Chapter 12

EVALUATION OF GOVERNMENT-SPONSORED R&D CONSORTIA IN JAPAN

by

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Introduction

Co-operative R&D has been widely celebrated as a means of promoting private R&D, and some see it as a major tool for enhancing industry competitiveness. Co-operative R&D is defined as an agreement among a group of firms to share the costs and results of an R&D project prior to the execution of that project. Co-operative R&D can be executed in many forms, including R&D contracts, R&D consortia and research joint ventures.[2] In this analysis, these forms are collectively referred to as R&D consortia or co-operative R&D projects, interchangeably.

Japan is regarded as a forerunner in the practice of co-operative R&D. The most celebrated example is the VLSI (Very Large Scale Integrated circuit) project, designed to help Japan catch up in semiconductor technology. The project, conducted between 1975 to 1985 with a budget of 130 billion yen (US$591 million) of which 22 per cent was financed by the government, developed state-of-the-art semiconductor manufacturing technology. All of the major Japanese semiconductor producers participated in this project, and Japanese semiconductor companies gained world leadership after the project. It is widely believed that this success story is only one of many.

The perceived success of the VLSI project has motivated other countries to emulate “Japanese-style” collaboration. The 1984 US National Co-operative Research Act was enacted to relax antitrust regulations in order to allow the formation of research joint ventures. Major co-operative R&D projects followed. SEMATECH was established in 1987 to develop semiconductor production technology with a US$1.7 billion budget as of 1996, half of which was financed by government. The Department of Defense sponsored co-operative ventures on the development of flat-panel displays (an estimated US$1 billion over five years beginning in 1994). A successor bill to the 1984 law, The National Co-operative Research and Production Act, was passed in 1993 to extend the 1984 law beyond research and development, to encompass the production of new technologies as well.

In Europe, the block exemption from Article 85 of the Treaty of Rome, which determines EEC competition rules, for certain categories of R&D agreements was introduced in 1985. Even earlier, many co-operative R&D projects were organised including the US$5.6 billion European Strategic Programme for Research and Development of Information Technology (ESPRIT) project in 1984, and the UK Alvey project in 1984, both for the development of computers and information technology. These projects were in response to another famous Japanese co-operative R&D project, the Fifth Generation Computer Project. Other European efforts include programmes under the European Research Co-ordination Agency (EURECA) started in 1985.

Despite all these developments, co-operative R&D has been examined empirically by only a few studies and comprehensive empirical research is almost non-existent. There are many case studies (for example, Katz and Ordover, 1990; Fransman, 1990; Murphy, 1991; Ouchi and Bolton, 1988; Dunning and Robson, 1988), but most treatments have been based on anecdotal evidence, or on the accounts of a few highly publicised co-operative R&D projects, namely MCC, SEMATECH in the US, ESPRIT in Europe, or the VLSI Project and the Fifth-Generation Computer Project in Japan. In many senses, these projects are not typical and, therefore, not representative of the R&D consortia in these countries. A deeper understanding of co-operative R&D requires a more systematic, cross-sectional analysis. The focus of past empirical research has been on the industry and firm characteristics of participants in co-operative R&D (Scott, 1988; Link and Bauer, 1987; Kleinknecht and Reijnen, 1992; Kodama, 1991; Shirai and Kodama, 1989) or on a simple comparison of two different sets of co-operative R&D (Aldrich and Sasaki, 1995). In general, the existing research on alliances does not provide any significant empirical evidence regarding the factors that determine co-operation, or on the likely outcomes of such co-operation (Smith *et al.*, 1995). As Parkhe (1993) suggested for research on joint ventures, the need for a more in-depth understanding of corporate partnering behaviour is dependent on the research of large data sets (Hagedoorn, 1995).

The goal of this chapter is to examine methodologies to evaluate government sponsored R&D consortia. Two major methodologies – a questionnaire analysis and an econometric analysis – are discussed. The advantages of each differs by the objective and the measure of the evaluation. The second section discusses the kind of criteria that can be used to evaluate government-sponsored R&D consortia. The third section examines a questionnaire analysis, taking Japanese R&D consortia as examples. Section 4 presents an econometric analysis on the same data. The final section summarises the findings from these analyses and discusses the role of co-operative R&D in Japan.

Evaluation criteria

There are several possible categories for the evaluation of government-sponsored R&D consortia. The first is regarding whose viewpoint should be taken. The second is the basis of evaluation of consortia performance, since the evaluation is a relative issue. These two categories are interrelated, and discussed here jointly. From the government's viewpoint, the success of government-sponsored R&D consortia can be measured as a project's achievements relative to its intended goals. Possible goals include broad ones such as stimulating a nation's basic research, increasing spillover effects of R&D consortia among participants or to non-participants, and improving the foundations of a nation's industrial competitiveness. More specific goals can be set for each project, such as technological goals or commercialisation goals.

An econometric analysis can be used to identify quantitative effects of R&D consortia. It is important to note that R&D consortia are only one of many factors determining the level and intensity of private R&D. The level of private R&D spending can be affected by many causes, including demand conditions and the technological opportunities faced by companies. It is therefore important to control for other determinants of R&D intensity to isolate the effect of R&D consortia. Econometric analysis is a useful tool in this respect.

From the participants' point of view, the evaluation criteria can vary. Firms have various motives for participating in R&D consortia, implying that evaluation criteria should depend on their initial motives. The benefits firms perceive from R&D consortia also depend on the process of R&D consortia, and so the design and organisation of R&D consortia affects their evaluation. Furthermore, outcomes of R&D consortia affect product-market competition as well as firm R&D. The success of the consortia itself is a secondary issue for participants as long as participation brings them tangible and intangible outcomes. In some cases the success or failure of an R&D consortium does not translate into advantages or disadvantages participants might benefit from/suffer.

The evaluation of the performance of R&D consortia from the participants' viewpoint, therefore, requires detailed qualitative analysis. A questionnaire analysis is an effective tool in this respect, and in the next section an example of an application is discussed.

Questionnaire analysis

Introduction

A questionnaire analysis is effective in evaluating the managerial perspective, including the motives for consortia participation and consortia design. This methodology facilitates the analysis of perceived overall successes, including the direct success of project outcomes and the general contributions of the project to a participant's competitive position. Questionnaire analysis allows for the collection of project- and company-specific data, which can be used to analyse the specific relationship between various aspects of a project and participants. One example is the analysis of the relationship between the design of consortia and outcomes caused by different designs. Qualitative data, as well as quantitative data, can be obtained from questionnaires. These data can be used for econometric analysis, and can become a basis of comparison with results from econometric analysis based on secondary data.

R&D consortia in Japan

The empirical analyses in this article concentrate on Japanese R&D consortia sponsored by governmental organisations.[3] This form of co-operative R&D is chosen because these ventures are most frequently cited as being important to industry competitiveness, particularly among Western observers. It is also chosen because it is comprehensive and detailed data are available.

Government-sponsored R&D consortia, in this article, include all significant company-to-company co-operative R&D projects formed with a degree of government involvement. The nature of government involvement in R&D consortia varies. The government can have significant influence on the formation of consortia, including input into the type of participants who will be involved and the directions the consequent research will take. One means by which the government wields this influence is through the provision of subsidies to the consortia that meet established criteria. In this article, a principal criterion identifying a government-sponsored R&D consortia is that the projects of the R&D consortia involved co-operation among private companies. In other words, projects which were primarily government procurement, and those in which government agencies simply allocated tasks with no private sector initiative, were excluded. Projects which were essentially the implementation of existing technology were also excluded. Annex 1 provides a detailed explanation of the data.

A large number of government-sponsored R&D consortia were set up between 1959 and 1992, of which 237 are included in my data set. 1 171 companies participated in these consortia during this period and many were involved in multiple projects. Inclusion of the multiple projects yields a data set with 3 021 company-project pairs. This data set was collected from each Ministry through direct contacts after examining a wide range of government White Papers and other government publications, and is as close as possible to an exhaustive list of all the government-sponsored R&D consortia in Japan.

Application to Japanese R&D consortia data

Methodology

Sakakibara (1997*a*, 1997*b*) presents an application of a questionnaire analysis on the data sub-sample described above. The questionnaire was based on the theoretical literature relating to co-operative R&D and on interviews with high-level corporate executives and senior government officials who have planned or organised R&D consortia. The questionnaire was aimed at high-level R&D managers who have supervised or participated in R&D consortia. In order to minimise misinterpretation of questions, the questionnaire was pre-examined by several industry managers and government officials who have co-ordinated R&D consortia.

The questionnaire's unit of analysis is a company-project pair: a company's answer to questions relating to a particular R&D consortium. The questionnaire consisted of three parts. Part 1 focused on the motives for participating in R&D consortia. Part 2 focused on issues relating to the design of the R&D consortium, including goals, industry participation patterns, and organisational and co-ordination characteristics. Part 3 focused on the outcomes of the projects, including the perceived merits and demerits, as well as on the overall evaluation of the project, and on the contribution of the project to the establishment of the participants' competitive position. Most answers were reported on a five-point Likert scale. Finer scaling than this was not considered to increase the accuracy of responses. For some questions, respondents were asked to complement these numerical responses with detailed comments. This questionnaire was administered in July-October 1993.

In order to achieve a high response rate and to obtain exact and objective answers, questionnaires were distributed to member companies of the Japan Research Industries Association (JRIA), a non-profit organisation formed by companies interested in building their R&D capabilities. This organisation's affiliation to the government (MITI) could be a potential source of bias in the answers. To minimise any biases, questions were asked only about co-operative R&D projects which have ended or reached the "near-completion" stage. Questions which directly evaluated the role of the government were minimised. In addition, complete anonymity was guaranteed. It turned out that responses were quite frank, and comments on questionnaires included responses that were critical of the government, respondents' own companies and other participating companies. Therefore, it is reasonable to say that these answers reflected the honest opinions of the R&D managers in participating companies. One way to test the accuracy of these responses is to confirm them with secondary data. The beginning year of each project obtained from the questionnaire was checked against the list of government-sponsored R&D consortia. The congruence of data obtained in 381 of the 398 cases (95.7 per cent) supports the validity of the questionnaire data and may also reflect favourably on the likely accuracy of other reported data.

Consortia participants were identified from the list of government-sponsored R&D consortia mentioned above, and questionnaires were sent to the JRIA member companies which were involved in the projects. Eighty-nine companies were asked to answer for 88 projects, which brings the overall potential sample to 512, because many projects had multiple participants whose responses were all sought. There were 398 useable responses from 67 companies concerning 86 projects, and the overall response rate was 77.7 per cent. The projects covered represent 41 4-digit SIC industries. Some questions were left unanswered; therefore the number of effective responses per question ranges from 355 to 398. Questions on multiple projects conducted by a single company were typically answered by different R&D managers, ruling out any bias by the same respondent.

Questionnaire respondents are mostly listed companies, reflecting the fact that the majority of the frequent consortia participants are typically listed companies. Projects about which responses were obtained include world-famous ones such as the VLSI Project and the Fifth-Generation Computer Project, as well as more obscure projects such as the coal gasification or processed food production technology-related projects.

We followed a methodology used by Levin *et al.* (1987) to analyse these answers. We treated ratings along a five-point semantic continuum as if they were interval data. This interpretation, rather than treating the data as ordinal, allowed comparisons to be made among questions. Questionnaires were designed to ensure that cross-question comparisons would arise naturally in the minds of the respondents. The same scale, 1 to 5, was used for each question.

Although the use of semantic scales to assess, for example, the importance of alternative motives of R&D consortia participation introduces considerable measurement error, more readily quantifiable proxies were not available. One could argue about the subjective nature of the data, since the scale of the responses is arbitrary, and may be quite non-linear (responses might tend to concentrate on the middle score 3, or some might systematically favour high scores). The importance of the various motives for R&D consortia participation, for example, was evaluated on a scale ranging from “1 = not important” to “5 = very important”. There is no natural or objective anchor for such evaluative ratings. Individuals may perceive the same environment, but simply use the scale differently.

There are many techniques available to control for differences among respondents in means and variances, but their application generally means abandoning one or more dimensions along which the data might be informative. For example, we are interested in inter-consortia or inter-firm differences in answers to a single question; controlling for fixed effects among respondents would vitiate such measures, since we expect a respondent’s mean score over all questions to depend on his/her own consortia or firm. Standardizing the variance of each respondent’s answers also raises similar problems: the distribution of “correct” responses is unknown and it almost certainly differs among consortia or firms. Cockburn and Griliches (1987), for example, tried various transformations on the data in Levin *et al.* (1987) to correct for these effects. Their transformations did not appreciably change the performance of the variables.

The basic statistics used in the following analysis are the mean responses to each question for the entire sample or sub-samples. Variations in responses among questions are robust to the use of alternative summary statistics, such as the mean of project means or the median of project means. We also used the number of responses taking the values 4 and 5 as an alternative to overall sample means and confirmed that overall patterns among questions are robust. Although there is undeniably much noise in the data, this suggests that the basic findings are robust. We also examined the distribution of questionnaire responses to check if there is any consortia or industry which drives the result one way or the other, and confirmed that there are no apparent “outliers”.

Design of consortia

Several questions were asked about the design of consortia. Table 1 shows that the pattern of consortia design changes from decade to decade. The stage of the target R&D outcome has changed from near-commercial to more basic, and project goals have become more ambitious. Participation from other industries has become wider, though the difference is not significant. Table 1 also suggests that, in general, participation from other industries tends to range widely, implying that the VLSI project-type, single-industry consortia are not necessarily typical of Japanese government-sponsored R&D consortia. In a separate question, 87 per cent of respondents answered that a technology leader in their industries participated in the project.

These changes over time are associated with change in consortia objectives, shown in Table 1. The importance of catching up with overseas competitors has declined, while the importance of entering new businesses has increased. As the Japanese industry has shifted from a simple follower stage to one of leadership among developed countries, R&D has become more basic, by consolidating broad ranges of complementary knowledge, in order to originate a new business or technology.

Table 1. Design of consortia and changes from decade to decade

Design of consortia	1960s	1970s[1]	1980s[1]
Stage of target R&D outcome	3.53	3.43	2.99***
(1 = basic, 5 = near commercial)	(0.18)	(0.10)	(0.07)
Project goal	3.21	3.54*	3.72***
(1 = achievable during project period, 5 = commercialisation would take a significant length of time after project)	(0.14)	(0.10)	(0.06)
Breadth of participation from other industries	3.00	2.89	3.22
(1 = single industry, 5 = wide variety of industries)	(0.33)	(0.14)	(0.08)
<Objective of the project>			
To catch up with advanced technologies already developed by overseas	3.72	3.31	2.83***
competitors (1 = not important, 5 = very important)	(0.25)	(0.14)	(0.08)
To enter a new business area/technology	3.29	3.44	3.55
(1 = not important, 5 = very important)	(0.39)	(0.14)	(0.08)

1. T-tests are comparisons of means versus 1960s. *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level, using a two-tailed test.

Source: Author's calculations from 379 to 398 responses. Standard errors in parentheses.

Effects of R&D consortia on private R&D investment – questionnaire-based results

The effects of R&D consortia on R&D spending are examined in this section, and the results summarised in Table 2. Panel A shows the answers to questions about the scale and pace of R&D that a company would have conducted in the absence of an R&D consortium. On average, if there is no co-operative R&D project, private projects would have been conducted at approximately 34 per cent of the scale of the actual ones – R&D consortia accelerated private R&D by three years. One might argue that respondents have an incentive to report a smaller R&D scale than that which would have actually occurred in the absence of the co-operative project, in order to demonstrate the necessity of government incentives. The respondents, however, are R&D managers who do not necessarily negotiate directly with the government. Nor would the respondents expect their questionnaire responses to directly affect governmental decision making. Therefore, it is reasonable to assume that the potential for biased responses is minimal.

Table 2. Effects of co-operative R&D on R&D spending

Panel A. Scale/pace of an R&D project that the firm would have carried out in the absence of an R&D consortium

	Overall sample means	Frequency distributions ( ) are Likert scales assigned to each answer				
Scale	2.37 (0.06)	Would not have done at all (=1)	in 25 per cent scale (=2)	in 50 per cent scale (=3)	in 75 per cent scale (=4)	Same as what happened (=5)
		96	143	97	36	24
Pace	2.94 (0.07)	10 years or more slower (=1)	5 years slower (=2)	3 years slower (=3)	1-2 years slower (=4)	Same as what happened (=5)
		56	80	96	76	47

Note: Standard errors in parentheses. Samples include missing values. Among respondents who answered 1 in a "scale" question, 34 did not answer a "pace" question. If we take this into consideration, the mean of a "pace" question becomes smaller, *i.e.* projects are more accelerated than the overall sample mean shows.
Source: Author's calculations from 389 to 396 responses.

Panel B. Private R&D investment on R&D consortia-related R&D
Question: How much of its own money did your company spend on project-related R&D?

Overall sample means	Frequency distributions -- ( ) are Likert scales assigned to each answer				
2.74 (0.06)	Didn't spend at all[1] (=1)	50 per cent of government budget (=2)	same amount as government budget (=3)	twice as much as government budget (=4)	more than twice (=5)
	45	141	120	32	47

Note: Standard errors in parentheses.
1. Including 12 answers stating they spent less than 50 per cent of government budget.
Source: Author's calculations from 385 responses.

To see how the R&D consortia have affected R&D spending, companies were asked how much of their own money was spent on R&D related to the consortia project. Project-related R&D spending is a firm's R&D spending in project-related areas, including its outlays in the R&D consortium and additional R&D conducted at the firm's laboratories. R&D spending is measured here as a percentage of government outlay per firm on the project.[4] Earlier discussions with companies indicated that firms would generally be willing and able to provide such percentage figures, whereas they would not be willing to disclose absolute expenditures for each R&D activity. In a consortium, the government precommits its contribution to the project as a percentage of the total project budget. The total scale of the project is also typically precommitted by the government, but can be modified as the project proceeds. Firms pay the rest of the project's expenditure, and they optimise in-house R&D spending related to the consortium. Panel B shows the results of the responses to the question. On average, firms undertook private R&D spending equal to more than 87 per cent of the government's budget allocated to that firm. Table 2 suggests that government-sponsored co-operative R&D serves as a complement, rather than a substitute, to private R&D.

One way to interpret these findings is the following. In the absence of a co-operative R&D project, the firm would have conducted the same R&D project at 34 per cent of the actual scale. In the actual R&D project, the ratio of private R&D outlay (which is the sum of a firm's outlay for a co-operative

R&D project and its outlay on associated in-house R&D) to government outlay per firm for a co-operative R&D project is 87 to 100. This means a firm spent 47 per cent of the total consortium-related R&D outlay; the rest was spent by government. Therefore, the existence of a co-operative R&D project increased private R&D investment from 34 per cent of the total project outlay to 47 per cent of the total project outlay – representing a 38 per cent increase in private R&D investment, on average, in the area related to the co-operative R&D project.

Sakakibara (1997*a*) identifies four major effects of R&D co-operation on a firm's R&D spending which provide a framework for understanding increased private R&D investment by consortia participants. The first effect is an increase in R&D efficiency. This is achieved through gains in economies of scale, elimination of otherwise overlapping investments, or facilitated acquisition of necessary complementary resources for R&D. In all cases, the marginal costs of R&D decline, implying that co-operation is likely to decrease R&D investment while increasing innovative output.

The second effect concerns the spillover of a firm's own R&D on others' R&D productivity. Spence (1984) argues that the existence of R&D spillovers makes it difficult for innovators to capture the full social benefits of their innovative activity, reducing the incentives to conduct R&D. Through R&D co-operation, firms internalise the externality created through spillovers, thus restoring the incentive to conduct R&D.

The third effect of co-operative R&D on private R&D spending relates to learning, which affects the intra-consortia spillover level. Cohen and Levinthal (1989) show that a high spillover rate in R&D among competitors can provide a positive incentive to conduct R&D when a company's own R&D increases its learning capability. Co-operative R&D is a "forced" spillover scheme. The implication is that the spillover rate among consortia participants is likely to be much higher than would be the case without co-operation, which gives participants an incentive to conduct more R&D.[5]

The fourth effect relates to the impact of R&D co-operation on product-market competition. Katz (1986) argues that if a higher level of R&D makes market competition more intense by lowering firms' marginal costs of production, then the resulting decline in profits will reduce their incentive to conduct R&D, implying that R&D consortia can result in less R&D. This argument applies to the case of consortia whose participants come from a single industry and who are more likely to compete directly in the product market. The argument is less applicable, however, to the government-sponsored consortia examined in this chapter, which have been found to more likely include participants from a range of industries. The expected degree of *ex-post* competition for these consortia will be lower.

In the case of Japanese R&D consortia, it would appear that the spillover and learning effects drive the results. To the extent that the efficiency effect impacts on consortia behaviour, it appears to result in stable R&D spending and increased amounts of innovative output, rather than reduced R&D efforts and stable levels of R&D output.

Outcome of the projects

To examine the perceived outcomes of co-operative R&D projects, managers were asked to rank each category of accomplishment on a five-point scale. Table 3 shows that the perceived benefits of the projects were rather intangible, such as researcher training and increased awareness of R&D in general. Tangible outputs, such as commercialisation of a product or process and increased patent applications, were not very important. This is consistent with the limitation that adverse selection imposes on participation. If firms perceive immediate benefits from an R&D project, they prefer to execute it privately. Policy makers also want these projects to be conducted privately, because the private returns on such kinds of projects would be greater than the social returns.

Table 3. Merits of the projects as perceived by participants[1]

Merits of the project	Overall sample means	Analysis of variance of differences among projects (F tests)[2]
Researcher training	3.52 (0.04)	1.38
Increase in awareness of the importance of R&D in general	3.50 (0.04)	1.24
Breakthrough in a critical technology	3.40 (0.05)	1.92***
Accelerated development of the technology	3.32 (0.05)	1.90***
Increase in private R&D budget and awareness of the subject	3.28 (0.05)	1.75***
Acquisition of knowledge from other participants	3.12 (0.05)	1.43***
Establishment of an ongoing information network with other participating companies	3.03 (0.05)	1.20
Commercialisation of a product or process	2.89 (0.06)	2.32***
Increase in the number of patent applications	2.73 (0.05)	2.35***
A superior position *vis-à-vis* non-participants	2.68 (0.06)	1.98***
Establishment of standards in a target industry	2.17 (0.05)	2.16***

1.. Range: 1 = None; 5 = Considerable. Standard errors in parentheses.
2. Covers 374 to 379 responses for 70 projects after eliminating projects which have only a single response; figures are F-ratios. Approximate .05 significance level (**) is 1.4, and .01 significance level (***) is 1.6.
Source: Author's calculations.

Table 4. Demerits of the projects as perceived by participants[a]

Demerits of the project	Overall sample means	Analysis of variance of differences among projects (F tests)[b]
Incurred higher than expected costs	2.86 (0.05)	1.16
Good researchers were tied up with the project, which became an obstacle to the pursuit of other important projects	2.64 (0.05)	1.36
Inflexibility of the project meant that the project goal or approach was deemed obsolete	2.36 (0.05)	1.10
Results such as patents belong to government as a condition of the subsidies, discounting the return to companies	2.34 (0.06)	2.12***
Dissemination of proprietary technology or know-how possessed by the company	2.03 (0.04)	1.62***
Opportunistic behaviour by other companies attempting to absorb as much as possible from others while keeping their own technology secret	1.96 (0.04)	1.56**

1. Range: 1 = None; 5 = Considerable. Standard errors in parentheses.
2. Covers 374 to 380 responses for 70 projects after eliminating projects which have only a single response; figures are F-ratios. Approximate .05 significance level (**) is 1.4, and .01 significance level (***) is 1.6.
Source: Author's calculations.

Table 5. Consortia design and outcome[a]

Panel A

Outcome of participation in a consortia	Overall sample means	Target industry maturity[b]	
		Emerging	Mature[c]
Increase in awareness on the importance of R&D in general	3.50 (0.04)	3.56(0.06)	3.38*(0.07)
Breakthrough in a critical technology	3.40 (0.05)	3.54(0.07)	3.17***(0.09)
Accelerated development of the technology	3.32 (0.05)	3.40(0.07)	3.18**(0.09)
Increase in private R&D budget and awareness in the subject	3.28 (0.05)	3.39(0.06)	3.07***(0.08)
Commercialisation of a project or process	2.89 (0.06)	3.04(0.08)	2.66***(0.10)
Increase in the number of patent application	2.73 (0.05)	2.85(0.07)	2.50***(0.09)

Panel B

Outcome of participation in a consortia	Overall sample means	Industry participation	
		Narrow	Wide[c]
Acquisition of knowledge from other participants	3.12 (0.05)	3.03(0.06)	3.22*(0.07)
Dissemination of proprietary technology or know-how my company possessed	2.03 (0.04)	2.08(0.06)	1.97(0.06)
Opportunistic behaviour by other companies attempting to absorb as much as possible from others while keeping their own technology secret	1.96 (0.04)	2.02(0.06)	1.91(0.06)

1. Range: 1 = None; 5 = Considerable. Standard errors in parentheses.
2. Because of missing values, sample sizes of sub-samples are different from overall sample means.
3. T-tests are comparisons of means of two sub-samples. *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level, using a two-tailed test.

Source: Author's calculations.

The analysis of variance column shows that there is some variation for differences among projects between questions. There is a relatively small difference among projects for responses dealing with predictable merits, such as researcher training, increased awareness of R&D in general, and the establishment of an information network. However, for more uncertain payouts such as commercialisation, increased patent applications and the establishment of standards, the difference among projects is larger.

Table 4 shows responses evaluating the demerits of the project. Compared with Table 3, the findings suggest that firms generally perceive that the merits of projects exceed their demerits.[6] Moral hazard in knowledge sharing was not perceived as a large problem for participating companies, nor were spillovers of their proprietary technology. This point is interesting because respondents are also research intensive companies in their industries, therefore they are potential victims of moral hazard problems with more to lose than to gain through Cupertino. Main concerns for participants were R&D costs and opportunity costs of tying their researchers to co-operative R&D projects.

The relationship between consortia design and outcomes is also examined. Table 5 shows the selected results. Panel A presents the comparison of the outcomes by maturity of target industries in which consortia were formed. The total sample was sub-divided into emerging and mature industries by means of the responses to the question, "What was the state of development of the subject industry?" (1 = emerging, 5 = mature). Responses of 3 or less are classed as emerging, and 4 or more as mature. Panel B classifies observations by breadth of industry participation, narrow and wide. These sub-groups were divided by means of the responses to the question, "How wide was participation from other industries?" (1 = from a single industry, 5 = from a wide variety of industries), with responses of 3 or less classified as narrow, of 4 or more classified as wide.

Panel A shows that more tangible merits are recognised in the projects whose target industry is emerging. The difference between the two sub-samples is significant. An interpretation of this result is that there is less conflict of interests in the projects whose participants have limited experience/knowledge, and so co-operation is facilitated. Also, there is more potential for innovation in emerging industries, both for pure private R&D and R&D consortia.

Panel B shows that wider industry participation is beneficial for sharing complementary knowledge, and the difference is significant. In observations with wider participation, spillovers of proprietary technology and opportunistic behaviour are recognised as less severe problems, although the difference is not statistically significant.

Contributions of consortia

Based on the merits and demerits, managers were asked to give an overall evaluation of each project. They were also asked to evaluate the contribution of co-operative R&D projects to their company's competitive position in target industries, relative to other factors such as domestic competition or the presence of demanding customers.

The overall evaluation of the typical project is a modest success with a mean score of 3.30 (range: 1 = complete failure; 3 = so-so; 5 = impressive success). Respondents' comments on this question cite the failure of commercialisation, the distance of project outcomes from commercialisation, changes in market needs/environment, and failure to meet market needs (*e.g.* insufficient cost reduction) as the main shortcomings leading to their evaluation.

In terms of contributions of R&D consortia to firms' competitive positions, R&D consortia are not considered a critical factor. The mean score to this question is 2.60 (range: 1 = irrelevant to competitive position; 5 = critical to competitive position). Again, this finding is consistent with the finding that most R&D consortia are set up for basic R&D, considering that many other factors intervene in the establishment of the competitive position of companies. R&D consortia are not a panacea for competitiveness.

Participants who benefit from R&D consortia

Who perceives the greatest benefits from R&D consortia? We employed ordinary least square analysis in order to determine the association between firm size and the contribution of R&D consortia to the establishment of their competitive positions. The dependent variable is the Likert-scale score on the contribution of R&D consortia to competitive positions, taken from the response to the questionnaire. Independent variables include firm sales, in real terms as of the first year of project, as a proxy for the company size, and project dummy variables. Table 6 shows that smaller companies benefit more from R&D consortia in the establishment of their competitive position. An explanation for this result is that smaller firms have more potential to grow than larger firms which have established competitive positions. It is also consistent with adverse selection given that larger firms have more to lose than do small firms.

Table 6. Association between firm size and contribution of R&D consortia to the establishment of competitive position

OLS, standard errors in parentheses.
Dependent variable: contribution of R&D consortia to the establishment of competitive position

Explanatory variables	Regression 1	Regression 2
Firm sales (billion yen)	-0.000135** (0.0000649)	-0.000105* (0.0000562)
Project dummies	Yes	No
Constant	1.797** (0.750)	2.697*** (0.0828)
Number of observations	375	375
R-square	0.258	0.0092
Adjusted R-square	0.036	0.0066

Note: *** significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level, using a two-tailed t-test.

Determinants of consortia performance

What makes R&D managers think that consortia are successful? What makes R&D managers think that consortia contribute to firms' competitive position? To establish associations between the performance of consortia and their merits and demerits, as perceived by managers, an Ordered Probit analysis was conducted by using consortia performance variables as dependent variables, and project outcome variables as explanatory variables. Project outcome variables are converted to 0/1 dummy variables by bifurcating the answers by their mean scores, assigning 0 to responses smaller than the means, 1 to responses larger than the means. The purpose of this analysis is to see the weight of each project outcome variable.

Table 7 shows that technological breakthrough and the commercialisation of technology strongly contribute to the evaluation of the project's success. Other intangible merits, such as accelerated technological development and the establishment of an information network are valued, though less so than tangible merits. When a project's goal becomes obsolete, this strongly favours a negative evaluation. In order for projects to be perceived as contributing to a firm's competitive position, only tangible merits, commercialisation and technological breakthrough, are important, along with the realisation of a superior position *vis-à-vis* non-participants.

When the project does contribute to the competitive position of a firm, opportunistic behaviour by other participants is perceived as an important drawback. This implies that when a firm gains significantly from a project, it is also clearly conscious of any opportunity loss from the project.

If the commercialisation of a project's outcome is responsible for a positive evaluation of the project and for the perception of the project as improving the participant firm's competitive position, then what facilitates commercialisation? Examining the relationship between commercial achievement and project design, Table 8 shows that commercialisation is easier for more applied R&D projects and projects with less ambitious goals. As indicated earlier, the targets of co-operative R&D projects have become more basic and more ambitious over time, implying that commercialisation has become more difficult to achieve or that independent efforts have become relatively more effective. It is, therefore, natural that companies do not perceive direct returns from R&D consortia.

Table 7. Ordered Probit for project evaluation and project outcomes

Project outcomes	Evaluation of the project	Contribution of project to competitive position
Merits		
Constant term	2.53***(.313)	-.220(.166)
Breakthrough in a critical technology	.595***(.149)	.432***(.137)
Commercialisation of a product or a process	.547***(.146)	.350***(.134)
Accelerated development of the technology	.445***(.166)	.104(.152)
Establishment of ongoing information networks with other participants	.353***(.151)	.089(.139)
Increase in private R&D budget and awareness of the subject	.226(.157)	.174(.146)
A superior position *vis-à-vis* non-participants	.213(.140)	.856***(.133)
Establishment of standards in an industry	.212(.137)	.221*(.127)
Researcher training	.202(.143)	.122(.132)
Increase in awareness of the importance of R&D in general	.161(.156)	.048(.144)
Acquisition of knowledge from other participants	-.00885(.141)	-.045(.130)
Increase in the number of patent applications	-.015(.144)	-.055(.134)
Demerits		
Inflexibility of the project meant that the project goal or approach is deemed obsolete	-.445***(.137)	-.190(.126)
Opportunity cost of sending good researchers to the project	-.396***(.139)	-.032(.128)
Incurred larger than expected costs	-.135(.143)	-.100(.134)
Opportunistic behaviour by other participants attempting to absorb from others while keeping their own technology secret	-.082(.143)	.481***(.135)
Dissemination of proprietary technology or know-how	-.011(.153)	.222(.141)
Results such as patents belong to government as a condition of subsidies, thus discounting returns	.065(.145)	.025(.135)
Log likelihood	-324.32	-449.00

Note: N=378. Standard errors in parentheses. *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level, using a two-tailed t-test.

Table 8. Commercialisation achievements and design of consortia

Outcome of consortia	Stage of target R&D outcome[1]		Height of project goal[2]	
	Basic	Near commercial[3]	Easy	Ambitious
Commercialisation of a product or process 1 = none, 5 = considerable	2.72 (0.08)	3.16*** (0.10)	3.10 (0.10)	2.76*** (0.08)

1. "Basicness" is based on the question, "What was the target outcome?" 1 = basic, 5 = near commercial. Samples which replied 3 or less are considered basic, 4 or more, near commercial.

2. Based on the question "How ambitious was the goal of the project?" 1 = achievable during project period, 5 = commercialisation would take a significant period after project. Easy is samples which answered 3 or less, ambitious those which replied 4 or more.

3. Standard errors in parentheses. T-tests are comparisons of means of two sub-samples. *** Significant at the 1 per cent level, ** significant at the 5 per cent level, * significant at the 10 per cent level, using a two-tailed test.

Econometric analysis

Introduction

This section presents an econometric analysis applied to the case of Japanese government-sponsored R&D consortia, based on Branstetter and Sakakibara (1997). We test the following hypotheses:

i) Participation in research consortia augments knowledge spillovers.

ii) The spillover-augmenting effect of research consortia raises the "research productivity" of participating firms, controlling for their R&D expenditures.

iii) As a result of *i)* and *ii)*, participation in research consortia may lead to an increase in R&D spending.

We use microdata drawn from a sample of participating and non-participating firms. We find evidence in favour of all three hypotheses.

Empirical challenges

There are two substantial challenges to an empirical estimation of the impact of participation in consortia on research productivity and research intensity. The first is the problem of *measurement*. Technological innovation, *per se*, is not observed. We observe instead the economic manifestations of this innovation, such as patenting and increases in revenue from the introduction of new products and processes or the refinement of existing ones. These empirical proxies are imperfect and potentially fraught with significant errors of measurement. As is well known, the *ex-post* economic value of patents varies enormously, with many patents never leading to new products and others leading to billions in new revenues. Our measures of revenue increases are clouded by the lack of hedonic price deflators which adjust for improvements in quality.

On the input side, there are also measurement issues. Our measures of capital input are taken directly from firms' accounts and deflated by a capital price index. As such, they are the product of numerous acts of creative accounting which may not accurately reflect economic fundamentals. Our measures of R&D input represent a vast improvement over the commercially available data series, such as the NEEDS database or the Japan Development Bank Corporate Finance Data Base. Having supplemented data from these sources with Japanese-language primary sources, we believe that our data are the best non-confidential data available.[7] Nevertheless, there are likely to be errors of measurement here too, since firms vary considerably in the extent to which "informal" research and "process engineering" are recorded in the formal R&D budget.

These measurement problems are common to all micro studies of innovation. In our case, there are some additional measurement issues peculiar to the topic at hand. First, especially prior to 1990, many if not most of the patents to *directly* emerge from the research undertaken within government-sponsored research consortia were, by government directive, assigned not to the participating firms but instead to the research joint ventures themselves. We are still in the process of obtaining data on patents assigned to these joint ventures. In our estimates reported in this paper, we include only data on patents assigned directly to firms. This means that we may systematically underestimate the total *direct* benefits of the consortia.[8] We are also missing, in this version, data on the government subsidy received per firm per project per year. This subsidy is not straightforward to compute, as the effective level of the subsidy differs across firms, projects and years, and the typical participating firm in our sample is involved in more than one project per year. However, the average level of the subsidies has been quite high – in the order of two-thirds of the total project budgets have been contributed by the government. Thus, we may also be underestimating the total social costs of the consortia. This is unfortunate, and if our goal were to undertake a comprehensive "social" cost/benefit analysis of these research consortia, this data problem would severely constrain our analysis.[9] However, our goal in *this* paper is to undertake the more modest task of estimating the impact of participation on the research inputs and innovation of the firms themselves. We *do* have sufficient data on the *private* costs and benefits of the consortia, both direct and indirect, to begin to undertake such analysis.

If the theoretical models of research consortia are at all correct, then the knowledge spillovers that take place through participation in consortia should have an impact on firm research inputs and research productivity that goes beyond the narrow topics investigated by the consortia. In other words, even if we do not observe all of the patents a firm generates through direct involvement in a certain project (because they are assigned to a research joint venture), we certainly observe the lingering effect of the project on the firm's subsequent research, and the subsidiary research activities that grow out of the initial project, as well as the costs associated with them. If these "indirect" effects are large, then we should find them in the data, even without complete information on the direct costs and benefits of the consortia. As it turns out, we can find evidence of such effects in the data.

As mentioned above, the theoretical literature on research consortia suggests that one of the primary benefits of these organisations will be to increase the impact of knowledge spillovers. Like innovation, spillovers cannot be observed *per se*. We utilise the microeconometric framework pioneered by Jaffe (1986) and modified by Branstetter (1996*a*, 1996*b*) to *empirically estimate* the differential impact of knowledge spillovers on firms which frequently participate in consortia and those which do not. This framework allows us to identify a significant and positive effect on knowledge spillovers associated with frequent participation in research consortia.

The final measurement issue has to do with aggregation. Even though we do empirical analysis at the level of the *firm*, there is reason to believe that this is still too aggregated. The reason for this is that the typical participant in research consortia is a fairly large firm with a fairly large research and product portfolio. The typical project targets only part of this research and product portfolio. Thus, one might expect, *ex ante*, that it would be hard to identify the impact of participation in consortia on the overall R&D effort, sales and patenting of the firm as a whole.[10] In this paper, we do find such "overall" effects, but the interpretation of these effects is rendered more problematic by this aggregation problem. As part of our research agenda on Japanese research consortia, we are currently gathering detailed data at the project level that will allow us to get around this aggregation problem.

In addition to problems of measurement, there is also the problem of the potential *endogeneity* of the intensity of participation in research joint ventures. The process by which the goals of R&D consortia and the participating firms are selected is a complex one, involving input from interested firms, academics and MITI's own experts. Ultimately, however, MITI decides which firms participate in which projects. This assignment is not random. To the extent that they can observe it, it is quite likely that MITI officials pick firms with higher "research quality" for participation in more consortia. If we find that research productivity is correlated with the intensity of participation in consortia, it may be that the chain of causality runs *from research productivity to participation*, rather than the other way around.[11]

This is a difficult issue to surmount, especially at our level of aggregation. We take two approaches. The first is the fixed-effect approach, in which we assume that, whatever "research quality" is, it evolves slowly over time, so much so that it does not change in the five-seven years of our sample period. If this assumption is correct, we can obtain consistent estimates of the impact of consortia on research productivity by looking only at the "within" dimension of the data. The second is the standard two-stage least squares (2SLS) approach, in which we first use exogenous and lagged endogenous variables to predict the number of research consortia a given firm will be involved in during a given year. In a second stage, we instrument our measure of participation using these predicted values. This allows us to utilise the cross-section dimension of our data. It also allows, in principle, for research quality to evolve over time. If both approaches, which make quite different assumptions, give us the same results, then we have reasonably robust evidence of an effect of participation on research productivity. This is precisely what we find. For the details of our methodology, see Branstetter and Sakakibara (1997).

Empirical estimates of the impact of consortia

Methodology

We have collected data on 226 firms' R&D spending, sales, capital stock, labour and materials usage, and patenting in the United States as well as in Japan, for the years 1983-89. Of these firms, 141 participated in at least one consortium. Data on participation in consortia come from Sakakibara (1997*b*) mentioned earlier. The other data come from the same sources and are prepared in the same way as in Branstetter (1996*b*). Unfortunately, data are not available for all variables on all firms in all years. In particular, data on R&D spending at the firm level and data on patent applications in Japan are not available for all firm-years. Thus, some of our regressions will be run on a smaller "balanced" panel with 208 firms.[12]

Our analysis proceeds as follows. First, we divide our sample firms into non-participants/ occasional participants and frequent participants as measured by their involvement in consortia over the entire sample period, 1983-89.[13] We present sample statistics for these two samples in Tables 9 and 10. Then, we attempt to quantify the effects of participation on the R&D input and output variables of the firm. Controlling for industry effects and R&D spending, we estimate a "patent" production function to assess the extent to which participation improves "R&D efficiency." Finally, we attempt to test if spillovers are stronger, on average, among participating firms.[14]

Sample statistics

Table 9 gives data on firms that were infrequent participants in MITI-organised research consortia. Since the typical consortia lasted more than one calendar year, we made our division on the basis of "project years." Using Sakakibara's data, for each firm in each year we noted how many consortia it was concurrently involved in. We summed these "project-years" over the entire sample period for each firm. Firms with 11 or fewer project-years over the entire sample period were deemed infrequent participants. Firms with more than 11 project years were deemed frequent participants.[15] Table 10 shows data on frequent participants.

Table 9. Summary statistics for infrequent/non-participants

Variable	Observations	Mean	Median	Standard deviation
R&D/sales	1 095	.042	.034	.030
Sales	1 196	112 013	59 683	191 382
Japanese patents	1 062	199.6	60	486.7
US patents	1 196	15.4	3	39

Table 10. Summary statistics for frequent participants
Participated in more than 11 project-years

Variable	Observations	Mean	Median	Standard deviation
R&D/sales	392	.045	.040	.025
Sales	414	742 200	375 012	1 073 775
Japanese patents	341	2 051.4	460	4 166.7
US patents	414	92	24	171.4

It is immediately obvious that frequent participants were significantly larger and more R&D-intensive than non-participants. Frequent participants also tended to take out more patents in the United States and in Japan. Do frequent participants tend to do significantly more R&D? One traditional measure of R&D intensity is the R&D/sales ratio. A Wilcoxon sign-rank test for the equality of the median R&D/sales ratio in both sub-samples *strongly rejected the hypothesis of equality,* providing statistical evidence that they do, although the actual magnitude of the difference is relatively small. Nevertheless, in terms of absolute yen expenditures, the frequent participants spend much more since, at the median, they are more than five times as large as the non-participants as measured by size. Because of this clear size difference, as well as differences in the industry mix of frequent participants and others, we need to make this comparison using control variables.

Effect of participation on R&D spending

We have run such a regression, using the log of firm i's capital stock to control for size and using industry dummies as additional control variables. Thus, our equation is

$$\log(R\&D_{it}) = \alpha_i + \beta_1 \log(capital_{it}) + \beta_2 (c_{it}) + \sum \delta_d D_d + \varepsilon_i$$

where $R\&D_{it}$ is firm i's R&D spending in year t, α_i is the individual effect, c_{it} is the number of consortia in which firm i is involved in year t and the δ s are the coefficients on our industry dummy variables.[16] This equation is not meant to be a realistic model of firm-level R&D spending, and it is certainly not meant as a structural model. We do not believe, for instance, that firms "optimise" R&D on the basis of their capital stock.[17] This regression is run only to test the hypothesis that increases in the intensity of participation are associated with increases in R&D. Given the *ad hoc* nature of our specification, we realise that our results are open to a number of interpretations.

Table 11. Estimation of the R&D expenditure equation

Variable	Random effects	Fixed effects
Constant	-1.34 (.346)	-1.13 (.425)
log(capital)	.975 (.030)	.931 (.043)
ind1	-.145 (.212)	n.a.
ind2	-.545 (.226)	n.a.
ind3	.085 (.215)	n.a.
ind4	-.645 (.223)	n.a.
c	**.0215 (.006)**	**.019 (.007)**

Note: Here the dependent variable is the log of real R&D spending by firms in the fiscal years 1983-89. Regression includes industry dummy variables.

The results in Table 11 come from our "unbalanced" panel, with 1 486 observations from 226 firms. Here, as in later equations, "c" is simply a count variable showing the number of projects in which the *i*th firm was involved in the *t*th year. Standard errors are given in parentheses. It seems clear from our results that, at the margin, participation in an additional consortium has a statistically positive and significant impact on R&D spending. Firms which participate in more consortia spend more on R&D, even after controlling for size and industry effects. We explore whether or not the same kind of relationship exists in the "within" dimension of the data and find that it does. Results did not qualitatively change when data were restricted to firms for which we have data on all variables in all years. The coefficient on c (about .02 in the fixed-effects model) is small, but the interpretation of the coefficient is the impact of an additional project-year on annual R&D spending. Some firms participate in more than ten projects per year, so the cumulative effect of a transition from being a non-participant to a frequent participant could be quite substantial. For instance, an increase in intensity of participation in the order of an additional five projects per year is associated with an increase in total R&D of over 10 per cent. However, we must note that, while our random effects estimates are robust to the inclusion of a full set of time dummies, our fixed-effects results are not. This is partially because a fixed-effects model sweeps out all cross-sectional variance, which is most of the total variance in the data. Taking out common time-series variance leaves relatively little "signal" in the data relative to the "noise". However, we acknowledge that the evidence for the impact of participation on R&D spending is not as robust as some of the other evidence presented.

Patent production function

We have found some evidence to show that participating firms are more R&D-intensive, a result that is consistent with the predictions of theory. Can we also make statistical inference regarding the productivity of that R&D spending? Here, we continue our exploration of the data by looking for a statistical relationship between a firm's "productivity" of R&D and its "intensity" of participation in R&D consortia. We measure productivity as patents generated per year, controlling for R&D spending, industry effects and firm effects. Results from both a random-effects specification and a fixed-effects specification are provided. The equation we seek to estimate is:

$$p_{it} = \beta_0 + \beta_1 r_{it} + \beta_2 c_{it} + \sum_d \delta_d D_{id} + \mu_{it}$$

where p_{it} is the log of the number of patents generated by firm i in year t, r_{it} is the log of a firm's own R&D investment, c_{it} is the number of consortia in which firm i is involved in year t, and the *D*s are dummy variables. Results are given in Table 12.

Table 12. Estimation of a "patent production function"

Variable	Random effects	Random effects-dummy	Fixed effects
log(R&D)	.605 (.0352)	.622 (.0339)	.507 (.044)
c	**.053 (.011)**	n.a.	**.0460 (.012)**
freq	n.a.	**.501 (.170)**	n.a.
cons	-2.45 (.371)	-2.66 (.371)	-2.30 (.356)
ind1	-.886 (.291)	-.873 (.294)	n.a.
ind2	-.431 (.311)	-.432 (.314)	n.a.
ind3	-.655 (.295)	-.571 (.297)	n.a.
ind4	-.635 (.304)	-.629 (.307)	n.a.

Note: The dependent variable is the log of patents granted in the US per firm classified by year of application, 1983-89. Independent variables are the log of R&D spending, the number of consortia the firm is affiliated with in a given year (c), a dummy variable signifying a "frequent participant" (freq), and four industry dummies.

The results in Table 12 show a positive and significant relationship between participation and patenting.[18] Here we use the numbers of US patents granted to Japanese firms as our dependent variable, although the results using Japanese patent applications are qualitatively similar. The third column shows the results when we use a dummy variable to identify the most frequent participants. It is, of course, difficult to assign any causal interpretation to the results in this column because of the likelihood that "research quality" is correlated with the intensity of participation in consortia. Because of this, in fact, the random effects estimates may be inconsistent. A fixed-effect model removes all constant factors, such as industry affiliation and, hopefully, research quality, from the regression, although this may worsen the bias that arises from measurement error. The results from the fixed-effects model are broadly consistent with our earlier regressions and suggest that at least some of the impact of participation on patenting is, in fact, driven by participation rather than some left-out variable such as "quality of the research team."[19]

The point estimate from the fixed-effect model suggests that participation in an additional consortium increases patenting by about 5 per cent, holding other variables constant.[20] This seems a small effect, but the cumulative effect of an increase in the intensity of participation from one to five projects per year could have a substantial cumulative effect on research productivity.[21]

While there are a number of reasons to think that at least some of the effect of participation on patenting is practically contemporaneous,[22] as we have modelled it, there are also reasons to believe that the full impact comes only after a lag of one or two years. In particular, a two-year lag makes sense because research personnel are typically rotated into research consortia, then rotated back to the parent firm on a two-year cycle. When they return to the firm, they bring with them a substantial amount of explicit and "tacit" knowledge about the new technology being developed in the consortia. To allow for these lags in a simple way, we substituted one- and two-period lagged measures of participation in place of our contemporaneous measures and re-estimated our fixed-effect model. The results are qualitatively similar to those reported in Table 12. Our lagged measure of "c" remains positive and significant, with a coefficient of approximately the same magnitude as in Table 12.

The alternative to a fixed-effects approach is to use instrumental variables. In Table 13 we present results based on the 2SLS model, using both the log of patents registered by Japanese firms in the United States and results using firms' patent applications to the Japanese Patent Office. The results are qualitatively similar to the fixed-effects results, although the magnitudes are larger. The R^2 from our first-stage regression of research consortia on our vector of exogenous variables and instruments is slightly more than .7, indicating a reasonably good fit. In our results, we used seven-, eight-, and nine-period lags of counts of project-years as instruments. Note that the point estimates of the impact of an additional consortium on research productivity are, in the case of the regression using Japanese patent applications, more than twice as high as those which we obtained in our fixed-effects model. These estimates imply that an increase in intensity of participation of the order of two projects per year would increase research productivity (as measured by patents per R&D dollar) by between 10 and 16 per cent.[23] We found that the 2SLS results do not qualitatively change when time dummies are included. We also found that the results do not qualitatively change when we use two-period lagged measures of participation rather than a contemporaneous measure of participation.[24]

Table 13. Two-stage Least Squares estimates

Variables	US patent grants	Japanese patent applications
c	**.0492 (.0118)**	**.0804 (.0099)**
lrnd	.7096 (.0254)	.7838 (.0236)
ind1	-.9122 (.1240)	-.9702 (.1133)
ind2	-.3856 (.1334)	-.1148 (.1219)
ind3	-.7155 (.1285)	-.2036 (.1171)
ind4	-.6561 (.1311)	-.2608 (.1210)
cons	-3.286 (.2278)	-1.423 (.2093)

Note: The dependent variables are log of patents granted in the United States per firm, classified by year of application (first column), and log of patent applications made by firms to the Japanese Patent Office, classified by year of application. Independent variables are the log of R&D spending, the number of consortia the firm is affiliated with in a given year (c), and four industry dummies. R&D, industry dummies, and 7-, 8-, and 9-period lagged "c" values are used as instruments in the first-stage regression.

The linear model has a great advantage in that the estimation of fixed and random effects is quite straightforward. However, the linear model has a serious drawback in estimation. Not a few firms take out no patents in any given year. The alternative to this is to use a model in which zeros are a natural and predicted outcome. The canonical model is the Poisson model and its generalisations. Results based on these models, using Japanese patent applications are presented in Table 14. Regressions run using US patents were qualitatively similar.[25]

It is possible to exploit panel data to run "fixed-effect" versions of the Poisson model and more general models based on it. The results of such an estimate are presented above in the fourth column of Table 14. As we can see, this result is completely congruent with both the linear fixed effect results and the Poisson pooled results and indicates that, even in the "within" dimension, participation has a reasonably strong and robust positive effect on research output even after controlling for private research input.

Of course, we have not included in these regressions the government subsidies provided to the firms. An alternative interpretation of results is that we are simply picking up the output effects of unmeasured subsidies. A "back-of-the-envelope" calculation *strongly* suggests that this interpretation is unlikely to be true. While we do not have precise data on the subsidies offered per firm per project per year, we can roughly approximate them. There are 131 consortia in which the firms in our sample participated during the years 1983 to 1989. If we allocate the total project budgets for these consortia equally over the planned duration of the projects, we obtain a figure of 503 484 million yen (in constant prices) in government subsidies for these projects over the seven years of our sample period. In order to obtain a subsidy figure per firm per year, we divide this sum by the number of firms which participated in these projects in each year (including participating firms for which we do not have R&D or patent data). Thus, the average government subsidy per firm per project per year is only 68.3 million yen.[26] In contrast, the average level of R&D spending for our 226 firms is 13 211 million yen. Since the average firm in our data set is involved in slightly less than one project per year, on average, the government subsidy per firm per year only accounts for about 0.52 per cent of annual firm R&D expenditure. This magnitude is much smaller than the estimated effect of participation on innovative output, which ranges from 4 to 8 per cent.[27] Although the government subsidy increased the effective R&D input for firms, the *much* more substantial increase of firm R&D output implies the presence of an effect of consortia participation that is greater than a simple "subsidy effect".

Table 14. Estimation of Poisson/Negative Binomial patent production functions

Variable	Poisson	Poisson-dummy	Negative Binomial fixed-effects model
log(R&D)	.948 (.001)	.972 (.001)	.613 (.0042)
c	**.012 (.0001)**	n.a.	**.093 (.0104)**
freq	n.a.	**.208**	n.a.
cons	-2.05 (.011)	-2.31 (.011)	
ind1	-1.09 (.007)	-1.12 (.007)	n.a.
ind2	-.263 (.007)	-.301 (.007)	n.a.
ind3	-.248 (.007)	-.243 (.007)	n.a.
ind4	-1.14 (.007)	-1.22 (.007)	n.a.

Note: Here the dependent variable is the count of applications to the Japanese patent office by firm by year. The other variables are the same as in Table 12.

Patents and spillovers

Finally, we present indirect estimates of the impact of consortia on knowledge spillovers. We do not have enough degrees of freedom to allow γ to vary with the number of project-years. Instead, we divide our sample into non-participants/infrequent participants and frequent participants and allow the parameter γ to vary across the two sub-samples. Then we construct a Chow test to identify whether the parameters are significantly different. In practice, this is done by running a regression including an *interaction term* in which the spillover term is multiplied by a dummy variable signifying whether or not the firm is a "frequent" participant. An F test on the significance of the coefficient of the interaction term is equivalent to a Chow test of a difference in that parameter, holding others constant. In some specifications, we also allow the *intercept terms* of frequent participants to differ from those of other firms. In the regression results below, it does seem that the patent output elasticity of spillovers, as we measure them, is much higher for the frequent participant sub-sample. We interpret these results as suggesting that it is indeed through the channel of augmenting spillovers that research consortia raise both R&D levels and R&D productivity. We estimated:

$$p_{it} = \beta_0 + \beta_1 freq_i + \beta_2 r_{it} + \gamma_0 k_{it} + \gamma_1 k_{it} * freq_i + \sum_d \delta_d D_{id} + \mu_{it}$$

where k_{it} is the potential spillover pool following Jaffe (1986). The results reported in Table 15 are representative of our findings. In the OLS model, the interaction term is positive and significant, but small in magnitude. In general, allowing the constant term to vary as well as the spillover parameter results in very large differences in the innovation output elasticity of the spillover term in the sub-sample. Allowing a separate constant term does have a useful interpretation. The managerial literature suggests that there are substantial "co-ordination costs" associated with the management of research consortia.[28] Research personnel must invest considerable time and energy in co-ordinating research activities across firm boundaries and overcoming the natural tendency to free-ride on the efforts of other participants. It is quite likely that the separate intercept term for frequent participants is picking up the effects of these co-ordination costs. The sign and magnitude of the coefficient suggest that these costs are quite substantial, a finding completely in accordance with the view of the managerial literature.[29] Furthermore, as we mentioned, firms were not generally permitted to apply for patents on research conducted within the consortia. Instead, those patents were frequently assigned to the consortia. This may have lead frequent participants to lower their propensity to patent.

Finally, we note that in a fixed-effects version of the patent production function, the interaction term is positive and of reasonably high magnitude, but is statistically insignificant. This result is not surprising, given our small sample size and the fact that our spillover term is certainly measured with error, a problem which is exacerbated when we use fixed-effects models. These results suggest that participation is associated with increased impact of spillovers, but the evidence is not conclusive.

Table 15. Estimation of spillovers model with patents as dependent variable

Variable	OLS model with interaction term	Random effects with interaction & dummy	Fixed effects with interaction term
log(R&D)	.716 (.030)	.591 (.049)	.356 (.084))
Spillover pool	**.448 (.094)**	**.570 (.141)**	**.949 (.215)**
Spillover*frequent	**.027 (.008)**	**.571 (.277)**	**.139 (.400)**
industry 1	-.556 (.167)	-.390 (.296)	n.a.
industry 2	-.122 (.176)	-.118 (.310)	n.a.
industry 3	-.538 (.163)	-.580 (.296)	n.a.
industry 4	-.525 (.179)	-.498 (.308)	n.a.
Frequent (dummy)	n.a.	-7.17 (3.71)	n.a.
constant	-9.47 (1.21)	-8.06 (1.26)	n.a.

Note: The dependent variable is patents granted in the United States to firms by date of application.

Conclusions

The questionnaire analysis found that R&D consortia both enlarge the scale and quicken the pace of R&D, and government-sponsored R&D consortia work as a complement of private R&D. R&D consortia typically involve wide participation from different industries. The perceived benefits of projects are rather intangible, such as researcher training and increased awareness of R&D in general. The more tangible merits are recognised in the projects focused on emerging industries. Opportunistic behaviour and spillovers of proprietary technology to participants are not perceived as severe problems in conducting co-operative R&D, even though the technology leaders, who potentially have more to lose from co-operation than do small firms, typically participated in consortia. Wider industry participation mitigates these problems. The overall subjective evaluation of the typical project's success is modest, and participants do not perceive R&D consortia to be critical to the establishment of their competitive position.

Our econometric analysis suggests that the predictions we made about the effect of participation in research consortia on R&D performance find support in the data. Namely:

- ◊ participation in R&D consortia tends to be associated with higher levels of R&D spending of participating firms;
- ◊ participation in R&D consortia also seems to raise the research productivity of participating firms;
- ◊ finally, our results suggest that at least one channel through which consortia have these positive effects may be through effectively augmenting knowledge spillovers.

Based on our empirical results we can assign numbers to these effects. The estimated elasticity of an additional consortium on R&D spending from our fixed effects and 2SLS estimates suggests that if a firm participates in an additional project per year, it will raise its total R&D spending by about 2 per cent and its patenting per R&D dollar (*i.e.* its research productivity) by between 4 and 8 per cent. These may sound like small effects but the cumulative impact of a large increase in the intensity of participation in research consortia could be substantial. Although we do not actually observe many such changes in our data, we should point out that an increase of five projects per year will raise R&D spending by more than 10 per cent, patenting per R&D dollar (adjusted for industry effects) by between 20 and 40 per cent, and could more than double the estimated elasticity of knowledge spillovers on the firm's own innovation.

In addition to the benefits of consortia, however, we have also found evidence of their costs. The managerial literature suggests that the co-ordination of research across firms can impose substantial administrative burdens on the research personnel of participating firms. We have presented econometric evidence consistent with this view in Table 15, which suggests that frequent participation in research consortia does increase the impact of R&D spillovers, but it also imposes other costs on the firm. The previous paragraph suggests that the *net* benefits of participation are positive.

Viewed as an instrument of industrial policy, our results to date suggest that the consortia did have the effect of stimulating innovative activity by the selected firms. We have not included a measure of the cost of government subsidies or the administrative costs incurred, nor do we yet have measures of the patents assigned directly to the joint ventures, so that a true "social" cost/benefit analysis of consortia is beyond the scope of the present paper. However, the finding of a positive effect of participation on innovation is a necessary, though not sufficient, condition for demonstrating that subsidising consortia is a worthwhile social investment. Between 1960 and 1991, the average government contribution to government-sponsored R&D consortia accounted for only 1.6 per cent of total R&D expenditure in Japan, suggesting the small magnitude of the costs incurred by government.

One interesting finding from the results of our questionnaire and econometric analyses is that both results coincide in the role R&D consortia play in the participating firms' R&D spending. Both analyses indicate that R&D consortia stimulate participating firms' private R&D efforts. R&D consortia also increase R&D outputs, and the net effect is increased R&D productivity.

On the whole, our preliminary results suggest that this is a fruitful area of research. As all advanced nations struggle to maintain growth and innovation in the face of changing technology and increasing international competition, policies to enhance R&D spending and bridge the gap between the social and private benefits of R&D offer one of the few methods available to governments for promoting sustainable growth. Our review of the policy history in this area suggests that governments throughout the advanced world will continue to resort to consortia. We may have much to learn from the successes and failures of the Japanese experience.

NOTES

1. This paper heavily draws on Sakakibara (1997*a*, *b*) and Branstetter and Sakakibara (1997). I would like to thank Richard Caves, Gary Chamberlain, Glenn Ellison, Drew Fudenberg, Zvi Griliches, Rebecca Henderson, Adam Jaffe, Marvin Lieberman, Michael Porter, and seminar participants at Harvard, UCLA, Hebrew University, the ASSA meetings in Washington, DC and New Orleans, and the Spring 1997 NBER Productivity Program meeting for helpful suggestions on earlier versions of this paper. I am grateful to the Japan Research Industries Association, especially Toyoharu Sumikama and Akira Numata for their help in managing the survey. I would also like to express my appreciation to Chihiro Watanabe and Toshihide Kasutani at the Ministry of International Trade and Industry, Japan for the co-ordination and helpful suggestions for the survey. Financial supports from the Alfred P. Sloan Foundation, the Harvard Business School Division of Research, and the Center for International Business Education and Research at the UCLA Anderson Graduate School of Management are gratefully acknowledged. This research was partly conducted when the author was a Special Researcher at the National Institute of Science and Technology Policy, Science and Technology Agency, Japan. Any remaining errors are my own. Aya Chacar and Makoto Nakayama provided excellent research assistance.

2. For an argument about the definition of co-operative R&D, see Katz and Ordover (1990).

3. This data set was originally prepared for *The Two Japans: Re-examining the "Japanese Model" of Competitiveness*, Michael E. Porter, Hirotaka Takeuchi with Mariko Sakakibara, forthcoming.

4. This way of private R&D measurement might sound odd to US readers, but this is the standard way of communicating with Japanese R&D managers. In government-sponsored R&D consortia in Japan, government funding is typically allocated to each participant. A firm measures its R&D investment as a percentage of this allocated fund.

5. Sakakibara (1993) shows that when firms possess highly complementary knowledge, participant firms will choose to increase the spillover rate in the consortia, and R&D spending also increases relative to the non-co-operation case.

6. For example, the score of the top demerit criterion, incurred bigger than expected costs, is smaller than the top six merit criteria at the 1 per cent level of significance, using a two-tailed t-test on the distribution of the difference between answers using paired observations.

7. Much of this data came from the R&D survey undertaken by Toyo Keizai as well as data reported in various issues of *Nikkei Kaisha Joho*. We thank Kazuyuki Suzuki, formerly of the Japan Development Bank, for guidance regarding these and other data sources.

8. Of course, firms had an incentive to "delay" patenting until after the official conclusion of the project so that they could secure the intellectual property rights to their innovations. To the extent that this happened, our measures of the direct benefits of consortia are complete.

9. We are currently engaged in building a project-level data base including information on patents assigned to the research joint ventures and government subsidies per project that will, at least in principle, allow us to undertake such a cost/benefit analysis.

10. This is particularly a problem with R&D spending. Survey evidence at the project level suggests that firms see R&D subsidies as a complement to their own R&D spending rather than a substitute for it.

However, if the overall firm R&D budget is fixed, then, at least in the short term, an increase in private consortia-related R&D spending may “crowd out’’ private R&D spending that is not consortia-related.

11 There is also the problem of confounding the effects of consortia with exogenous changes in technological opportunity. If consortia are quickly established in “hot” fields, it may be that our estimates are picking up not the direct effect of consortia but the indirect effect of these changes in technological opportunity. Our ability to control for this at the firm level is limited, though we believe that some of these “technological opportunity” effects are likely captured in our year and industry dummy variables.

12. Our sample was selected on the basis of availability of micro data on research inputs and outputs. It thus consists of firms that are, on average, larger and more R&D-intensive than is generally the case in the “universe” of Japanese manufacturing firms. This is especially true for the “infrequent participants”. We are currently working to expand the data set in both the cross-section and time-series dimension.

13. The data on participation come from multiple sources. The construction of this data is described in detail in Sakakibara (1997*b*).

14. One potential problem that we do not address in this paper is the issue of unmeasured technological collaboration outside the official consortia sanctioned and subsidised by MITI. It is well known that Japanese firms are actively involved in inter-firm technological collaboration. Frequently, but not always, this co-operation takes place within so-called “production *keiretsu*”, in which firms and their suppliers engage in the deliberate exchange of proprietary information and research personnel to enhance the efficiency of product and process innovation. The effects of this knowledge transfer on research productivity and spillovers are explored in Branstetter (1996*b*) and compared with the impact of participation in the research consortia studied here. However, Branstetter’s (1996*b*) preliminary results indicate that the knowledge transfer which takes place within *keiretsu* is qualitatively different from that which takes place in the research consortia modelled here. Thus, concerns that omitting variables on *keiretsu* affiliation might substantially bias the results reported here are not supported by the data.

15. This cut-off number is the 75 percentile in our sample data.

16. The industry dummies used are, in numerical order, chemicals/pharmaceuticals, general machinery, transportation, and precision instruments. The reference industry is the electronics sector.

17. Of course, there are other potential indices of firm size, including log of sales and log of employment. All of these indices have problems as measures of “size”. Sales can fluctuate quite dramatically relative to capital stock for various reasons. Our measures of employment include only “full-time” workers whereas many Japanese firms use large numbers of part-time workers. Still, we note that the results of Table 5 are not sensitive to the use of sales or employment as alternative measures of size.

18. In these equations, we regress patents by the *i*th firm in the *t*th year on the number of research joint ventures that firm has participated in during that year. If research consortia augment firm patenting through R&D spillovers, then one might expect its effects to enter with some lag. The short time-series dimension of the data and the limited variation in participation in that dimension are such that the lag structure is difficult to estimate.

19. A Hausman test rejects the equivalence of random-effects and fixed-effects models. The Hausman test is distributed Chi-square with two degrees of freedom. The p-value of our test statistic of 13.52 is od the order of 0.0012.

20. These results are robust to the inclusion of a measure of firm size, such as the log of capital stock or the log of employment.

21. The positive, significant impact of participation remains even after controlling for the possible effects of Japan's "bubble economy" of the late 1980s. Even after the inclusion of a full set of time dummies, which sweeps out the common "within" variance as well as the cross-sectional variance, the effect of participation remains positive and "marginally" significant (the p-value is approximately .07).

22. For example, there is anecdotal evidence that researchers in consortia frequently communicate with their parent companies, sometimes daily. When an consortium is formed as a dispersed organisation whose research facilities are located at participants' research labs, this communication can be even more frequent.

23. We used a Lagrange Multiplier test to test the validity of our instruments by regressing the residuals from the second stage of our two-stage least squares regression on the instruments used in the first stage. The null hypothesis that our instruments were valid is strongly supported by the data.

24. The results of this and other supplementary regressions mentioned in the text are available from the authors upon request.

25. The results of the Poisson models are robust to the inclusion of time dummies.

26. Even if we assume that subsidies were given entirely to the larger, listed firms that participated in the project, the subsidy per firm per project per year rises to only 95.2 million yen. This adjustment raises the subsidy per firm per project per year to 0.72 per cent.

27. Recall that the estimated innovative output elasticity of own R&D spending is less than 1. This implies that our estimate of the incidence of the government subsidy would have to underestimate the "true" incidence by a factor of 6 to 8 in order to fully explain even the *lower* bound of our range of estimates of the effect of participation on innovative output.

28. See the cited works by Doz (1987), Hladik (1988) and Jorde and Teece (1990) for evidence.

29. Sakakibara has found direct evidence of this in her interviews with Japanese R&D managers. She also cites the work of other researchers which confirms the existence and importance of these costs in Sakakibara (1997*a*).

REFERENCES

ALDRICH, H.E. and T. SASAKI (1995), "R&D Consortia in the United States and Japan", *Research Policy*, 24, 301-316.

BRANSTETTER, L. (1996*a*), "Are Knowledge Spillovers Intranational or International in Scope: Microeconometric Evidence from the United States and Japan", NBER Working Paper.

BRANSTETTER, L. (1996*b*), "Innovation, Knowledge Spillovers, and Dynamic Comparative Advantage: Evidence from Japan and the United States", PhD Thesis, Harvard University.

BRANSTETTER, L. and M. SAKAKIBARA (1997), "Japanese Research Consortia: A Microeconometric Analysis of Industrial Policy", NBER Working Paper, Cambridge, MA.

COCKBURN, I. and Z. GRILICHES (1987), "Industry Effects and Appropriability Measures in the Stock Market's Valuation of R&D and Patents", Discussion Paper No. 1360, Harvard Institute of Economic Research.

COHEN, W.M. and D.A. LEVINTHAL (1989), "Innovation and Learning: The Two Faces of R&D", *Economic Journal*, 99, pp. 569-610.

DOZ, Y.L. (1987), "Technology Partnerships Between Larger and Smaller Firms: Some Critical Issues", *International Studies of Management and Organization*, 17, pp. 31-57.

DUNNING, J.H. and P. ROBSON (eds.) (1988), *Multinationals and the European Community*, Basil Blackwell, New York.

FRANSMAN, M. (1990), *The Market and Beyond: Co-operation and Competition in Information Technology Development in the Japanese System,* Cambridge University Press, Cambridge.

HAGEDOORN, J. (1995), "A Note on International Market Leaders and Networks of Strategic Technology Partnering", *Strategic Management Journal*, 16, pp. 241-250.

HLADIK, K.J. (1988), "R&D and International Joint Ventures", in F.J. Contractor and P. Lorange (eds.), *Co-operative Strategies in International Business*, Lexington Books, Lexington, MA.

JAFFE, A. (1986), "Technological Opportunity and Spillover of R&D: Evidence from Firms' Patents, Profits, and Market Value", *American Economic Review*, 76, pp. 984-1001.

JORDE, T.M. and D.J. TEECE (1990), "Innovation and Co-operation: Implications for Competition and Antitrust", *Journal of Economic Perspectives*, 4, pp. 75-96.

KATZ, M.L. (1986), "An Analysis of Co-operative Research and Development", *RAND Journal of Economics*, 17, pp. 527-543.

KATZ, M.L. and J.A. ORDOVER (1990), "R&D Co-operation and Competition", *Brookings Papers on Economic Activity: Microeconomics,* pp. 137-203.

KLEINKNECHT A. and J.O.N. REIJNEN (1992), "Why Do Firms Co-operate on R&D? An Empirical Study", *Research Policy*, 21, pp. 347-360.

KODAMA, F. (1991), *Analyzing Japanese High Technologies: The Techno-Paradigm Shift*, Pinter.

LEVIN, R.C., A.K. KLEVORICK, R.R NELSON and S.G. WINTER (1987), "Appropriating the Returns from Industrial Research and Development", *Brookings Papers on Economic Activity*, 3, pp. 783-820.

LINK, A.N. and L.L.BAUER (1987), "An Economic Analysis of Co-operative Research", *Technovation*, 6, pp. 247-260.

MURPHY, W.J. (1991), *R&D Cooperation among Marketplace Competitors*, Quorum Books, Westpoint, Connecticut.

OUCHI, W.G. and M.K. BOLTON (1988), "The Logic of Joint Research and Development", *California Management Review*, 30, pp. 9-33.

PARKHE, A. (1993), "'Messy' Research, Methodological Predispositions, and Theory Development in International Joint Venture", *Academy of Management Review*, 18, pp. 227-268.

PORTER, M.E., H. TAKEUCHI with M. SAKAKIBARA (forthcoming), *The Two Japans: Reexamining the "Japanese Model" of Competitiveness.*

SAKAKIBARA, M. (1993), "Complementary Knowledge Sharing in Cooperative R&D: R&D Consortia as a Partial R&D Co-operation", paper presented at the Harvard University Industrial Organization Seminar.

SAKAKIBARA, M. (1997*a*), "Heterogeneity of Firm Capabilities and Cooperative Research and Development: An Empirical Examination of Motives", *Strategic Management Journal*, Special Issue, Summer, pp. 143-164.

SAKAKIBARA, M. (1997*b*), "Evaluating Government-sponsored R&D Consortia in Japan: Who Benefits and How", *Research Policy*, forthcoming.

SCOTT, J.T. (1988), "Diversification versus Co-operation in R&D Investment", *Managerial and Decision Economics*, 9, pp. 173-186.

SHIRAI, I. and F. KODAMA (1989), "Analysis on the Participants of R&D Consortia" (in Japanese), National Institute of Science and Technology Policy, Report No. 5, Science and Technology Agency of Japan.

SMITH, K.G., S.J. CARROLL and S.J. ASHFORD (1995), "Intra- and Interorganizational Co-operation: Toward a Research Agenda", *Academy of Management Journal*, 38, pp. 7-23.

SPENCE, M. (1984), "Cost Reduction, Competition, and Industry Performance", *Econometrica*, 52, pp. 101-121.