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This study greatly benefitted from interviews with a number of people at ICOT, MITI, and other organizations, especially Professor Kazuhiro Fuchi of the University of Tokyo. The major part of the research was conducted while Odagiri, Nakamura, and Shibuya were all affiliated with MITI's Research Institute of International Trade and Industry (MITI/RI) as, respectively, special research fellow, senior research fellow, and research fellow. We thank Professor Ryutaro Komiya, the director, and other members of MITI/RI for comments. None of the opinion expressed in this paper represents that of MITI or any other organization.

ABSTRACT

This paper investigates the advantages and disadvantages of publicly supported government-industry research consortium as a vehicle for conducting basic research, taking Japan's Fifth-Generation Computer Systems (FGCS) Project as a case. After examining the organization, activities, and achievements of the project, we apply the usual explanations of cooperative R&D to the Project. Complementarity of resources from different companies may not have been as important as in the cases of previous research associations in Japan (e.g., the VLSI Association) but the establishment of a temporary research institute with seconded researchers was an effective way to deal with the limited mobility of researchers in the Japanese labour market. Perhaps more importantly, the Project fostered the spillover of created knowledge.

1. Introduction

The Fifth-Generation Computer Systems (FGCS) Project was undertaken by the Japanese government and the industry with the aim of developing a computer with learning and inferential capacity. After three years of preparation, the project started in 1982 and was concluded in March 1995. At its centre was the Institute for New Generation Computer Technology (ICOT), a research institute financially supported by the Ministry of International Trade and Industry (MITI) with, at its peak, about a hundred research staff seconded from MITI's Electrotechnical Laboratory (ETL), Nippon Telegraph and Telephone (NTT, a public corporation in the beginning but later privatized), and a number of private companies. In short, it was a government-industry research consortium funded by the government.

The project differed in an important way from Japan's earlier joint R&D projects whose basic aim was to catch up with the leading technologies of IBM and other technological leaders. Although the research on parallel inference had been already made in the US (without success), nowhere had a parallel computer of non-von Neumann type been really developed and, as a consequence, there was much uncertainty as to the feasibility of the project. Neither was there any model to follow. The research was bound to be basic (if not as basic as the study of, say, elementary particles) and little prospect for commercialization was at hand.

The question arises whether the government-industry consortium is an appropriate and efficient organizational form for such a research. Most of the previous economic studies on joint R&D, such as Ordover and Willig (1985), d'Aspremont and Jacquemin (1988), Kamien, Muller, and Zang (1992), and Suzumura (1992), have been investigating the economic consequences of joint R&D that would immediately affect the profitability or cost structure of participating firms. Arguably, however, joint R&D is more suitable for basic research than for development research because in-appropriability of invented knowledge, that discourages private R&D investment, must be most serious for basic research (Arrow, 1962).

This paper aims to inquire into the advantages and disadvantages of joint research as a vehicle for basic research, taking the FGCS Project as a case. Although this Project has been studied by Feigenbaum and McCorduck (1983), Motooka and Kitsuregawa (1985), Fransman (1990), and others, the project was completed only recently and we can make use of more recent and more complete evaluation of the project.

In Section 2, we will discuss the background behind the Project and its inception, followed by the discussion of its organization and activities in Section 3. Its achievement will be evaluated and its impact on the scientific community discussed in Section 4 . In Section 5, the advantages and disadvantages of joint R&D will be discussed, first in a general fashion and then in relation to the FGCS Project. Section 6 summarizes the discussion with concluding remarks.

2. How It Started[1]

In contrast to the preceding four generations of computers (First Generation: ENIAC invented in 1946 and others which used vacuum tubes, Second Generation: IBM 1401 introduced in 1959 and others which used transistors, Third Generation: IBM S/360 introduced in 1964 and others which used integrated circuits, and Fourth Generation: IBM E Series introduced in 1979 and others which used VLSI) which have massively increased the computational capacity but are still based on the von Neumann architecture and require specific and precise commands to perform a task, FGCS was conceived as a computer that can infer from an incomplete instruction, by making use of the knowledge it has accumulated in its data base. Such a computer, it was expected, can be used for consultation (say, legal or medical consultation), translation, and other purposes.

For the Japanese industry, the FGCS Project was considered both strategically important and a natural successor to its previous projects. There were at least three reasons. First and foremost, since FGCS is based on an architecture distinct from that of previous four generations of computers which had been invented by von Neumann and commercially developed by IBM among others, it was expected to give Japanese computer makers a big step towards overcoming IBM's technological dominance and its worldwide marketing strength.[2]

Second, as the research for FGCS had not really started in any country, the project gave a chance for Japan to be the forerunner. The history of the Japanese electronics industry (or, for that matter, of any other Japanese high-tech industry: see Odagiri and Goto, forthcoming) has been that of catching up with the West technologically. Now that the Japanese computer technology has nearly caught up with that of the US, the FGCS Project was expected to play a dual role of, firstly, to push the industry into a leading presence in the world market and, secondly, to demonstrate to the world that Japan can make a technological contribution, refuting the criticism that Japan had been free-riding on the technologies developed elsewhere. In fact, Okamatsu (1982, 38, our translation), then the director of MITI's Electronics Policy Division, wrote that "Japan has to conduct incessant R&D efforts in order to raise its potential for creative technological development, to keep developing as a leading nation in technology, and to make an international contribution with its own technology."

Third, FGCS was expected to use VLSI (very large-scale integrated circuits) for computing and memory devices, and parallel processing. Therefore, as a sequel to the VLSI Project (1976-1986) and the Supercomputer Project (1981-1989) which had started research on parallel processing, the FGCS Project was expected to benefit from the technological stock accumulated through these projects.[3]

Nevertheless, it is far from reality to argue that the industry wholeheartedly shared MITI's view. In fact, the industry at the time was dominated by a view that the IBM computer architecture would continue to dominate the market for another couple of decades; hence, they opposed MITI's plan that private companies should be involved with the project. Some companies believed that nothing would be gained from taking part in such a futuristic project because research into parallel inference had hardly made any progress in the US.

The first initiative, therefore, had to come from MITI and ETL. In the second half of the 1970s, a section within ETL under K. Fuchi's leadership was searching the direction for its future research and came to believe in the potentialities of *Prolog*-based logic programming and of a new computer with inferential capacity. Since, for the reasons discussed above, MITI itself was considering a new project towards computer systems beyond the conventional von Neumann type, meetings were held in 1978 among the members of MITI's Electronics Policy Division, ETL, companies, and academics, to examine the technical features that the new computer system should take.

In the following year, a committee, called the Main Committee for the Fifth Generation Computer, was set up within the Japan Information Processing Development Center (JIPDEC) to examine the question more systematically in a period of three years. The committee, chaired by T. Motooka, then professor of the University of Tokyo, consisted of researchers from universities, public and private research institutions, and computer makers, with more than a hundred people involved at one time or another. Three subcommittees were set up: Subcommittee for Computer Architecture (SCA; chaired by H. Aiso, Professor of Keio University), Subcommittee for Basic Theory (SBT; chaired by Fuchi), and Subcommittee for Systematization Technology (SST; chaired by H. Karatsu, executive director of Matsushita Communication Industrial Co.). Fuchi's SBT proposed that the project should target at a new non-von Neumann type parallel computer; however, SCA, to which every participating company sent its member, opposed it in favour of extending the scope of conventional computer architecture. Gradually, SBT's enthusiasm influenced the members of SCA and, finally, all the three subcommittees settled on the direction suggested by SBT.

This direction was also supported by MITI which had been concerned with the three points raised at the beginning of this section. Yet, some of the MITI officials were sceptical and questioned the wisdom of investing a massive amount of money in such a futuristic project. To gain more understanding of the viability of the project, an international conference on FGCS was held in October 1981 with nearly a hundred participants including those from 14 nations outside of Japan, a few being paid by MITI but mostly participating at their own expense. Although some participants thought the project to be too ambitious and were sceptical of its feasibility, the project was generally received with enthusiasm, convincing MITI of its worthiness.

Companies were still reluctant to be involved. Yet, as MITI secured a substantial amount of budget for the project in fiscal 1983, the companies realized MITI's intention to commit itself to the project and became more willing. Arguably MITI was in a position of a Stackelberg leader and the firms, followers. In addition, the interest on AI (artificial intelligence) boomed around the time and the companies started to realize the potential value of FGCS research as a complement to their own AI research.

In 1982, after six meetings, a special eight-company committee within the Japan Electronic Industry Development Association (JEIDA) submitted a request to the MITI for a permission to establish a new incorporated foundation in accordance with the terms and provisions of Article 34 of the Civil Law. Soon, the permission was granted and the Institute for New Generation Computer Technology (ICOT) was duly established. T. Yamamoto, then president of Fujitsu, was appointed the chairman of the board of directors and T. Yoshioka, an ex-MITI official, the representative director. In addition, the board of directors had nine members which included ETL's Fuchi who became ICOT's research director, NTT's R&D director, and the presidents of all the companies (besides Fujitsu) on the special committee -- Hitachi, Mitsubishi Electric, NEC, Oki, Toshiba, Matsushita Electric Industrial, and Sharp.

3. The Organization and Activities

Budget

The budget of the FGCS Project is shown in Table 1. During the 13 year period of 1982-1994, the total of 57 billion yen (roughly $ 320 million) was paid by the government. The amount is quite modest in comparison to the entire R&D expenditure of the electronics and communication industry which was 536 billion yen in 1980 only and 2,150 billion yen in 1990, or in comparison to that of IBM which was 1.5 billion dollars (¥ 370 billion) in 1982 only.[4] Per-year expenditure of the project never exceeded a mere one per cent of the industry expenditure.

**** TABLE 1 ABOUT HERE ****

Research Themes

The project consisted of four stages (see Table 1) along which research theme evolved. During the initial stage (1982-1984), research was conducted on the basic technologies for FGCS. The technologies developed included (1) ESP (Extended Self-Contained Prolog), a sequential logic-programming language based on Prolog; (2) PSI (Personal Sequential Inference Machine), the world's first sequential inference computer to incorporate a hardware inference engine; (3) SIMPOS (Sequential Inference Machine Programming and Operating System), the world's first logic-programming-language-based operating system written with ESP for the PSI; and (4) GHC (Guarded Horn Clauses), a new parallel-logic language for the implementation of parallel inference.

During the intermediate stage (1985-1988), research was done on the algorithms needed for implementation of the subsystems that would form the basis of FGCS and on the basic architecture of the new computer. Furthermore, on the basis of this research, small and medium-sized subsystems were developed. The technologies developed included (1) KL1, a logic language for parallel inference; (2) PIMOS (Parallel Inference Machine Operating System), a parallel-machine operating system based on the use of KL1 (Kernel Horn Clauses 1); (3) KAPPA (Knowledge Application Oriented Advanced Database and Knowledge Base Management System), a knowledge-base management system capable of handling large amounts of complex knowledge; and (4) Multi-PSI, an experimental parallel inference machine consisting of 64 element processors linked together in the form of a two-dimensional lattice.

During the final stage, 1989-1992, the object was to put together a prototype fifth-generation computer based on the technologies developed during the two preceding stages. The project team developed a number of additional features including (1) PIM (Parallel Inference Machine), a parallel inference computer consisting of 1,000 linked element processors; (2) improvement of PIMOS; and (3) KAPPA-p, a parallel data-management system. For the knowledge programming system the team also developed (4) interactive interface technology, (5) problem-solving programming technology, and (6) knowledge-base creation technology. To test the prototype system, the team also carried out research into (7) the integration and application of parallel programming technology. Furthermore, (8) several application software programs were developed to run on the PIM.

The project continued on a more limited scale during 1993-1994. In addition to follow-up research on, say, a new KL1 programming environment (called KL1C) on sequential and parallel UNIX-based machines, many efforts were made to disseminate the FGCS technologies, for instance, to distribute ICOT free software and to disclose technical data on the Internet.

Organization

The organizational structure of the FGCS Project is summarized in Figure 1. As a consignee of the project, ICOT received the entire funds from MITI. Although a major part of these funds actually went to companies for software development and the development and manufacture of hardware (see the right bottom corner of the figure), ICOT was in charge of the entire project, with negotiations and consultation with MITI, and conducted the central and more basic part of the research as opposed to more development-related research commissioned to the companies.[5] Most of the following discussion, therefore, will be focused on the activities of ICOT.

**** FIGURE 1 ABOUT HERE ****

Participation of Companies

Companies were invited to participate in ICOT as supporting members. There were two types of supporting members -- special supporting members and general supporting members. Members of either type enjoyed the privilege of invitation to research presentations, subscription to the journals and research reports published by ICOT, and others, and paid the annual membership charge which was 450,000 yen per general supporting member and several tens of millions of yen per special supporting member. In return, special supporting members had the right to secondment of their researchers to ICOT, and the right to take part in ICOT's management as board members.[6] The list of supporting members is in Table 2.

**** TABLE 2 ABOUT HERE ****

The eight companies that formed the aforementioned special committee became the special supporting members, as well as NTT. No other company applied to be a special supporting member.

All these nine companies remained to be the central members throughout the project. By contrast, of the 39 companies who became the general supporting members at one time or another, only 7 remained so throughout the 1983-1994 period.

The membership application was open to both domestic and foreign firms and, as Table 2 shows, the Japanese subsidiaries of Unisys, NCR, DEC, Hewlett Packard, IBM, and Xerox became the general supporting members. In fact, when MITI invited applications for consignees for the FGCS Project in the MITI Official Bulletin, Nihon Unisys (then Nihon Univac) and IBM Japan came to MITI to receive the documentation but neither applied, thereby leaving ICOT as the only applicant. Fuchi believes that neither made a bit because at the time these foreign firms had a technological edge over the Japanese rivals and worried that this edge might be dissipated under the pressure to release technical information during the course of the project.[7]

Researchers

The Research Centre of ICOT, under the direction of Fuchi who resigned from ETL to become the full-time director (succeeded by S. Uchida in 1993), was made up of the researchers most of whom were seconded from companies (mostly the eight special supporting member companies), in rotation for terms of between three and four years each. Fuchi and his deputies took pain so that only the suitable and able would be sent to ICOT: often, they designated the researchers they want at ICOT and pressed the employers to second these researchers to ICOT.

As shown in Table 3, the Research Centre consisted of a few laboratories and expanded over the period from approximately 30 researchers in three laboratories during the initial period, to 50 to 70 researchers in five laboratories during the intermediate stage, and then to nearly 100 researchers in seven laboratories during the final stage.

**** TABLE 3 ABOUT HERE ****

In order to promote research collaboration, ICOT assigned researchers from different companies to each laboratory. Initially, all of the laboratories were headed by supposedly neutral researchers (e.g., from ETL or NTT) but, in the final stage, those from companies headed some of the laboratories. These were the people who had been with ICOT since the earlier stages and had unreserved respect of the other researchers. Here is a difference from the previous VLSI Research Association in which five of the six laboratories were headed by those seconded from different companies (and another by a researcher from ETL), with each laboratory having a close relationship with the company (or ETL) from which the head of the laboratory was seconded (to be called the home company, hereafter).

The researchers at ICOT were seldom required (or expected) to feed the research result back to their home companies and, consequently, ICOT was viewed more as a separate entity than an extension of company laboratories. Information was thus freely exchanged among the members of ICOT without regard to their home companies, and it was easier to pursue research with little prospect for commercialization.

In the beginning ICOT attempted to recruit researchers from universities but met serious obstacles caused by the Japanese university system, particularly that of national universities. Basically all the faculty members have tenure and the mobility of professors is more limited than in the US; hence, quitting from universities to join a short-lived organization like ICOT creates uncertainty as to future job opportunity. In addition, a move from national universities to a private institution like ICOT would entail a disadvantage in the pension scheme. Taking a temporary leave of absence from a national university is also difficult because university hiring policy is constrained by the number of faculty posts set by the Ministry of Education which does not allow the university to hire temporary substitutes for professors on leave. For these reasons, no university scholar joined ICOT as researchers. Instead, many of them contributed as members of the working groups to be discussed below.

ICOT, however, recruited several young researchers who had just completed their doctorates and were interested in pursuing further research at ICOT. In these cases, ICOT chose not to recruit the prospective researchers directly to the Institute's payroll but first to find them a position with one or other of the companies involved in the project on the mutual understanding that, after, say, six months, the company(s) would second them to ICOT. Apparently, this arrangement was devised to have a temporary organization like ICOT function in an economy where lifetime employment is a norm in companies and universities.[8] However, the total number of staff recruited in this way was less than twenty or ten per cent of the entire staff.

Working Groups

To maintain interaction with outside research community, ICOT organized a number of working groups, each with a separate research theme. There were only 6 working groups in the beginning with 72 outside researchers participating. However, as the interest in FGCS increased and the research within ICOT progressed, more working groups were set up. At the peak year of 1991, there were 16 working groups with 259 outsiders involved.

About a half of these participants were university faculty members. Since, as discussed above, ICOT found it extremely difficult to recruit these people on a full-time basis, it instead tried to gain from their expertise through their participation to working groups, which typically met once a month. The participation also gave opportunities for the university members to be informed of the progress at ICOT and of research done by other working group members. Furthermore, they could occasionally utilize the research facility of ICOT. As Fransman (1990, 208) observed, "through this arrangement university researchers get access to funding and equipment, link into the ICOT network, which as noted serves as a clearing house for information in the area of applied artificial intelligence, and take part in larger mission-oriented cooperative research. On the other hand, ICOT research benefits from university expertise in more fundamental and specialized areas. In addition, many ICOT-related ideas and applications receive further research in university laboratories where professors and postgraduate students are involved in the experimentation and testing processes."

For ICOT, that is, working groups served the dual purpose of gaining a valuable input from outside in the form of advice and research results, and of publicizing the work done within ICOT to outside researchers, thereby promoting the interest on FGCS among the research community. A valuable network was thus created among the researchers in universities, research institutions, companies, and ICOT. This network was utilized when ICOT recruited company researchers and postgraduate students in the manner discussed above. The network was further expanded when a number of ICOT researchers themselves were subsequently hired as professors as we will discuss later.

In addition, international conferences were held five times including the one in 1981 mentioned earlier and the ones at the conclusion of each stage of the project. These conferences served similar purposes as the working groups.

4. The Achievement

In 1991 MITI established a Basic Computer Technology Development Committee under the chairmanship of Professor H. Tanaka of the University of Tokyo to evaluate the performance of FGCS Project. The Committee's report raised three contributions of the project. (1) The general-purpose massively parallel processing technology developed by the project has eliminated many of the bottlenecks in the writing of parallel processing software. (2) By enabling an increase in processing capacity of anything from several hundred to several thousand times that of a conventional von Neumann type computer, the project has opened a way for research in areas such as the creation of predicate logic based high-order inference engines, the establishment of real knowledge bases, and the realization of intelligent interactive processing. (3) By developing the new techniques generated by the project further, it should be possible to enable experts in other fields, such as medicine and law, to express their knowledge in computer-understandable terms and to create their own medical or legal knowledge bases and related application systems.

Since it is an evaluation by MITI's own committee, the optimistic tone of the report may have to be discounted. Probably, an objective evaluation would have to wait another decade or two in view of the basic-research orientation of the project. Instead of attempting any technical evaluation, therefore, we will concentrate on quantitative evaluation here. The question we ask is twofold: how much output it has made and how much of that output was fostered by the collaboration among researchers from different companies.

Patents

The FGCS Project applied for 382 patents of which 163 had been registered as at April 1995. This figure compares unfavourably to that of the VLSI Research Association Project which made 1,210 applications (the combined total of patent and utility model patent applications as at the end of March 1990) with 329 registered. A simplistic comparison is meaningless, however, because the FGCS Project was oriented towards more basic research. Fuchi, in fact, argues that "VLSI R&D was carried out with a view to early application. By contrast, the time horizon by reference to which the FGCS Project was implemented extended for ten and in some cases twenty years into the future. Even if patents are applied for, their practical application is unlikely until after the resultant patent rights have expired; hence, there is little point in making patent applications simply for the sake of acquiring rights."[9]

Furthermore, ICOT was interested in offering their research results as public property so that further R&D would be facilitated. Hence, its basic patent policy was to make an application only when such an application is necessary to prevent other parties from making an application and monopolizing the use of the knowledge.[10]

Not surprisingly, with only a few exceptions, the patent applications are concentrated in IPF (International Patent Classification) G06F, namely, "digital computers, etc., in which at least part of the computing is executed electrically" within the IPF section of physics. In comparison, a large part of patent applications in the VLSI Project was within the section of electricity (with IPF code starting with H), supporting the view that the FGCS Project was oriented more towards basic research than the VLSI Project.

16 applications were made as joint inventions between ICOT's researchers (say, A) and the researchers in companies (say, B). We further inquired into the names of the companies from which As were seconded and found that, in only 6 of these 16 (namely, one-third), they are the same with B's companies. This finding supports the view that the research conducted by ICOT's staff was not constrained by their home companies.

Research Papers

ICOT published a series of Technical Reports (TRs) and Technical Memorandums (TMs). The numbers of TRs and TMs are summarized in Table 4. The number of papers appearing in the two series reached an impressive 2,371 during the 14 year period. Both series accepted contributions by outsiders but roughly a half of the papers had the first authors affiliated to ICOT. The real contribution of ICOT authors is likely higher because they might have appeared only as the second (or third) authors.

**** TABLE 4 ABOUT HERE ****

To examine the extent of research collaboration, we counted the number of TRs and TMs of which the authors were affiliated to separate organizations. The proportion of these papers reached about 30 per cent in the case of domestic collaboration. For international collaboration, we counted the number of TRs and TMs of which at least one of the authors was affiliated to foreign organization(s). This number was 66 or 3 per cent. Many of them appeared as TRs which, supposedly, were more definite contributions. About a half of these were written jointly with Japanese authors. These figures suggest that a significant degree of research collaboration took place around ICOT, particularly with domestic researchers.

Contributions were also made by the presentation of research results at conferences. During 1986-1994, 1,810 presentations were made within Japan and 430 presentations abroad. Like working groups, these presentations were encouraged both to receive comments and to publicize ICOT's works.

As is well known, a mere counting of research papers teaches little in terms of their quality. To assess quality, we counted the number of citations and compared it among four comparative research organizations. The procedure for this comparison is as follows. The first sample consists of the eleven researchers who had worked at ICOT for eight years or more; the second consists of eight professors (including associate and assistant professors) of a computer-related department of a top-ranked Japanese university; the third consists of twelve researchers engaged in computer-related research in a Japanese national research institute; and the fourth consists of ten researchers in a similar semi-public European research institute. We counted the number of papers (under the subject category 'computer' in the SCISEARCH database) published by these researchers during 1974-1994 and then the number of citations (again, by the papers under the subject category 'computer' in the database) to the papers and other works of the researchers. The result is shown in Table 5.

**** TABLE 5 ABOUT HERE ****

The relative contribution of ICOT researchers is impressive. Although they are somewhat behind the university professors in terms of the number of papers, clearly theirs are more often cited than those of any other organizations. We infer, therefore, that ICOT not only published many papers but many *good* papers. Their impact on the research community must have been indeed significant.

Software

By the end of March 1995, ICOT had disclosed 100 pieces of software. They were made accessible free of charge via the Internet and the transfer of files have been made 14,000 times. Roughly a half of these were made by Japanese users, a quarter by US users, and the rest by German, French, Korean, British, and other users. Although we have no means of knowing how often they were actually *used*, the large number of access certainly suggests the extent of interest to ICOT's research by outside researchers.

International Contribution

As discussed earlier, from the start of the project MITI was concerned with making an international contribution. Thus, besides making papers and software available to the international research community and holding international symposia, several measures were taken. First, foreign visitors to ICOT were welcomed, and the number of these visitors reached 438 in 1985 alone from the US, Sweden, the UK, Germany, France, Canada, Finland, Australia, and other countries.

Second, five to twelve researchers were invited every year for a short stay (say, a month) at ICOT to make discussions or joint research with the staff of ICOT. During 1982-1994, 94 researchers were invited in total, of which 32 were from the US, 16 from the UK, 11 from Germany, and 8 from Sweden.

Third, two researchers from the US National Science Foundation and six from the French Institute National de Recherche en Informatique et Automatique (INRIA) conducted research at ICOT for six months to a year each at the expense of the NSF or INRIA. In addition, one from the US and another from China stayed at ICOT for a year each, using the fellowship program of Japan's Science and Technology Agency.

Fourth, ICOT conducted joint research with several overseas institutions, including US Argonne National Laboratory, US National Institute of Health, Lawrence Berkeley Laboratory of the US Department of Energy, Swedish Institute of Computer Science, Australian National University, University of Oregon, and Bristol University of England.

5. The Case for Joint R&D

Motivations for joint R&D and its consequences have been discussed by many. In this section, we summarize them and examine how they apply to the FGCS Project.

Collaboration in R&D can take place in several ways. Apparently, economists have been most concerned with collaboration in decision-making. The models by d'Aspremont and Jacquemin (1988) and Suzumura (1992) assumed that, under cooperative R&D, firms in an oligopolistic market jointly set the level of R&D of each and every firm, whereas the level of output is chosen independently by each firm given the cost condition which is a function of the pre-determined R&D level. To the extent that the consequence of spillover to others of a firm's research outcome is taken into account, joint decision-making should minimize the welfare loss caused by the discrepancy between social and private benefits of R&D. Also the waste of duplicate research may be minimized. On the other hand, the reduced threat of being outflanked by rivals would lessen their incentives for R&D. Following Kamien, Muller, and Zang (1992), let us call this motivation for R&D collaboration the *cartelization factor*.

The extent of spillover may be enhanced by the collaboration in the use of knowledge generated by joint R&D, for instance, when the consortium let every firm use its patents freely. Ordover and Willig (1985) assumed such collaboration in their model of research joint venture and, similarly, Kamien, Muller, and Zang (1992) regarded it as the essence of research joint ventures. Let us call it the *spillover factor* of research collaboration.

Of course, collaboration can take place in the R&D activity itself, for instance, by establishing a common laboratory and by having researchers from different organizations work together towards a common research project. Such collaboration is advantageous when economies of scale or economies of scope are present. These economies may arise from indivisibility of research-supporting assets, such as the library and computing services, although few empirical evidences actually support the presence of such economies of scale (Kamien and Schwartz, 1982). Perhaps more importantly, the economies of scope may arise from the complementarity of R&D resources, particularly human resources and accumulated technology stock. That is, people from different fields or different organizations would learn from each other and the fusion of their knowledge might create a new idea towards which their research would be re-targeted. We call this the *complementarity factor* of research collaboration.

In fact, such complementarity has been raised most often as the motivation for joint R&D. In a survey study by the Japanese Fair Trade Commission, two thirds of 130 firms participating in joint R&D raised increased research efficiency as the reason for joint R&D. Furthermore, complementarity was the major reason for increased research efficiency (Rokuhara, 1985). Cases of joint R&D between firms in a vertical relationship, such as the one between an automobile assembler and an auto-parts manufacturer, are common in which the complementarity of R&D expertise must be prominent.

In many cases, including the FGCS Project, research consortiums also work as an organizational form with which the participating firms persuade the government to provide subsidies. Giving subsidies to a consortium instead of giving it to individual firms makes it easier for the government to minimize the administrative cost and avoid any criticism of favouritism to particular firm(s). We thus call this the *subsidization factor* of joint R&D and, in fact, in many of Japan's past research associations, this factor appears to have been one of the (if not *the*) most important reasons for their establishment (Goto, forthcoming, and Odagiri, 1992, Chapter 11).

An immediate effect of subsidization, of course, is to reduce the expense by the firms. A less direct effect, which may be called the *national commitment factor*, takes place when subsidization is taken by the other countries as a signal that the government is committed to promoting the domestic industry. As a consequence, the domestic industry becomes a Stackelberg leader in an international oligopolistic market, which enhances the relative welfare position of the country (Spencer and Brander, 1983).

However, there are also several disadvantages in research collaboration. Firstly, the participants have an incentive to free-ride by paying little, seconding fewer and less capable researchers, or resisting the disclosure of their technology to the partners, because they can share the research outcome anyway. Secondly, collaboration may be difficult among researchers who have been working in companies with different corporate culture. And thirdly, cooperation in R&D may generate environment that is conducive to collusion in the product market as well. Needless to say, many antitrust agencies and economists have been most concerned with this last effect.[11]

Which of these advantages and disadvantages were relevant in the case of the FGCS Project? We first note that the project targeted at basic research with little expectation of commercialization. The firms were accordingly reluctant to participate and the government had to support it by providing the entire budget. No doubt a large part of the country's FGCS research at the time was concentrated in ICOT; therefore, cartelization did take place in terms of R&D decision-making, contributing to the elimination of duplicate research. Yet, no anti-competitive behaviour in the product market was expected because commercial development, if it should take place, would be made by individual companies.

Because of the nature of the research, ICOT never intended to monopolize the research outcome and, in fact, made efforts to make it accessible to a wide community within and outside Japan. That is, it sought to maximize spillover. It also sought to maximize the benefit of complementarity among researchers with different background. For this purpose, the leaders of ICOT, Fuchi in particular, took pains to recruit promising researchers from the companies and postgraduate schools (thereby minimising the risk that companies second lesser researchers to free-ride) and to promote communication and joint research among the members, for instance, by placing people from different companies in a laboratory headed by a supposedly neutral person and by adopting an open office system whereby all the staff of a laboratory shared a large room.

The subsidization factor was certainly important, more to MITI than to the firms, in view of the fact that the project was initiated by MITI and ETL and the firms were, at least initially, reluctant to participate. MITI was eager to free the Japanese industry from IBM's technological dominance and to counter the criticism that Japan was free-riding on the basic technology developed elsewhere.

In retrospect, the commitment factor was also important not to push the domestic industry to the position of a Stackelberg leader in the product market but to push the Japanese technology as the standard. This effect was most important in the adoption of Prolog as a basis upon which ICOT developed its own programming languages. Although Prolog had been invented in France and studied in the UK, it was the decision of the FGCS Project (led by Fuchi) to choose Prolog over other languages, such as Lisp, and develop it further that had many researchers realize its practicality. Many firms, including some of the participants to the project, were sceptical of Prolog and favoured Lisp over Prolog at the time the project was launched. Yet, as the government-sponsored project had committed itself to Prolog and ICOT started to apply Prolog for many purposes and, furthermore, as researchers started to return to their home companies, these companies increased their efforts in Prolog-related R&D however hesitantly. In an uncertain and underdeveloped situation where many standards are competing, the national commitment factor can contribute not only to promoting the domestic industry but also to limiting the worldwide allocation of resources to the standards to be eventually dropped. Of course, the choice of a right standard is essential; otherwise, the commitment would only delay the diffusion of the right standard or have a wrong standard to prevail, making switching costs prohibitively high. It is too early at this stage to assert that the choice of Prolog at ICOT was a right one; yet, as Fransman (1990, 218) has argued, "even if at the end of the day Lisp wins the competitive battle, ICOT will have played a significant positive role by increasing the level of awareness in Japan about artificial intelligence in general and more specifically about the relative advantages and disadvantages of languages like Prolog and Lisp."

6. Conclusion

In sum, the FGCS Project was a publicly supported research collaboration organized among a national research institute (ETL), universities, and companies, including NTT. Unlike previous research associations (RAs) in Japan, such as the VLSI RA, it established a more formal research institute, ICOT, but, like RAs, this institute was not intended as a permanent organization and was dissolved after 13 years of operation. Moreover, again unlike previous RAs, the project was into basic research without any prospect for commercialization. Therefore, the publication of research results was emphasized and MITI raised the slogan of 'international contribution to the world scientific community.' The spillover factor was, therefore, an important motivation for the project with MITI expecting the private companies, especially those seconding their researchers to ICOT, to continue the research towards application and product development.

It is difficult to evaluate the performance of the project. Some conclude that the project was a failure because hardly any viable product with the planned inferential capability was developed (*Nikkei AI*, 1991). Arguably such a criticism is unfounded because, in view of the futuristic nature of the research, it may take another decade or two before any commercial product is made (see the interview to Fuchi in *Nikkei AI*, 1991). We have shown that, in view of the number of papers and citations, their impact on the research community must have been significant and further research on the subject was stimulated worldwide. As Fuchi argues, the full impact of the project may be felt only after the turn of the century.

The complementarity factor has been often the most important factor for launching a joint R&D project and many ICOT researchers themselves express this view regarding the FGCS Project (*ICOT Journal*, 1985). None the less, it is unclear whether the same level of result would have failed to be attained were ICOT organized as an independent research institute with its own staff. The research on FGCS had been hardly developed at any of the firms and, therefore, there were not much technological stock with which they could contribute to the project. Of course, the researchers had several years of experience in their firms before joining ICOT and the knowledge they had learned at the companies was brought to the research at ICOT. The complementarity of such knowledge among the researchers must have been an advantage. Yet, the question remains whether such complementarity would have been lacking were ICOT to hire people of diverse background as an independent organization.

To answer this question is extremely difficult. A more relevant question, perhaps, is whether it would have been possible at all for a temporary organization like ICOT to hire good people when, as most typically in Japan but, to a lesser extent, in other advanced economies as well, internal labour markets are developed within companies, characterized by long-term employment, on-the-job training, and internal allocation of human resources. Quitting a company to join ICOT would have been a risky choice because a job might be difficult to find after ICOT is disbanded and, even if it is found, the income is likely to be reduced. In reality, therefore, it is fair to argue that ICOT, a government-industry research consortium, was devised as a mechanism with which it would be able to secure good researchers under the Japanese labour system.

Even this arrangement did not help the purpose of inviting researchers from universities as the ICOT staff. The main reason was the rigidity of human management in universities, particularly national universities. The fact that ICOT was supported by MITI while national universities were under the authority of the Ministry of Education made it even more difficult or disadvantageous for the university researchers to move to ICOT. More flexibility is urgently needed in the personnel policy of Japanese universities.

This argument notwithstanding, we count 24 former ICOT researchers who quit their home companies or ETL to join university faculties, including Fuchi himself who joined the University of Tokyo. Therefore, mobility between industry (and research institutions) and universities are by no means absent. These people now teach ICOT-related subjects, such as Prolog, parallel processing, and artificial intelligence, in their universities, arousing interest on these subjects among fellow professors and students, and supporting the students making research in the field.

In a basic-research oriented project like FGCS, this diffusion of knowledge to the academic world (through these professors and the professors involved with ICOT's working groups) and to the industry (through the former ICOT researchers returning to their companies) must have been the largest contribution. That it was planned as a temporary project not only made government financing easier but also forced the project leaders to narrow the research target (e.g, by adopting Prolog only) and fostered the diffusion of knowledge after the end of the project. Whether or not it was organized out of necessity to facilitate recruiting, the result was an increased diffusion of the knowledge generated in the project.

Generally speaking, the complementarity of R&D resources tends to be the most important factor in a development-oriented joint R&D since the firms must have accumulated related technological bases by the time the project is organized. In a basic-oriented joint R&D, by contrast, such bases are unlikely to be present making complementarity less important; instead, increased spillover can be the largest benefit. Such R&D project should be concluded within a pre-determined period in order to encourage the participating firms to apply the diffused knowledge individually for further research and commercial development. Since the firms lack an incentive to invest in the project for its high uncertainty, long gestation period, and lack of appropriability, the government is bound to support it financially. Therefore, to set the duration of the project beforehand is also essential to limit the financial burden of the government By contrast, the need for government support appears much less obvious for development-oriented joint R&D.

NOTES

1. For the detail of the organization and performance of the FGCS project, see Nakamura and Shibuya (1995) or its shorter version, Nakamura and Shibuya (forthcoming).

2. To the Japanese makers, this desire to be freed from IBM's dominance became especially ardent after the settlement of patent infringement by Hitachi and Fujitsu with IBM in the early 1980s. However, this incident was not directly related to the inception of the FGCS Project, which took place a few years earlier.

3. See Fransman (1990) for these projects.

4. The R&D expenditure of the industry is from the *Report on the Survey of Research and Development* (Management and Coordination Agency). The figure for IBM is from Feigenbaum and McCorduck (1983).

5. The proportion of funds that went to companies has not been disclosed. Fransman (1990, 228) estimates this proportion as 80 per cent during 1982-1987. This fact does not imply that 80 per cent of the research was done in companies, because a large part of such money was spent by the companies to manufacture costly prototypes and machines while, at ICOT, most of the money was spent purely for research.

6. During the final stage of the project, the right to secondment to the Institute was extended to general supporting members as well.

7. Our interview.

8. By no means, however, do we imply that lifetime employment is guaranteed in labour contracts of Japanese companies: in fact, *de facto* dismissals do take place more frequently than is usually believed. See Odagiri (1992), Chapter 3.

9. Our interview.

10. Because the FGCS Project was funded by the government, all patent rights secured on inventions made in connection with the project were unconditionally transferable to the government even if the inventor had been seconded by a company. The company, of course, were permitted to make use of the patents by paying royalties calculated according to the terms and provisions of 'national patent right utilization agreement'. Yet, the need to pay royalty might have hindered a wide use of patented knowledge for further research and application, which explains why Fuchi was reluctant to make patent applications. This restriction has been relaxed since then and, in some of the recent government-funded research projects, patent rights are shared by the government and companies.

11. See, for instance, Geroski (1993). On the other hand, Jorde and Teece (1990) argue that the current US antitrust regulation is applied too strictly to cooperative R&D.

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Table 1. Budgets for the FGCS project

FY	General account	Special account	Total	Stage
1982	426,000	0	426,000	Initial stage
1983	2,722,702	0	2,722,702	(1982～1984)
1984	5,123,654	0	5,123,654	8,272,356
1985	4,779,480	0	4,779,480	Intermediate stage
1986	4,500,950	990,121	5,491,071	(1985～1988)
1987	4,051,129	1,580,000	5,631,129	
1988	3,800,498	1,928,458	5,728,956	21,630,636
1989	3,722,365	2,760,606	6,482,971	Final stage
1990	3,464,800	3,478,197	6,942,997	(1989～1992)
1991	3,083,433	4,080,399	7,163,832	
1992	1,000,052	2,591,974	3,592,026	24,181,826
1993	0	1,388,072	1,388,072	
1994	0	1,408,072	1,408,072	
Total	36,675,063	20,205,899	56,880,962	54,084,818

Unit: ¥1,000
Source: MITI

Table 2. Changes in roll of ICOT supporting members from 1982 to 1994

FY	Supporting Members	Special Supporting Members	General Supporting Members	Representative Supporting Members: Special Supporting Members: OKI	SHARP	TOSHIBA	NEC	NTT	HITACHI	FUJITSU	MATSUSHITA	MITSUBISHI	General Supporting Members: Burroughs	NIHON UNIVAC	NCR JAPAN	TOKYO SANYO	DEC JAPAN	OEC JAPAN R&D CENTER	CANON	SANYO	NIPPON DATA GENERAL	RICOH
1982	9	9	0																			
1983	26	9	17	*	*	*	*	*	*	*	*	*										
1984	34	9	25	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1985	37	9	28	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1986	39	9	30	*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*
1987	38	9	29	*	*	*	*	*	*	*	*	*	*	*	*		*		*	*	*	*
1988	34	9	25	*	*	*	*	*	*	*	*	*	→	NIHON UNISYS			*		*	*	*	*
1989	33	9	24	*	*	*	*	*	*	*	*	*		*			*		*	*	*	*
1990	31	9	22	*	*	*	*	*	*	*	*	*		*			*		*	*		*
1991	31	9	22	*	*	*	*	*	*	*	*	*		*			*		*	*		*
1992	29	9	20	*	*	*	*	*	*	*	*	*		*			*		*	*		*
1993	26	9	17	*	*	*	*	*	*	*	*	*		*			*		*	*		
1994	25	9	16	*	*	*	*	*	*	*	*	*					*		*	*		

FY	Representative Supporting Members: General Supporting Members: SEIKO	FUJI ELECTRIC	YOKOGAWA HEWLETT PACKARD	SONY	OMRON	IBM JAPAN	FUJI XEROX	NISSAN	ANRITSU	KDD	TOYOTA	KAO	MITSUBISHI RESEARCH	MITSUBISHI HEAVY INDS.	CSK	NIPPON STEEL	MITSUBISHI KASEI
1982																	
1983																	
1984	*	*	*	*	*												
1985	*	*	*	*	*	*	*	*	*	*							
1986	*	*	*	*	*	*	*	*	*	*	*						
1987	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1988	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
1989		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1990		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1991		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
1992		*	*	*		*	*	*		*	*	*	*	*	*	*	
1993		*	*	*		*	*			*		*	*			*	
1994		*	*	*		*	*			*		*	*			*	

Source: Institute for New Generation Computer Technology

Table 3. Research Staff of ICOT: Number by Laboratory and by Home Company in 1982, 1985, and 1989

	1982(intial stage)			1985(intermediate stage)					1988(final stage)						
	1st	2nd	3rd	1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th	6th	7th
Head of Laboratory	NTT	ETL	ETL	ETL	ETL	NTT	ETL	NTT	HITACHI	FUJITSU	OKI	NTT	NTT	FUJITSU	ETL
eputy head of Laborator	ETL			ETL	NTT				NTT		MATSUSHITA	NEC	MRI		MRI
(Senior research fellow)															
ETL											1				
OKI EIECTRIC	2						1								
SHARP															
TOSHIBA		1	1		1	1			1						
NEC	2				1		1	1		1					
NTT	1														
BITACHI			1	1		1	2	1				1			1
FUJITSU		1		2			1					1			
MATSUSHITA															
MITSUBISHI ELECTRIC	1		1	1	1		1	1	1	1		1			
OTHERS												1			
Total(1)	6	2	3	4	3	2	6	3	2	2	1	4	0	0	1
(Research fellow)															
ETL						1									
OKI ELECTRIC	1		1	1	1	1	2	1				1		1	1
SHARP	1		1		1		1		2	3	1			2	2
TOSHIBA	1		1	1	2	2	1	1					1	1	2
NEC		2		1					1		1	1			
NTT							1		1						
BITACHI	1	1								1	1				2
FUJITSU	1	2			1	1					1	1	2		
MATSUSHITA	1		1	1	1	1	1	1				1	1	1	3
MITSUBISHI EIECTRIC		2	1				3		1	2	2		1		
FUJITSU SSL									1				1		1
KDD					1									1	
NIPPON STEEL															1
SANYO ELECTRIC															1
SONY									1					1	
TOSHIBA SYSTEMS										1					
OTHERS												1			
Total(2)	6	7	5	4	7	6	9	3	7	7	6	5	6	7	13
Total of (1)+(2)	12	9	8	8	10	8	15	6	9	9	7	9	6	7	14

Notes: Researchers on loan to the Research Planning Department are not included.
MRI = Mitsubishi Research Institute, Fujitsu SSL = Fujitsu Social Science Laboratory, Toshiba Systems = Toshiba Information Systems

Source : Institute for New Generation Computer Technology

Table 4. The Number of Technical Papers and Technical Memorandums

Year	Technical Reports				Technical Memorandums			
	Total	ICOT	Joint		Total	ICOT	Joint	
			Dom.	Int.			Dom.	Int.
1982	2	2	0	0	2	2	0	0
1983	36	25	3	4	32	28	1	1
1984	58	34	15	3	101	53	23	1
1985	52	31	12	1	123	51	48	2
1986	74	33	19	1	126	56	49	0
1987	107	65	26	0	179	82	56	0
1988	115	68	31	5	237	90	76	3
1989	82	50	23	0	190	84	56	4
1990	81	52	16	10	140	68	37	1
1991	114	52	31	7	148	49	57	1
1992	104	56	47	4	97	41	32	6
1993	36	26	15	3	49	23	20	2
1994	40	15	25	5	28	15	15	2
1995	13	11	n.a.	n.a.	5	3	n.a.	n.a.
Total	914	520	263	43	1457	645	470	23
	100%	56.9%	28.8%	4.7%	100%	44.3%	32.3%	1.6%

Note:

ICOT = The number of papers of which the first authors are affiliated to ICOT

Joint, Dom. = The number of papers of which the authors are affiliated to separate domestic organizations

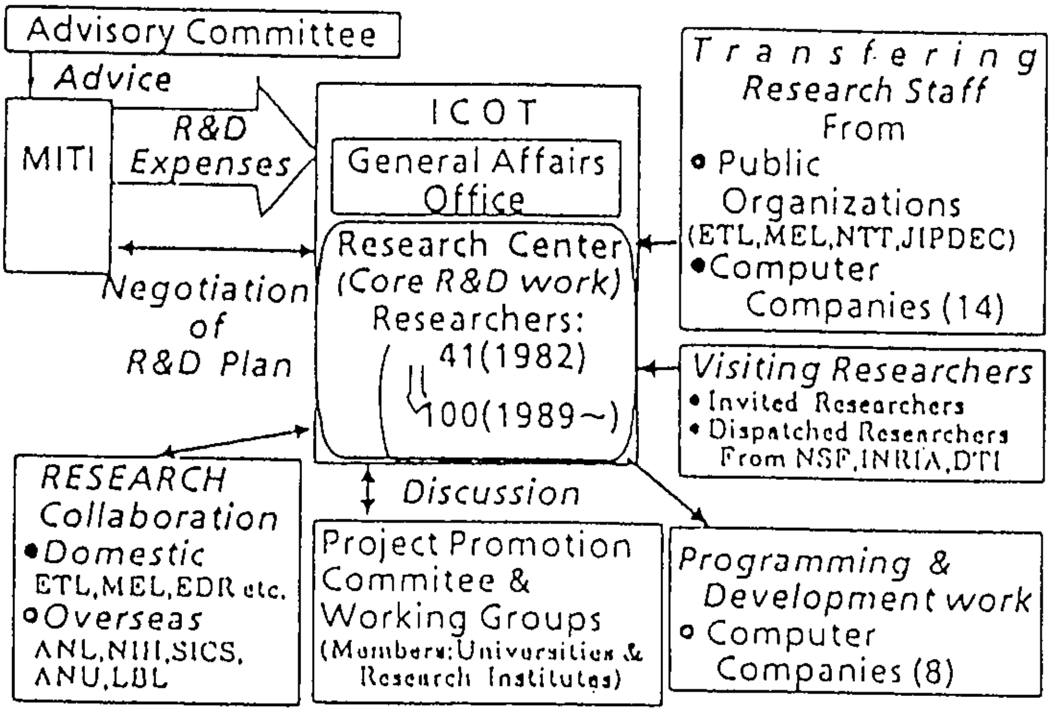
Joint, Int. = The number of papers of which one or more of the authors are affiliated to foreign organizations

Table 5. Number of Research Papers and Citations by the Researchers of ICOT and Other Organizations

Organization	No. of Researchers Examined	No. of Papers		No. of Citations	
		Total	Per-Researcher	Total	Per-Researcher
ICOT	11	69	6.3	436	39.6
Japanese university	8	70	8.8	171	21.4
Japanese institute	12	33	2.8	309	25.8
European institute	10	29	2.9	184	18.4

Source: Our calculation from SCISEARCH Database.

Figure 1. Structure for Promoting the FGCS Project



Abbreviations:

Japanese Institutions

EDR	Electronic Dictionary Research Institute
ETL	Electrotechnical Laboratory
ICOT	Institute for New Generation Computer Technology
JIPDEC	Japan Information Processing Development Center
MEL	Mechanical Engineering Laboratory
MITI	Ministry of International Trade and Industry
NTT	Nippon Telegraph and Telephone

Foreign Institutions

ANL	Argonne National Laboratory (USA)
ANU	Australian National University
DTI	Department of Trade and Industry (UK)
INRIA	Institute National de Recherche en Informatique et Automatique (France)
LBL	Lawrence Berkeley Laboratory (USA)
NIH	National Institute of Health (USA)
NSF	National Science Foundation (USA)
SICS	Swedish Institute of Computer Science

Source: Institute for New Generation Computer Technology