experimental work was performed at a Japanese institution.

Conclusions

Are links between Japanese companies and universities strong or weak? Those arguing that links are weak point to the restrictive organization of Japanese universities combined with low levels of funding leading to low quality research of no interest to companies. However, not every department is *koza*-based, and more flexibility is now being introduced into the organizational structure. The funding levels were undoubtedly low during the 1980's, but the most recent budget contained substantial increased and more is promised. Evidence about Japanese scientific performance shows levels comparable to other industrialized nations and improvement over the 1980's and thus provides no basis for the conclusion that Japanese universities have nothing to offer industry. The regulations governing university-industry interaction are also said to be rather restrictive. The regulations may prohibit consultancy, which is common in America, but they also encourage secondment, which facilitates exchange of tacit knowledge. Probably the regulations are also commonly circumvented. Collaboration under these official mechanisms increased dramatically during the 1980's; though unfortunately, the exact level of industrial contribution to universities is difficult to ascertain. In short, there was little to prevent close university-industry links during the 1980's, and changes in the system should further facilitate university-industry linkage.

The data collected for this study indicate that there are indeed substantive research links between Japanese companies and Japanese universities and that these links are more numerous than links with foreign universities. As in studies of Western university-industry links, a variety of motivations and types of exchange were found. Many of these involved use of university equipment, going against the common idea that universities are too ill equipped too be of use to companies. As no indicator of quality, such as citations, was developed we do not know how good the collaborative research was. But it was substantial enough to be published in, for the most part, international journals. In short, it was successful scientific research. This is not entirely surprising. When the companies choose a research partner, they seem to look for two characteristics: topics of interest to them and a track record in the production of high quality research.

One difference between the types of research links that Japanese and Western companies initiate may be the substantial role of secondments in Japan, visible especially in the formal programs under which employees are sent to foreign universities. If Western companies do not second researchers to Japa-

nese universities on such a regular basis, this would contribute to the perception that the Japanese extract much more from Western systems than does the West from the Japanese.[32] In addition, combined with the relatively large proportion of Japanese R&D expenditure accounted for by companies, the relatively large presence of Japanese corporate researchers in Western universities may affect perceptions that good research in Japan is conducted in companies. Not only do corporate researchers mingle in the American research community on their sabbaticals, but corporate researchers also have money to attend international conferences. The regulations governing expenditure of government money in Japan make travel to foreign (or domestic) conferences almost impossible for university researchers, unless they use their own or corporate money. If the net result is that Japanese corporate researchers participate more fully in the international scientific community, this may well affect their performance and almost certainly the foreign perception of their performance.[33]

The Japanese companies examined here are not self-sufficient in research resources. Sometimes they do not have enough personnel, or they do not have the right equipment to perform needed experiments. Then they must look outside. Although they do turn to foreign universities, by far their favorite partner is a Japanese institution. If Japanese institutions, particularly universities, are weak, ill-equipped or under-staffed, Japanese industrial research will be affected. If current changes in the system release pent-up creative energies and lead to a renaissance in Japanese university research, Japanese corporate research will benefit.

Acknowledgements

The research reported here was 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. It is part of a project comparing EC and Japanese corporate basic research. The empirical research was undertaken while the author was a visiting fellow at the National Institute for Science and Technology Policy of the Science and Technology Agency in Tokyo.

This work would not have been possible without the generosity of the R&D managers who gave their time to be interviewed for this study and especially those who administered the survey of collaborative papers. I am grateful to R. Hinder, P. Isard, S. Iwashita, B. Martin, R. Sano, and K. Takagi for their extremely helpful comments on previous drafts. Nevertheless, I remain responsible for any errors and misinterpretations.

Notes

1. The NSF noted: 'It is not known what was included [in the MITI estimates of expenditure in foreign and domestic universities] or how these estimates were calculated' (NSF, 1986a). The NSF had earlier reported this item uncritically and provided figures of 34 billion yen and 17 billion yen with out indicating sources (NSF, 1985a). This was then referenced in NSB, 1989c; and Dore and Sako, 1989.
2. Unfortunately, companies were not asked how much they spent in Japanese universities (NSF, 1986a: p. 2).
3. In 1987 a frustrated academic who had spent 17 years on the first rung of the career ladder murdered the dean of faculty who passed him over for promotion (Swinbanks, 1987a). In March 1991 the deans of 10 science faculties released a report detailing the problems facing young university researchers (Swinbanks, 1991c).
4. A symmetrical comparison of the problems in the U.S. and Japanese university research funding system is provided in: National Research Council, 1989b: p. 7.
5. F. Kodama, quoted in Sun (1989). Although Kodama says inbreeding is getting worse, Irvine et al. note that policy initiatives to alleviate the situation have been implemented, for example 'requiring holders of certain types of fellowships to undertake research at a university other than the one awarding their doctorate' (Irvine et al., 1990: p. 171).
6. Similar problems afflict both universities and national research institutes, because researchers in both are civil servants, and so have the same conditions of employment.
7. This happens because the grants come from STA and Monbusho would consider an STA grant to a university professor as 'direct intervention in traditional [Monbusho] territory.' The delays are generated by the Ministry of Finance which is annoyed at the way the fund was 'bulldozed' through the diet (Swinbanks, 1991a).
8. Similar regulations govern research contracts with universities.
9. The Human Frontier funds are so classified, although most of the money comes from Japan because the headquarters of the organization is in Strasbourg.
10. Funds are allocated to *koza* according to a standard formula based essentially on the number of researchers, on whether the research is experimental or non-experimental and on whether or not the *koza* is in charge of a graduate school (Tamaru, 1989).
11. Converted to common currency using purchasing power parities and offical exchange rates.
12. We will not know whether this new money improves Japan's international rankings on academic research expenditure until Irvine et al. (1990) is updated. Irvine et al. put forward the hypothesis that new money was not being put into university faculties, via competitive grants, because the faculties themselves were resistant to the restructuring necessary to bring greater flexibility to the system. Some support for this thesis is provided by the previously mentioned restructuring of Tokyo University into graduate schools. 'As a result, general research funds for each research group will increase by at least 25 per cent' (Swinbanks, 1992).
13. Methodological discussion of bibliometric studies of Japanese science from the SCI can be found in Hicks et al. (1992).
14. 'A citation ratio of 1.00 reflects no over- or under-citing of scientific and technical literature. A high ratio indicates a greater influence, impact, or utility than would have been expected...' (NSF, 1991: p. 97).
15. These are the numbers of universities performing research as indicated by the presence of PhD courses as of 1987 (Monbusho, 1988: p. 8).
16. Though even in America the true amount of money passing from industry to unviersity is probably not reflected in official statistics (NSF, 1982).
17. Professor F. Kodama and Professor T. Ikoma, personal communication.
18. Internationally comparable figures for total university funding in 1988 are not available.
19. Intramural expenditure on R&D in national universities extramurally financed from companies (Statistics Bureau, 1988: Table 3, Summary).

20. ASBR includes research grants from all government departments and Monbusho funding for attached and inter-university institutes. GUF is core funding. (Irvine et al., 1990).
21. Different databases, or even different versions of the SCI, will produce different results. The coverage of this data and the methodology are described in Hicks et al. (1992).
22. The alternative is to allocate papers fractionally. Papers cannot be fractionated according to number of authors from each institution because the database does not include the necessary information. Therefore, papers must be split evenly among all the listed institutions. Continuing the above example, if fractional allocation were used, Japanese companies would be credited with one-quarter of a paper, Japanese universities with one-quarter of a paper and foreign universities with one-quarter of a paper.
23. The only available, internationally comparable figures were produced by the NSF in 1984 using a slightly different journal set. In that year, U.S. companies co-authored 7 percent of their papers with a foreign institution and 25 percent with a domestic university (National Science Board, 1989: Table 5–29).
24. The total number of companies here is 26, not 28, as 2 corporate-funded, but stand-alone, non-profit research institutes were not included on the grounds that they do not spend money in universities like normal corporate laboratories. If the ranking were adjusted for size of university, Osaka University would be number one; it has approximately half the number of faculty and graduate students of University of Tokyo, but collaborates with almost the same number of companies. In 1987, Osaka University had 488 faculty and 2848 graduate students. University of Tokyo had 868 faculty and 5265 graduate students (Sigurdson and Anderson, 1991).
25. The JPC survey is perhaps the only available survey on the topic. Unfortunately, its results should be treated with caution as 53 percent of the respondents reported that they were basing responses to questions about fulfillment of expectations with regard to university-industry relations on instinctive judgments without direct experience (Japan Productivity Center, 1990).
26. Due to time constraints the automobile companies were not visited. In addition one company refused my request for an interview.
27. Small grants of around $8,000 in the mid-1980s escape taxation.
28. It is often noted that Japanese executives are more likely than their Western counterparts to have science and engineering backgrounds. Presumably, since links are maintained between professors and former students, Japanese academic scientists have access to and find sympathy in the upper echelons of Japanese corporations, a situation which Western academics might envy.
29. *tatemae* means a principle, policy, rule, basis or system, as opposed to *honne* – one's real (true) intention or one's true (real, underlying) motive (Kenkyusha, 1990).
30. Note that neither individuals nor departments were matched, just universities. Thus the co-authored papers may be unrelated to the joint research. The comparison overestimates the connection between joint research and co-authored papers (Monbusho, 1987; 1988; NSF, 1989).
31. Histories of collaborative papers are extremely difficult to obtain. If the company's laboratory was relatively small, the R & D manager often knew the story of each paper. However, the stories of papers produced in large laboratories were only obtained by identifying the locations of 20 or 30 researchers and asking them about their papers. I am extremely grateful to those who collected this information for me.
32. This is one facet of 'symmetrical access' (NRC, 1988; Blume, 1990).
33. Extent of communication is a key factor affecting scientific performance (Hicks, 1992).

References

Bloeden, R. V. and D. R. Stokes (1991). 'Ensuring effective knowledge transfers for university/industry collaborative research,' a paper presented at the R&D conference on external aquisition of technological knowledge, Kiel Germany, July 8–10.

Bloom, J. (1990). *Japan as a Scientific and Technological Superpower.* Washington, DC: U.S. Department of Commerce, National Technical Information Service, PB90-234923.

Darknell, F. and E. Darknell (1982). 'State college science and engineering faculty: collaborative links with private business and industry,' in National Science Board/National Science Foundation, *University-Industry Research Relationships: Selected Studies.* Washington, DC: NSB/NSF, NSB82-2.

Dibner, M. D. and R. S. White (1989). *Biotechnology Japan.* New York: McGraw Hill.

Dore, R. and R. S. White (1989). *How the Japanese Learn to Work.* London: Routledge.

Findeis, A. F. (1972). 'Graduate education in science and engineering in Japan,' *Science* 177: 583–588.

Fransman, M. and S. Tanaka (n.d.). *The Strengths and Weaknesses of the Japanese Innovation System in Biotechnology,* JETS paper no. 3. Edinburgh: University of Edinburgh.

Hane, G. (1991). *Research and Development Consortia and Cooperative Relationships in Japan's Superconductivity Industry,* research report *chyosa kenkyu shiryo* 18. Tokyo: National Institute of Science and Technology Policy, Science and Technology Agency.

Hicks, D. (1992). 'Instrumentation, interdisciplinary knowledge, and research performance in spin glass and superfluid helium three,' *Science, Technology and Human Values* 17: 180–204.

Hicks, D., P. Isard and M. Hirooka (1992). 'Science in Japanese companies,' *Japanese Journal of Science and Technology Studies* 1: 109–140.

Hoshi, T. (1984). 'Industry-university cooperative research in Japan,' *Bulletin of the Japan Society of Precision Engineering* 18: 80–84.

Irvine, J., B. Martin and P. Isard (1990). *Investing in the Future: An International Comparison of Government Funding of Academic and Related Research.* Aldershot: E. Elgar.

Japan Productivity Center and St. Paul Rikkyo University (1990). *Utilization of Foreign Universities and Other Research Institutes by Japanese Corporations.* Tokyo: Japan Productivity Center.

Katz, S. (1992). *Bibliometric Assessment of Intranational University-University Collaboration,* unpublished D.Phil. thesis, Brighton: SPRU.

Kenkyusha's New Japanese-English Dictionary. Tokyo: Kenkyusha, 1990, 4th ed.

Kondo, J. (1992). Science Council of Japan, answering question in *Future National Research Policies Within the Industrialized Nations,* a report of a symposium, April 1992, Government-University-Industry Research Roundtable. Washington DC: National Academy Press, p. 77.

Kodama, F. (1991). *Analyzing Japanese High Technologies.* Pinter: London.

Lastres, H. (1993). D.Phil. thesis, Brighton: SPRU.

Maddox, J. (1991). 'Japan's graduate university matures,' *Nature* 353: 113.

Monbusho (n.d.). *Gakujitsu kenkyu ronbun su no kokusai hikaku chosa.* (International comparison of numbers of academic research papers). Tokyo: Monbusho.

Monbusho (1988, 1992). *The University Research System in Japan.* Tokyo: Monbusho.

Narin, F. and J. D. Frame (1989). 'The growth of Japanese science and technology,' *Science* 245: 600–605.

Narin, F. and E. S.Whitlow (1990). *Measurement of Scientific Cooperation and Coauthorship in CEC-related Areas of Science,* vol. 1, a report to the Commission of the European Communities by CHI Research. Cherry Hill, New Jersey: CHI.

National Research Council (1988). 'Symmetrical access in science and technology,' a paper prepared for discussion at U.S.-Japan meeting on symmetrical access, Honolulu, Hawaii, March 31-April 1.

National Research Council (1989a). *Learning the R&D System: National Laboratories and Other Non-Academic, Non-Industrial Organizations in Japan and the United States.* Washington DC: National Academy Press.

National Research Council (1989b). *Learning the R&D System: University Research in Japan and the United States.* Washington DC: National Academy Press.

National Research Council (1989c). *The Working Environment for Research in U.S. and Japanese Universities: Constrasts and Commonalities.* Office of Japan Affairs. Washington DC: National Academy Press.

National Science Board (1989). *Science and Engineering Indicators: 1989.* Washington DC: USGPO, NSB89-1.

National Science Board (1991). *Science and Engineering Indicators: 1991.* Washington DC: USGPO, NSB91-1.

National Science Foundation (1982). *University-Industry Research Relationships: Myths, Realities and Potentials.* Washington DC: National Science Board.

National Science Foundation (1985a). *Current Programs to Support University/industry Cooperation in Japan,* report memorandum 69, The Tokyo Office of the U.S. National Science Foundation, March 25.

National Science Foundation (1985b). *University-industry Cooperation in Japan: Recommendations of the Japan Techno-economics Society,* report memorandum 70, The Tokyo Office of the U.S. National Science Foundation, April 5.

National Science Foundation (1986a). *Japanese Company Support for Academic Research in the United States,* report memorandum 108, The Tokyo Office of the U.S. National Science Foundation, September 12.

National Science Foundation (1986b). *American Universities' Scientific and Technical Contacts with Japan: MIT's Industrial Liaison Program and other MIT Contacts,* report memorandum 110, The Tokyo Office of the U.S. National Science Foundation, November 12.

National Science Foundation (1987). *Monbusho to Establish University-Industry Joint Research Centers,* report memorandum 119, The Tokyo Office of the U.S. National Science Foundation, March 19.

National Science Foundation (1989). *University-Industry Joint Research Projects Supported by Monbusho*, report memorandum 175, The Tokyo Office of the U.S. National Science Foundation, March 29.

National Science Foundation (1991). *International Science and Technology Data Update: 1991.* Washington, DC: National Science Foundation, NSF 91-309.

National Science Foundation (1992). *Japanese Government's General Guidelines for S&T Policy Revised on April 24, 1992,* report memorandum 230, The Tokyo Office of the U.S. National Science Foundation, May 6.

Negishi, M. (1990). 'Research activities in Japan and Japanese articles registered in Western databases,' in D. Monch et al., eds. *Japanese Information in Science, Technology and Commerce.* Proceedings of the 2nd international conference of *Gesellschaft fur Mathematik und Datenverarbeitung,* October 23–25, 1989, Berlin. Amsterdam: IOS Press, pp. 184–197.

Nelson, R. and R. Levin (1986). 'The influence of science, university research, and technical societies on industrial R&D and technical advance.' *Yale University Research Program on Technological Change Policy Discussion Paper Series,* number 3, June.

Office of Technology Assessment (1984). *Commercial Biotechnology.* New York: Pergamon.

Peters, L. S. and H. I. Fusfeld (1982). 'Current U.S. university/industry research connections,' In National Science Board/National Science Foundation, *University-Industry Research Relationships: Selected Studies.* Washington DC: NSB/NSF, NSB82-2.

Science Watch (1990). 'Japanese scientists increase their presence in world-class journals.' May, p. 7.

Science Watch (1991a). 'No slippage yet seen in strength of U.S. science.' January/February.

Science Watch (1991b). April, p. 1.

Science Watch (1991c). 'Japanese papers in physics, chemistry rise in impact in 1980's.' September, p. 8.

Science Watch (1991d). 'The group of seven's fortunes in the physical sciences: 1981–90.' November/December, p. 8.

Science Watch (1992). 'The group of seven's fortunes in the biological sciences: 1981–90.' January, p. 8.
Sigurdson, J. and A. M. Anderson (1991). *Science and Technology in Japan.* Harlow, UK: Longman, 2nd ed.
Statistics Bureau (1988, 1989). *Report on the Survey of Research and Development.* Tokyo: Statistics Bureau, Management and Coordination Agency.
Stenberg, L. (1992). 'Molecular beam epitaxy: A mesoview of Japanese research organization,' in *Dynamics of Science-Based Innovation.* Berlin: Springer-Verlag.
Sun, M. (1989). 'Japan faces big task in improving basic science,' *Science* 243: 1285–1287.
Swinbanks, D. (1987a). 'Permanent assistant's frustration leads to professor's murder,' *Nature* 329: 576.
Swinbanks, D. (1987b). 'Japan's international standing improved by paper boom?' *Nature* 330: 199.
Swinbanks, D. (1988a). 'Graduate university aimed at research flexibility,' *Nature* 333.
Swinbanks, D. (1988b). 'Japanese students protest at plans for graduate school,' *Nature* 333: 695.
Swinbanks, D. (1989a). 'Partnership research success,' *Nature* 337: 109.
Swinbanks, D. (1989b). 'Objections to Japan's system,' *Nature* 340: 494.
Swinbanks, D. (1990a). 'The taxman's human face,' *Nature* 347: 703.
Swinbanks, D. (1990b). 'Industrial funds flow freely,' *Nature* 348: 7.
Swinbanks, D. (1990c). 'New money and new ideas,' *Nature* 348: 100.
Swinbanks, D. (1991a). 'Cycle of feast or famine,' *Nature* 349: 730–731.
Swinbanks, D. (1991b). 'A foray into red tape,' *Nature* 350: 644.
Swinbanks, D. (1991c). 'The trials of young researchers,' *Nature* 351: 679.
Swinbanks, D. (1991d). 'University of Tokyo set for major reform,' *Nature* 351: 679.
Swinbanks, D. (1992). 'Universities win,' *Nature* 355: 99.
Tamaru, K. (1989). 'Funding of research in Japan,' *Science and Public Affairs* 4: 31–41.
Thrasher, D. K., producer (1991). 'Selling our brains.' 20/20 program broadcast, December.
Yamamoto, A. (1989). 'Japanese universities feel the chill,' *Nature* 339: 575–576.