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Effect and limit of the government role in spurring technology spillover — a case of R&D consortia by the Japanese government

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Abstract

Why should rivals cooperate? This is the fundamental question posed by R&D consortia. The answer to this question provides a reasonable elucidation of the inside of the black box which enabled Japan to achieve the high-technology miracle in the 1980s.One reasonable answer to the question can be a virtuous cycle spurring technology spillover among participants, and also between consortia and economy as a whole.Prompted by this postulate, this paper attempts to analyze the effect and limit of the role of the government in spurring technology spillover through an emprical analysis of R&D consortia initiated by the Japanese Government over the last four decades.

Keywords: R&D consortia; Technology spillover; MITI's industrial technology policy; Translog cost function

1. Introduction

The workshop report on "R&D Consortia and US–Japan Collaboration" organized by the US National Research Council (NRC) published in 1991 (NRC, 1990) triggered its report by raising a question, "Why should rivals cooperate?". This is the fundamental question posed by R&D consortia. Furthermore, the answer to this natural question leads one to elucidate the source of the mystery, which enabled Japan's high-technology miracles in the 1980s. The foregoing workshop initiated by the NRC is spurred by this postulate. A review of Japan's industrial technology policy reveals that R&D consortia played a core role in achieving industrial technology policy effectively by inducing industry's vitality, leading to the enhancement of Japan's technological level (Johnson, 1982; Okimoto, 1989; Wakabayashi et al., 1999; Watanabe et al., 1991). All this corresponds to the US NRC's postulate. Originated by the enactment of the Law of Engineering Research Association (ERA) in 1961, R&D consortia played a leading role in MITI's Ministry of International Trade & Industry's (MITI)[1] National R&D Program projects by (i) encouraging broad involvement of cross-sectoral industry in these projects, (ii) stimulating cross-sectoral technology spillover and inter-technology stimulation, (iii) inducing vigorous industry activity in the broad area of industrial R&D, (iv) thereby leading to an increase in industry's technology knowledge stock, and (v) constructing a virtuous cycle between the participation of the consortia with qualified human resources and results achieved by the consortia (Watanabe, 1999).

However, notwithstanding such a conspicuous achievement in the 1970s and the 1980s, in line with the stagnation of Japan's industrial R&D in the 1990s, performance of R&D consortia has declined resulting in a vicious cycle between participation and expected results. The quality of participants decreased as the productivity of consortia R&D decreased, resulting in a further decrease in participants quality. To date, a number of studies have attempted to analyze the function of

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[1] MITI was renamed to METI (Ministry of Economy, Trade & Industry) in January 2001 due to the Japanese Government's reorganization

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R&D consortia (Bernstein and Sakakibara, 1997; Sakakibara, 2001). However, the majority of their works focus on case analyses of particular R&D consortia (Callon, 1995), and few works have taken the analyses for the elucidation of the inducement of industry's R&D through technology spillover. Watanabe (1999), in his analysis on the cross-sectoral as well as inter-technology spillover impacts stimulated by R&D consortia, identified that the spillover mechanism would be the core function of R&D consortia.

Noteworthy studies on the numerical analysis of the impacts of technology spillover can be classified into (i) those based on the growth accounting approach (Denison, 1962), tracing inter-sectoral technology spillover by means of cost change in input–output (I–O) tables as demonstrated by Yoshioka et al. (1994), (ii) those identifying spillover technology by tracing patent citation (Scherer, 1965), (iii) those measuring technology spillover flow by means of technology distance (Griliches, 1979) based on proximity of technologies (Jaffe, 1986), and (iv) those analyzing impacts of spillover technology flow by means of cost change by translog cost function (e.g., Bernstein and Nadiri, 1988). Watanabe's approach (1999) is expected to be further developed by utilizing these numerical analyses, and further development has been attempted in his recent works focusing on the measurement of assimilation capacity (Watanabe et al., 2002b, Watanabe and Asgari, 2002, Watanabe et al., 2002a).

Another important subject for R&D consortia is to identify the sources of inducement for firms to participate in the consortia. Sakakibara (1997), based on a questionaire to participants in Japanese Government-initiated R&D consortia, identified that the strongest inducing factor for firms to participate in the R&D consortia is to complement their technological knowledge. Miyajima (1999), by means of a numerical analysis of the governing factors of R&D intensity in one hundred firms of Japan's leading six sectors, identified that the ratio of own fund or debt and firms total assets play a decisive role in deciding their R&D intensity, and suggested that this finding would be suggestive to identifying inducing factor for firms participation in R&D consortia.

Identification of the causality between benefits of consortia participation and inducement for participation decision is also an important question. Watanabe (1997) demonstrated a role of R&D consortia as an incentive for contributors to MITI's Vision formulation by providing them with opportunities to realize their proposals incorporated in the Vision. However, it does not necessary identify the above causality.

On the basis of the foregoing review, the focus of this paper is, first, to attempt to elucidate a function of the Government-initiated R&D consortia in inducing industry's intensive R&D by participating in the consortia and stimulating technology spillover. Second, to analyze trends in the impacts of both inner- and inter-technology spillover within consortia and interaction with the economy as a whole. Third, attempts to demonstrate a hypothesis that the effects of such technology spillover would induce firms' participation in the consortia.

An empirical analysis was conducted taking all consortia established over the period 1961 (the year of the enactment of the Law of Engineering Research Association)–1997 amounting to one hundred and twenty six, as summarized in Table 1 (see Appendix for names of these consortia). The total number of firms that participated in these consortia is 2100. An in-depth analysis was conducted taking the leading 56 firms in both electrical machinery and chemical industries for identification of their motivation of participation in R&D consortia. The next section summarizes a chronological review of the Government-initiated R&D consortia.

The following section provides an analytical framework. We then demonstrate the results of the analysis and their interpretation, and the final section briefly summarizes new findings and policy implications.

2. Chronological review of the government-initiated R&D consortia

Generally, firms' R&D is conducted on its own independent initiative or jointly with other parties. Advantages of the latter include complementing knowledge and experiences with partners, protecting potential diffusion of investment cost through emulation by other parties, diversifying cost and risk, and avoiding duplication loss of research facilities (Miyata, 1997). R&D consortia are typical examples to maximize these advantages.

Government-initiated R&D consortia in Japan are based on the UK's Research Association[2] and were triggered by the enactment of the Law of Engineering Research Association in 1961. A strong requirement in Japan to enhance its technological competitiveness facing the trade liberalization urged such enactment. In addition, structural impediments encompassed Japan's industrial technology structure including the low level of firms' R&D expenditure; another motivation that necessitated such R&D consortia was the overlapping of certain areas of R&D.

Therefore, the Engineering Research Association

[2] The Agency of Industrial Science and Technology (AIST) of MITI sent a survey team headed by Dr. Masao Sugimoto (Director General of Mechanical Engineering Laboratory of AIST) to the UK in 1953 aiming at learning the UK's industrial technology development system. The survey team was deeply impressed by the UK's Research Association system and recommended AIST to consider introducing a similar system in Japan.

Table 1
Number of R&D consortia initiated by MITI[a] (1961–1997)

Research association	Foundation	Corporate juridical party	Public corporation	Private corporation	Total[b]
110 (94)[c]	13 (13)	1 (1)	1 (1)	1 (1)	126 (110)

[a] In addition to these MITI-initiated R&D consortia, R&D consortia initiated by other Ministries counted 20 (18 by the Ministry of Agriculture, Forestry and Fishery, as well as 2 by the Ministry of Transportation) over the period 1964–1989.
[b] In addition to the above, seven consortia participated in MITI-initiated R&D projects over the period 1998–2000. They consist of six foundations and one private corporation.
[c] Figures in parentheses indicate number of consortia in operation after 1981.

established under the auspice of the law was given the following structural features (Nakamura 2001a,b):

1. A temporary association responsible for the accomplishment of R&D for certain R&D projects. The association would terminate its role upon completing its R&D responsibility, and
2. Facilities to be provided, including tax exemptions supportive to organizing a consortium, and conducting its R&D.

Following the enactment of the Law of Engineering Research Association in 1961, the Industrial Structure Research Council (which has since been reorganized as the Industrial Structure Council and the lndustrial Technology Council), an advisory council to the Minister of MITI, published a report in 1963. This report became MITI's (Japan's) first overall 'Vision' by presenting a systematic view on the direction of Japan's industrial development at a time when the Japanese economy was beginning to achieve high growth. There was a growing recognition that further deregulation would follow the shift from direct intervention such as important allocations to indirect inducements, with a greater emphasis on private business initiatives. In line with this view, the Council's Advisory Committee for Industrial Technology presented the following systematic view on the direction of Japan's industrial technology in 1963, which highlighted the significant role of the R&D consortia:

1. Japan's industrial technology should shift from an imported technology-dependent structure to an indigenous technology development,
2. The government should take the initiative in implementing such a shift, and
3. Tie-ups among industry, universities, and national research laboratories for priority R&D projects should be pursued.

In response to this view, MITI established the Entrustment Commission System for R&D of Industrial Technology (Entrustment System) in 1964 which was developed to the National R&D Program (Large-scale Project) in 1966. This program

1. focused on priority R&D projects,
2. was initiated by the Engineering Research Associations (R&D consortia), and
3. was under an entrustment system.

This program founded the base for MITI's long-lasting national R&D program project scheme (Watanabe, 1997) and triggered the base for establishing a successive number of R&D consortia.

Table 2 summarizes the policy steps in the initial stage of establishing R&D consortia as a substantial policy tool in implementing Japan's (particularly MITI's) industrial technology policy.

Induced by the Engineering Research Association, a number of consortia were established in the 1970s and 1980s, however these trends changed to decreasing trends in the 1990s (see Appendix for a list of 126 R&D consortia initiated by MITI by year of operation).

Looking at the figure, we note that the Government support to R&D consortia demonstrated a dramatic increase after 1972. This dramatic increase corresponds to the full-fledged start of the MITI-initiated National R&D Program projects centered by the Large-Scale Project established in 1966 as illustrated in Fig. 2.

Fig. 1 demonstrates that the Government support to R&D consortia continued to increase up until the latter part of the 1980s. This increase can be attributed not only to the increase in the number of consortia but also to the establishment of new National R&D Programs such as the R&D Program on Basic Technologies for Future Industries in 1981. While this Government support changed to a decreasing trend with 1989 as its peak, it again changed to an increasing trend from 1993 with a dramatic increase in 1996. These increases can be attributed to the restructuring of MITI-initiated National R&D Programs (establishment of Industrial Science & Technology Frontier Program and The New Sunshine Program) in 1993 and also the enactment of the Science and Technology Basic Law in 1995.

Table 2
Policy steps in establishing R&D consortia as core facility for national R&D program project

1961	Enactment of the Law of Engineering Research Association (ERA)
1963	MITI's Vision in the 1960s (Industrial Structure Council of MITI) 1. Shift from import technology-dependent structure to indigenous technology development 2. Government initiatives 3. Tie-ups among industry, universities, and national research institutes for priority R&D projects
1964	The Expenses Commission System for R&D of Industrial Technology (Entrustment System)
1966	The National R&D Program (Large-scale Project) 1. Priority R&D Program 2. Initiated by the Engineering Research Association with tie-ups among industry, universities, and national research institutes 3. Under the entrustment system

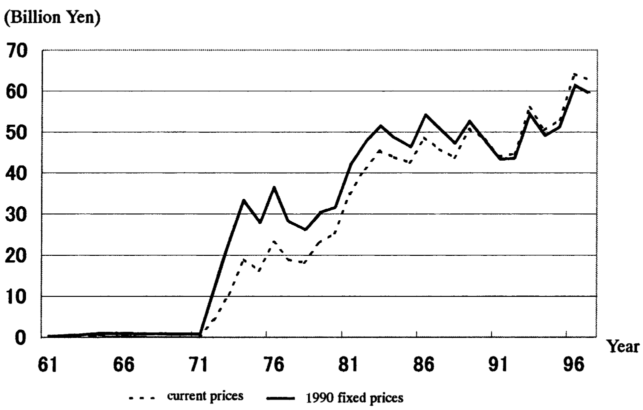


Fig. 1. Trend in the amount of government support to R&D consortia initiated by the Japanese Government (1961–1997). Sources: Forum of Engineering Research Association, Research Institute of Financial Policy, Agency of Industrial Science and Technology, New Energy and Industrial Technology Development Organization.

Fig. 3 illustrates the trend in the ratio between the Government support in R&D consortia initiated by the Japanese Government and industries' R&D expenditure over the period 1961–1997.

Fig. 3 demonstrates that the Government support ratio dramatically increased from the early 1970s, corresponding to the increase in the amount of Government support demonstrated in Fig. 2. Looking at Fig. 3, we note that this ratio changed to a decrease with its peak in the middle 1970s and continued its decreasing trend. This can be attributed to the rapid increase in industry's own R&D expenditure.

Another noteworthy finding indicated by Fig. 3 is that while the Government-initiated R&D consortia played a significant role in Japan's industrial technology policy from the middle of the 1970s by inducing industry's vigorous R&D investment, contrary to our expectation, the government support ratio is extremely small at less than 1.4%. This fact suggests a sophisticated function incorporated in the Government-initiated R&D consortia that, similar to the catalysis of a chemical reaction, induces industry's vigorous R&D investment by a small amount of direct support, and prompts us to the following hypothetical view with respect to an inducing mechanism encompassed in the consortia:

1. Mutual stimulation and inducement between firms participating in the consortia spurred by respective competitive spirit, and
2. Multiplier impacts and learning effects through the interaction between firms.

In addition, the foregoing observations prompt us to the following hypotheses:

1. Structural change has emerged in the effects of technology spillover derived from the Governmental-initiated R&D consortia,
2. The effects of such spillover have significant relevance with inducement for firms' participation in the consortia, and
3. A virtuous cycle between the spillover effects and firms' participation in the consortia has changed to a vicious cycle in these years.

This paper attempts to demonstrate these hypotheses.

3. Analytical framework

3.1. Model synthesis

3.1.1. Effects of technology spillover derived from the government-initiated R&D consortia

3.1.1.1. Technology spillover to the nation's economy as a whole. *Construction of translog cost function*: First of all, it is assumed that there exists in the Japanese industry the following twice-differentiable aggregate cost function:

$$C = C(Y,p_i,T_I,T_G) \quad (1)$$

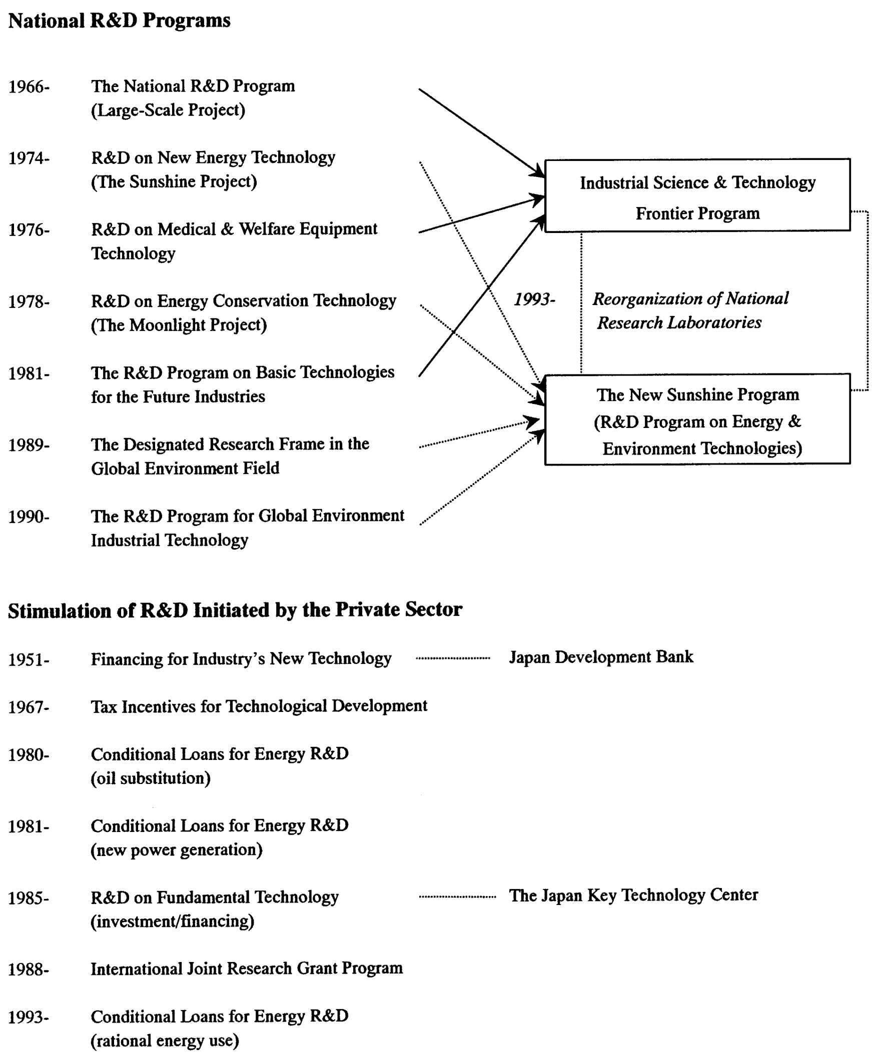


Fig. 2. Chronology of MITI-initiated National R&D Programs.

Fig. 3. Trend in the Ratio between Government Support in R&D Consortia initiated by the Japanese Government and Industries' R&D Expenditure (1961–1997). Sources: Forum of Engineering Research Association, Research Institute of Financial Policy, Agency of Industrial Science and Technology, New Energy and Industrial Technology Development Organization.

where C is the gross cost; Y the production, p_i: the prices of production factors; T_I: the technology stock generated by indigenous R&D [3]; and T_G: the technology stock generated by R&D in the government-initiated R&D consortia.

The following translog cost function can be obtained by a making Taylor expansion to the secondary term:

$$\begin{aligned} \ln C = {} & c_0 + \alpha_y \ln Y + \alpha_{T_I} \ln T_I + \alpha_{T_G} \ln T_G \\ & + \sum_i \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \sum_i \beta_{yi} \ln Y \ln p_i \qquad (2) \\ & + \sum_i \beta_{T_I i} \ln T_I \ln p_i + \sum_i \beta_{T_G i} \ln T_G \ln p_i + \beta_{yT_I} \ln Y \ln T_I \end{aligned}$$

[3] Technology stock is the accumulation of knowledge developed through the course of R&D activities (Goto, 1993; Watanabe et al., 1998; Griliches, 1998. See measurement footnote 11).

$$+ \beta_{yT_G}\ln Y \ln T_G + \beta_{T_I T_G}\ln T_I \ln T_G$$

where $I,j = L,K,M,E$ (labor, capital, raw materials, and energy).

The right side of Eq. (2) indicates factors governing cost. As Growth Accounting Theory (Denison, 1962; Jorgenson and Griliches, 1967) suggest, since cost decrease represents technological progress (increase in Total Factor Productivity: TFP), contribution to technological progress can be identified by measuring impacts of each respective factor on the right side to cost decreases.

Thus, the effects of technological progress by the government-initiated R&D consortia can be identified by measuring the parameters α_{T_G} (single effect) and $\beta_{T_G i}$, β_{yT_G}, $\beta_{T_I T_G}$ (multiple effect).

Under the assumption of the symmetrical nature of coefficients and of the linear homogeneity of the cost function, the following restrictions are imposed on the parameters in Eq. (2):

$$\sum_i \alpha_i = 1 \tag{3}$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{yi} = \sum_i \beta_{T_I i} = \sum_i \beta_{T_G j} = 0. \tag{4}$$

In addition, for the twice-differentiable cost function, the following condition should be satisfied:

$$\beta_{ij} = \beta_{ji} \quad i \neq j. \tag{5}$$

Taking partial differentiation of both sides of Eq. (2) by $\ln p_i$, the following equation can be obtained:

$$\frac{\partial \ln C}{\partial \ln p_i} = \alpha_i + \sum_j \beta_{ij} \ln p_j + \beta_{yi} \ln Y + \beta_{T_I,i} \ln T_I + \beta_{T_G,i} \ln T_G. \tag{6}$$

Adopting Sheppard's adjustment, the left hand can be represented by cost share as follows:

$$\frac{\partial \ln C}{\partial \ln p_i} = \frac{p_i}{C}\frac{\vartheta C}{\vartheta p_i} = \frac{p_i X_i}{C} = m_i. \tag{7}$$

Synchronizing Eqs. (6) and (7), the following equation can be obtained:

$$m_i = \alpha_i + \sum_j \beta_{ij} \ln p_j + \beta_{yi} \ln Y + \beta_{T_I,i} \ln T_I + \beta_{T_G,i} \ln T_G. \tag{8}$$

By conducting a regression analysis imposing constraints Eqs. (3), (4) and (5), the parameters of Eq. (8) can be identified. Conducting regression analysis of Eq. (2) by substituting these identified parameters for parameters in Eq. (2), other parameters in Eq. (2) can be identified.

Measurement of the impacts of technology spillover: Contributions of industry's own technology stock (T_I) and technology stock generated by R&D consortia (T_G) to cost decrease in cost function (Eq. (1)) represent effects of technology spillovers by T_T and T_G, respectively (Bernstein and Nadiri, 1988; Bernstein, 1989). Therefore, the effects of technology spillover can be identified by measuring the elasticities of respective technology stock to cost, $\frac{\partial C}{\partial T_I}\cdot\frac{T_I}{C}$ and $\frac{\partial C}{\partial T_G}\cdot\frac{T_G}{C}$.

From Eq. (2), the following equation can be obtained and by applying parameters obtained by the regression analyses of Eqs. (2) and (8), elasticities can be measured, thereby the effects of spillovers can be identified.

$$\frac{\partial C}{\partial T_I}\frac{T_I}{C} = \frac{\partial \ln C}{\partial \ln T_I} = \alpha_{T_I} + \sum_i \beta_{T_I i} \ln p_i + \beta_{yT_I} \ln Y + \beta_{T_I T_G} \ln T_G \tag{9}$$

$$\frac{\partial C}{\partial T_G}\frac{T_G}{C} = \frac{\partial \ln C}{\partial \ln T_G} = \alpha_{T_G} + \sum_i \beta_{T_G i} \ln p_i + \beta_{yT_G} \ln Y + \beta_{T_I T_G} \ln T_I. \tag{10}$$

3.1.1.2. Inter-firm technology spillover. As reviewed above, the prime advantage for firms to participate in the government-initiated R&D consortia includes the effects of inter-firm technology spillover. While these effects in aggregated level can be measured through cost decrease by using translog cost function depicted in Eq. (1), aiming at measuring the impacts of technology spillover on each respective firm, a new approach is attempted to measure spillover effects in each respective firm by utilizing the number of patents application.[4,5]

The number of patent applications by publication[6] (P) as a proxy of the results of firms' R&D activities can be depicted by the following equation:

$$P = P(T_C, R_C, R_G) \tag{11}$$

where T_C is thetechnology stock of the firm examined; R_C the R&D expenditure of the firm examined; and R_G the government R&D expenditure for consortia in which firms examined are participating.

Taking the logarithm and assuming the secondary term, Eq. (11) can be developed to the following equation:

[4] Watanabe et al. (1998) measured inter-firm technology spillover in Japan's photovoltaic solar cell (PV) development by analyzing the correlation between patent applications in PV R&D and technology stock of PV R&D as well as R&D expenditure for PV R&D. An analysis in this section is based on the same approach.

[5] Grupp (1996) postulated that while the effects of basic research are traced by bibliometric analysis, effects of applied and development research could be measured by the trend in patents application.

[6] Number of patent applications counted by date of publication of application.

$$\ln P = C + \alpha_1 \ln T_C + \alpha_2 \ln R_C + \alpha_3 \ln R_G + \beta_1 \ln T_C \ln R_C + \beta_2 \ln R_C \ln R_G + \beta_3 \ln R_G \ln T_C. \tag{12}$$

Taking partial differentiation of both sides of Eq. (12) by $\ln R_G$, the following equation can be obtained:

$$\frac{\partial \ln P}{\partial \ln R_G} = \alpha_3 + \beta_2 \ln R_C \beta_3 \ln T_C. \tag{13}$$

Since

$$\frac{\partial \ln P}{\partial \ln R_G} = \frac{\partial P}{\partial R_G} \frac{R_G}{P}, \tag{14}$$

the left side of Eq. (13) indicates R&D elasticity to patent application in the government-initiated R&D consortia, which represents the effects of inter-firm technology spillover expected to be obtained by participating in the consortia.

3.1.2. Factors inducing firms' participation in the government-initiated R&D consortia

In line with the previous approach (Miyata, 1997), firms' benefits obtained by the consortia can be classified into the following three categories:

1. Benefit of inter-firm technology spillover by participating in the consortia,
2. Benefit of spillover impacts on the nation's economy even when not participating in the consortia, and
3. Benefit of the government support on R&D expenditure which would otherwise be borne by themselves.

In order to examine whether these benefits function as inducements for firms' to participate in the consortia, numerical analysis using a probit model is attempted. A dependent factor is employed whether the firm has participated in the consortia (1) or not (0). Such explanatory factors are employed as inter-firm technology spillover (SO_1: a proxy of the benefit (i)), spillover impact on the nation's economy (SO_2: a proxy of the benefit (ii)), as well as debt capital ratio (DA), growth rate of sales (DS), and cash flow and capital assets ratio (CF). The last three factors are employed as proxies of the benefit (iii) (Miyajima, 1999).Thus, an inducement function can be depicted as follows:

$$y = \alpha_0 + \alpha_1 DA + \alpha_2 DS + \alpha_3 CF + \alpha_4 SO_1 + \alpha_5 SO_2 \tag{15}$$

where $y = 1$ in the case of participation, and 0 in the case of non-participation.

3.1.3. Cyclical correlation between inducement for firms' participation in R&D consortia and their spillover effects

Watanabe (1997; 1999) demonstrated that inter-firm, trans-sector, and inter-technology spillovers could be of the utmost excitement for firms participating in the consortia, and firms' enthusiasm in participation in the consortia depends on this excitement reacting to the degree of the spillover effects leading to a cyclical correlation.

Prompted by this postulate on the basis of the results of the analyses on the effects of spillover and inducing factors for firms' participation in the consortia, and also utilizing the results of the questionnaire surveys conducted by the Japan Federation of Economic Organizations (1989), National Institute of Science and Technology Policy (1993), and Economic Research Institute of Japan Society for the Promotion of Machine Industry (1999)[7], an attempt to demonstrate the above postulate is conducted.

3.2. Data construction

3.2.1. Macro and micro data

Sectoral level macro data used for this analysis are based on production, production factors, their cost and price data constructed within the framework of the National Accounts.[8]

Firm-level micro data are based on sales, R&D expenditure, technology stock, number of patent applications, cash flow and debt capital ratio obtained from firms' securities report (Toyo Keizai, annual issues) and patents index (Japan Patent Information Organization).

3.2.2. Data on government support to the government-initiated R&D consortia

While almost all government-initiated R&D consortia are facilitated by government subsidy or entrustment, annual amounts of these support to respective consortia are not published. Therefore, in this analysis, utilizing data published by the Forum of Engineering Research Associations (1991) and corresponding annual subsidy published by MITI and NEDO (1990), estimates are conducted on the annual subsidy to each respective consortium.

On the basis of these estimates, focusing on MITI-initiated R&D consortia over the period of 1981 to 1997 (108 consortia out of 126), technology stock of the government-initiated R&D consortia (T_G) is measured taking into account their pregnancy period. Pregnancy period (lead time) and the rate of obsolescence of technology are estimated to be 3.6 years and 9.5%, respectively (Watanabe, 1999).

[7] These surveys revealed that the expectation to the government-initiated R&D consortia by firms has been decreasing in the 1990s.

[8] Data sources are as follows: Annual Report on National Accounts (Economic Planning Agency, annual issues), Year Book of Labor Statistics (Ministry of Labor, annual issues), Industrial Statistics (MITI, annual issues), Comprehensive Energy Statistics (Agency of National Resources & Energy of MITI, annual issues) , and Economic Statistics Annual (The Bank of Japan, annual issues).

Table 3
Estimated coefficient of translog cost function for the manufacturing industry (1980–1997)

Parameter [a]	Estimated value	t-value	P-value
α_{TI}	–2.11E^{-06}	–1.48	(0.15)
β_{TIL}	0.041	6.89	(0.00)
β_{TIK}	7.86E^{-03}	0.82	(0.41)
β_{TIE}	–0.014	–3.15	(0.00)
β_{yTI}	0.019	8.01	(0.00)
β_{TITG}	–0.046	–4.24	(0.00)
α_{TG}	4.59E^{-04}	2.19	(0.04)
β_{TGL}	–2.09E^{-03}	–3.03	(0.00)
β_{TGK}	3.61E^{-03}	2.06	(0.04)
β_{TGE}	–1.36E^{-03}	–1.59	(0.11)
β_{yTG}	0.035	4.27	(0.00)

[a] See footnote 10 as for the parameter of ln p_m (β_{TIM})

Table 5
Estimated coefficient of translog cost function for the electrical machinery industry (1980–1997)

Parameter [a]	Estimated Value	t-value	P-value
α_{TI}	3.49E^{-05}	1.07	(0.29)
β_{TIL}	0.036	2.43	(0.02)
β_{TIK}	–0.014	–1.05	(0.27)
β_{TIE}	–9.96E^{-03}	–2.04	(0.04)
β_{yTI}	0.050	10.00	(0.00)
β_{TITG}	–0.238	–4.13	(0.00)
α_{TG}	9.08E^{-04}	2.04	(0.05)
β_{TGL}	–8.14E^{-03}	–4.74	(0.00)
β_{TGK}	–4.24E^{-03}	–2.63	(0.00)
β_{TGE}	1.94E^{-03}	2.79	(0.04)
β_{yTG}	0.197	3.92	(0.00)

[a] See footnote 10 for the parameter of lnp_m (β_{TIM})

4. Analysis and interpretation

4.1. Spillover effects induced by R&D consortia

4.1.1. Spillover effects to the nation's economy

By applying Eqs. (9) and (10) derived from the translog cost function (2) to Japan's whole manufacturing, chemical, and electrical machinery industries, the spillover effects from these industries' own technology stock T_I as well as technology stock of the government-initiated R&D consortium T_G to the nation's economy as a whole can be measured.The results of the regression analysis on Eqs. (2) and (8) under restrictions of Eqs. (3), (4) and (5) are summarized in Tables 3, 4 and 5. A negative value of the parameter demonstrates positive spillover effects as it indicates cost reduction effects.

4.1.1.1. Manufacturing industry. Table 3 summarizes estimated coefficients of translog cost function for the whole manufacturing industry over the period 1980–1997.

Table 4
Estimated Coefficient of Translog Cost Function for Chemical Industry (1980–1997)

Parameter [a]	Estimated Value	t-value	P-value
α_{TI}	–2.24E^{-05}	–2.39	(0.02)
β_{TIL}	0.031	2.37	(0.02)
β_{TIK}	2.91E$^{-0.3}$	0.17	(0.87)
β_{TIE}	0.027	2.08	(0.04)
β_{yTI}	0.030	7.19	(0.00)
β_{TITG}	–0.038	–3.34	(0.00)
α_{TG}	–4.16E^{-04}	–1.57	(0.13)
β_{TGL}	–3.50E^{-03}	–2.36	(0.02)
β_{TGK}	4.04E^{-03}	1.81	(0.07)
β_{TGE}	–1.36E^{-03}	–0.74	(0.04)
β_{yTG}	0.032	3.45	(0.00)

[a] See footnote 10 for the parameter of lnp_m (β_{TIM})

All coefficients in Table 3 demonstrate statistical significance, except the t-value of $\hat{a}_{TIK}$ which indicates spillover effect of own technology stock through change of capital price.Based on these results, the effects of technology spillover by both industries' own technology stock (T_I) and technology stock generated by R&D consortia (T_G) are measured by means of respective elasticity to cost as enumerated by *STI* and *STG*, respectively: [9]

$$STI = \frac{\vartheta C}{\vartheta T_I}\frac{T_I}{C} = -2.11E^{-06} + 0.041\ln p_l + 7.86E^{-03}\ln p_k - 0.035\ln p_m - 0.014\ln p_e + 0.019\ln Y - 0.046\ln T_G \quad (16)$$

where E^{-06} indicates 10^{-6}.

$$STG = \frac{\vartheta C}{\vartheta T_G}\frac{T_G}{C} = 4.59E^{-04} - 2.09E^{-03}\ln p_l + 3.61E^{-03}\ln p_k - 0.16E^{-03}\ln p_k - 0.16E^{-03}\ln p_m - 1.36E^{-03}\ln p_e + 0.035\ln Y - 0.046\ln T_i. \quad (17)$$

Eqs. (16) and (17) indicate that coefficients of both T_G and T_I are negative, demonstrating their contribution to increased technology spillover. It is also demonstrated that values of *STI* and *STG* decrease as T_G and T_I increase, which indicates that T_G and T_I play complementary roles.

[9] The parameter of ln p_m (β_{TIM}) was calculated by Eq. (4).

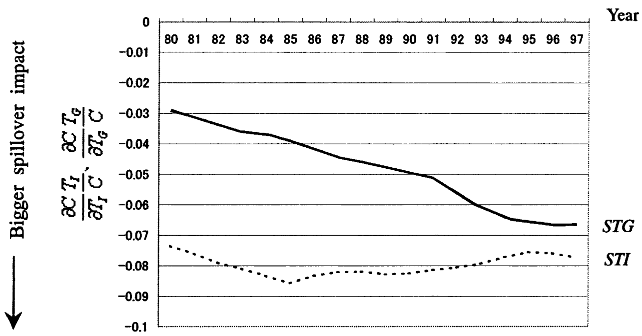


Fig. 4. Trend in spillover impact of technology stock in manufacturing industry and the government-initiated R&D consortia on the nation's economy (1980–1997).

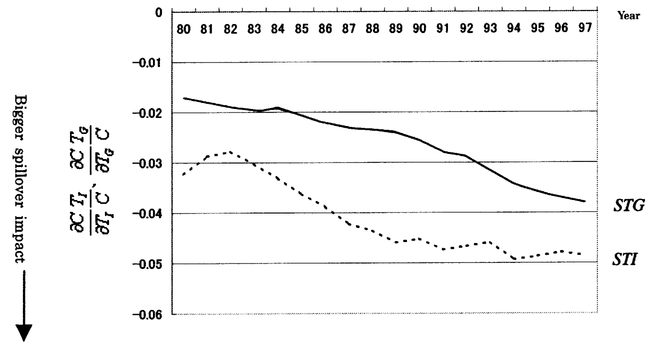


Fig. 5. Trend in spillover impact of technology stock in the chemical industry and the government-initiated R&D consortia on the nation's economy (1980–1997).

Fig. 4 illustrates the trends in *STI* and *STG* which demonstrate that while the value of *STG* has continued to decrease (spillover effect has continued to increase), *STI* changed to an increase (spillover effects decreases) from the middle of the 1980s. This decrease of spillover effects can be attributed to stagnation of the government subsidy to R&D consortia[10], due to the shift of consortias' R&D target from applied research to basic research, and also the stagnation of the industry's R&D expenditure due to the bursting of the bubble economy.

In addition, Fig. 4 demonstrates that *STG* also changed to stagnation (spillover effects stagnate) from the latter half of the 1990s.

4.1.1.2. Chemical industry. Table 4 summarizes estimated coefficients of translog cost function for the chemical industry over the period 1980–1997.

As summarized in Table 4, statistical significance is generally high except for $\hat{a}_{TIK}$. Based on these results, the effects of technology spillover by both industries' own technology stock (T_I) and technology stock generated by R&D consortia (T_G) are measured by means of respective elasticity to cost as enumerated by *STI* and *STG*, respectively:

$$STI = \frac{\vartheta C}{\vartheta T_I}\frac{T_I}{C} = -2.24E^{-05} + 0.031\ln p_l + 2.29E^{-03}\ln p_k - 0.061\ln p_m - 0.027\ln p_e + 0.030\ln Y - 0.038\ln T_G \quad (18)$$

$$STG = \frac{\vartheta C}{\vartheta T_G}\frac{T_G}{C} = 4.16E^{-04} - 3.45E^{-03}\ln p_l + 4.04E^{-03}\ln p_k - 8.14E^{-04}\ln p_m - 1.36E^{-03}\ln p_e + 0.032\ln Y - 0.038\ln T_I. \quad (19)$$

Eqs. (18) and (19) indicate that, similar to the manufacturing industry as a whole, T_G and T_I contribute to a decrease *STI* and *STG*. In addition, they indicate that both T_I and T_G contribute to cost decrease as α_{TI} ($= -2.24E^{-05}$) and α_{TG}($= -4.16E^{-04}$) in Eq. (2) indicate negative values. It is also demonstrated that values of *STI* and *STG* decrease as T_G and T_I increase, which indicates that T_G and T_I play complementary roles.

Fig. 5 illustrates trends in *STI* and *STG* which demonstrate that while the value of *STG* has continued to decrease (spillover increases), *STI* changed to stagnation (spillover stagnate) in the 1990s

4.1.1.3. Electrical machinery. Table 5 summarizes estimated coefficients of translog cost function for the electrical machinery industry over the period 1980–1997. All coefficients in Table 5 demonstrate statistical significance. Based on these results, the effects of technology spillover by both industries' own technology stock (T_I) and technology stock generated by R&D consortia (T_G) are measured by means of respective elasticity to cost as enumerated by *STI* and *STG*, respectively:

$$STI = \frac{\vartheta C}{\vartheta T_I}\frac{T_I}{C} = 3.49E^{-05} + 0.041\ln p_l - 0.014\ln p_k - 0.024\ln p_m - 1.94E^{-03}\ln p_e + 0.050\ln Y - 0.238\ln T_G \quad (20)$$

$$STG = \frac{\vartheta C}{\vartheta T_G}\frac{T_G}{C} = 9.08E^{-04} - 8.14E^{-03}\ln p_l - 4.24E^{-03}\ln p_k + 10.44E^{-03}\ln p_m - 1.36E^{-03}\ln p_e + 0.197\ln Y - 0.238\ln T_I. \quad (21)$$

Eqs. (20) and (21) demonstrate that, while similar to manufacturing and chemicals, T_G and T_I contribute to

[10] The relationship between stagnation of Government subsidy to R&D consortia and spillover effect can be explained as follows: Technology stock of government-initiated R&D consortia at t period is $T_{Gt} = R_{Gt-m} + (1-\rho)T_{Gt-1}$, where m: time lag; ρ: technology obsolescence rate. This equation indicates that stagnation of R_G leads to the stagnation of T_G which, as can be enumerated by Eq. (16), results in increase in STI (decrease in spillover effects).

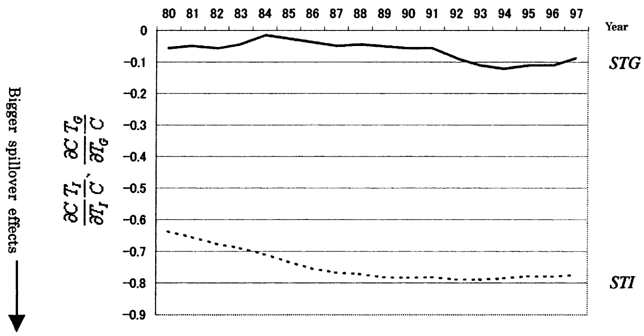


Fig. 6. Trend in spillover impact of technology stock in electrical machinery industry and the government-initiated R&D consortia on the nation's economy (1980–1997).

decrease *STI* and *STG*, contrary to chemical, both T_I and T_G contribute to cost increase.Similar to the previous analyses, *STI* decreases as T_G increases while *STG* decreases as T_I increases, which demonstrates that T_G and T_I play mutually complementary functions.

Fig. 6 illustrates trends in *STI* and *STG* which demonstrate that both *STG* and *STI* continued to decrease (spillover increase) over the whole period examined. Negative value and its decreasing trend in *STI* is conspicuous. However, similar to the chemical industry, *STI* changed to stagnation (spillover stagnate) in the 1990s.

4.1.2. Inter-firm spillover effects

In order to evaluate inter-firm spillover effects between participants in the government-initiated R&D consortia, firm-level analysis is conducted focusing on participating firms in chemical and electrical machinery industries.The reason why these industries are chosen for this analysis is as follows:

1. They are R&D-oriented industries with a high level of R&D intensity (ratio of R&D expenditure to sales),
2. They are enthusiastic in participating in the government-initiated R&D consortia, and
3. The number of consortia demonstrates firms in these industries as the highest share of the participants.

4.1.2.1. Behavior of leading firms in each industry. An analysis is conducted taking 31 chemical firms and 29 electrical machinery firms (altogether 60 firms) as listed in Table 6. The number of patent applications counted by date of publication of application is used as a proxy of the effects of technology spillover. A time lag between patent application and publication is estimated to be two years.

Chemicals: A regression analysis of Eq. (12) is conducted for 31 chemical firms listed in Table 6 over the period 1986–1997. Then, by utilizing Eq. (13), factors governing inter-firm technology spillover are identified. The results of the identification for Ube Industries, Sekisui Chemical, Shin-Etsu Chemical, Sumitomo Chemical, and Hitachi Chemical, which demonstrate high statistical significances, are summarized in Table 7.

Fig. 7 illustrates the results of the analysis of the inter-firm spillover effects between participants on Ube Industries. Table 7 suggests that the inter-firm spillover effects on Ube Industries decrease as its own technology stock increases while opposite to the increase in its R&D expenditure. These are considered to be due to the increase in own technology stock, leading to the increase in the number of patent applications, which, in return, results in the decrease in the influence of the government-initiated R&D consortia, while the execution of R&D contributes to an increase in assimilation capacity, leading to an increase in the inter-firm spillover effects. As a balance of these negative and positive effects, inter-firm spillover effects continued to decrease as demonstrated in Fig. 7. Fig. 7 demonstrates that such a decreasing trend accelerated in the 1990s and the inter-firm spillover effects turned to negative in the latter half of the 1990s, losing the merit of participating in the consortia.[11]

Fig. 8 illustrates the result of the analysis of the inter-firm spillover effects between the participants on Shin-Etsu Chemical. Table 7 suggests a similar structure as Ube Industries with respect to the contribution of technology stock. Consequently, the inter-firm spillover effects tended to decrease continuously, and became negative after 1992.

Electrical machinery: Similar to the chemical industry, regression analysis of Eq. (12) is conducted for 29 electrical machinery firms listed in Table 6 over the period 1986–1997, then factors governing inter-firm technology spillover are identified. The results of the identification for Hitachi, Sanyo Electric, Fuji Electric, Yokogawa Electric, Oki Electric, and Matsushita Electric, which demonstrate high statistical significances, are summarized in Table 8.

Fig. 9 illustrates the result of the analysis of Hitachi. Table 8 suggests that the inter-firm spillover effects on Hitachi decreases as its own R&D expenditure increases. This is considered to be due to patents in the electrical machinery industry, contrary to the chemical industry, being generally generated by R&D activity rather than technology stock. Accordingly, own R&D in the electrical machinery industry does not lead to assimilation capacity of technology spillover compared to the chemical industry. As illustrated in Fig. 9, spillover effects on Hitachi decreased over the 1980s, then turned to a slight increase in the 1990s. This can be interpreted that as own R&D stagnated after the bursting of the bubble economy, the influence of the consortia increased relatively.

[11] Actually, Ube Industries began to withdraw from several consortia after around 1994.

Table 6
Firms examined for inter-firm spillover effects analysis

Chemical (31 firms) [a]		Electrical machinery (29 firms)	
Asahi Kasei	Tosoh Corp.	Hitachi	Matsushita Electric Works
Showa Denko	Tokuyama Corp.	Toshiba	Canon
Sumitomo Chemical	Central Glass	Mitsubishi Electric Corp.	Meidensha
Mitsubishi Chemical	Toagosei	Fuji Electric	Toshiba Tec Corp.
(Mitsubishi Kasei)	Denki Kagaku Kogyo	Matsushita Electric Industrial Co.	Japan Radio Co.
(Mitsubishi Petrochemical)	Shin-Etsu Chemical	Sharp	Kokusai Electric
Sekisui Chemical	Nippon Sanso Corp	Sony	Aiwa
Mitsui Chemicals	Nippon Shokubai	Sanyo Electric	TDK
(Mitsui Petrochemical)	Kaneka Corp	Victor Company of Japan	Alps Electric
(Mitsui Toatsu Chemical)	Kyowa Hakko Kogyo	NEC	Pioneer
Chisso Corp.	Daicel Chemical Industries	Fujitsu	Yokogawa Electric
Nissan Chemical Industries	Ube Industries	Oki Electric	Casio
Kureha Chemical Industry	Hitachi Chemical	Matsushita Communication Industrial Co.	Rohm
Ishihara Sangyo Kaisha	Sekisui Plastics	Omron	Kyocera
Nippon Soda	Nippon Kayaku	Denso Corp.	
	Nippon Steel Chemical		

[a] Mitsubishi Kasei and Mitsubishi Petrochemical merged into Mitsubishi Chemical in 1994. Mitsui Petrochemical and Mitsui Toatsu Chemical merged into Mitsui Chemicals in 1997. The number of chemical firms (31) indicates the number before the merger.

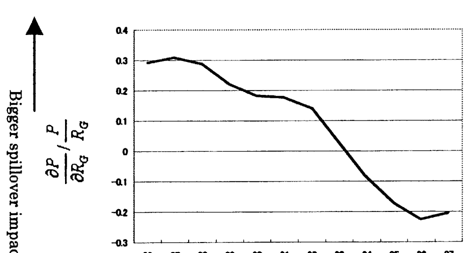
Table 7
Estimated coefficient of translog patent function for selected chemical firms (1986–1997)

Name	Parameter	Estimated value	t-value	P-value
Ube Industries	α_3	6.496	1.62	(0.16)
	β_2	0.667	1.85	(0.11)
	β_3	–0.851	–4.11	(0.01)
Sekisui Chemical	α_3	6.887	1.63	(0.15)
	β_2	2.132	2.26	(0.06)
	β_3	–1.577	–3.02	(0.02)
Shin-Etsu Chemical	α_3	3.830	4.89	(0.00)
	β_2[a]	-	-	-
	β_3	–0.337	–4.79	(0.00)
Sumitomo Chemical	α_3	19.949	4.23	(0.01)
	β_2	–1.026	–3.14	(0.02)
	β_3	–1.150	–3.81	(0.01)
Hitachi Chemical	α_3	13.947	2.97	(0.03)
	β_2	1.488	2.34	(0.06)
	β_3	–1.866	–2.96	(0.03)

[a] β_2 (coefficient of R_c) of Shin-Etsu Chemical is eliminated as the firm maintains a dominant position in vinyl chloride and silicon-based technology stock (T_C) rather than on annual R&D expenditure (R_C).

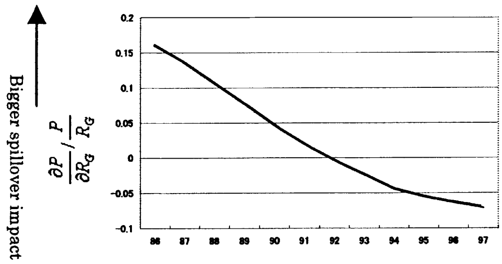
Fig. 10 illustrates the result of a similar analysis on Fuji Electric. Similar to Hitachi, as own R&D expenditure increases, the spillover effect between the participants decreases. As a result, spillover effect continued to decrease over the whole period examined, and changed to negative in the 1990s.

4.1.2.2. Structural trend. Looking at the results demonstrated above, which indicate the structural trend of spillover effect between participants of consortia to representative chemical and electrical machinery firms over the mid-1980s to the 1990s, as a whole, spillover effect decreased from 1990 except for a few electrical machinery firms in which spillover effects increased relatively as a result of stagnation of own R&D after the bursting of the bubble economy. This structural trend has a consistency with the result shown in Fig. 4, which indicates that spillover effects of technology stock of the manufacturing industry to the economy stagnated after the middle of the 1980s.



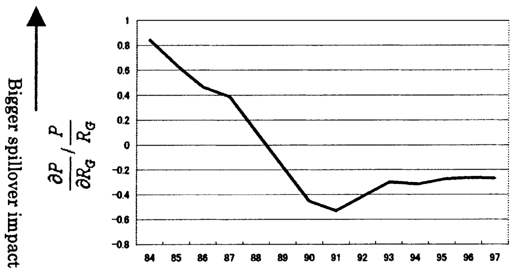
$$\frac{\partial P}{\partial R_G}\frac{R_G}{P} = \frac{\partial \ln P}{\partial \ln R_G} = 6.496 + 0.667 \ln R_C - 0.851 \ln T_C$$

Fig. 7. Trend in spillover impact between the participants of R&D consortia (Ube Industries; 1986–1997).



$$\frac{\partial P}{\partial R_G}\frac{R_G}{P}=\frac{\partial \ln P}{\partial \ln R_G}=3.83-0.337\ln T_C$$

Fig. 8. Trend in spillover impact between the participants of R&D consortia (Shin-Etsu Chemical; 1986–1997).



$$\frac{\partial P}{\partial R_G}\frac{R_G}{P}=\frac{\partial \ln P}{\partial \ln R_G}=34.6-2.72\ln R_C$$

Fig. 9. Trend in spillover impact between the participants of R&D consortia (Hitachi; 1984–1997).

Table 8
Estimated coefficient of translog patent function for selected electrical machinery firms (1986–1997)

Name	Parameter [a]	Estimated Value	t-value	P-value
Hitachi	α_3	34.617	3.22	(0.00)
	β_2	–2.723	–3.24	(0.00)
	β_3	–	–	–
Sanyo Electric	α_3	2.072	3.60	(0.00)
	β_2	–0.166	–3.39	(0.00)
	β_3	–	–	–
Fuji Electric	α_3	7.954	5.12	(0.00)
	β_2	–0.594	–5.13	(0.00)
	β_3	–	–	–
Yokogawa Electric	α_3	–11.068	–1.67	(0.15)
	β_2	2.572	2.28	(0.06)
	β_3	–1.221	–2.92	(0.03)
Oki Electric	α_3	2.072	1.55	(0.12)
	β_2	–0.166	–1.55	(0.12)
	β_3	–	–	–
Matsushita Electric Works	α_3	–5.659	–1.60	(0.16)
	β_2	1.734	2.07	(0.08)
	β_3	–1.041	–2.14	(0.08)

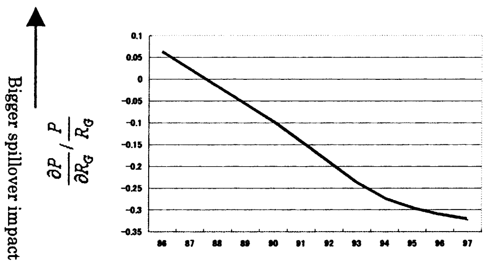
[a] β_3 (coefficient of T_C) of Hitachi, Sanyo Electric, Fuji Electric, and Oki Electric was eliminated, respectively, as they hold significant positions in electronic products such as semiconductors, and the rate of obsolescence of technology for such products is high.

4.1.2.3. Participation density (averaged subsidies to participants in R&D consortia) and its effect. Fig. 11 demonstrates the correlation between "participation density" measured by average R_G (government subsidies to R&D consortia in which firms examined participated) and average spillover effects which each participant received over the period 1986–1997.[12] Looking at the figure, we note a positive correlation, suggesting that the firms anticipate higher technology effects as their participation increase.

4.2. Inducing factors of firms' participation in R&D consortia

In order to demonstrate the hypothesis that the benefits of technology spillover could be major inducing factor for firms' participation in R&D consortia, probit model analysis using Eq. (15) is conducted. In this analysis, debt capital ratio (*DA*), growth rate of sales (*DS*) and cash flow per capital assets ratio (*CF*), as well as inter-firm technology spillover (SO_1) and spillover impacts on the nation's economy (SO_2) are used for explanatory variables. A panel data of five selected chemical firms as listed in Table 7 over the period 1986–1997 are used for this analysis. In addition, the results of the analyses with respect to spillover effects between participants and also to the economy are used. The result of the analysis is summarized in Table 9. Looking at the table, we note that while the value of R^2 is low, t-values of SO_1 and SO_2 are relatively high (9% and 11%, respectively), which suggests that these factors function as inducing factors of firms' participation. Marginal inducement effect for participation in R&D consortia suggests that inducement

[12] Since the scale of Hitachi, Fuji Electric, and Oki Electric is different from the other eight firms and integral observation is difficult, these three firms are not included in Fig. 11.



$$\frac{\partial P}{\partial R_G}\frac{R_G}{P}=\frac{\partial \ln P}{\partial \ln R_G}=7.954-0.594\ln R_C$$

Fig. 10. Trend in spillover impact between the participants of R&D consortia (Fuji Electric; 1984–1997).

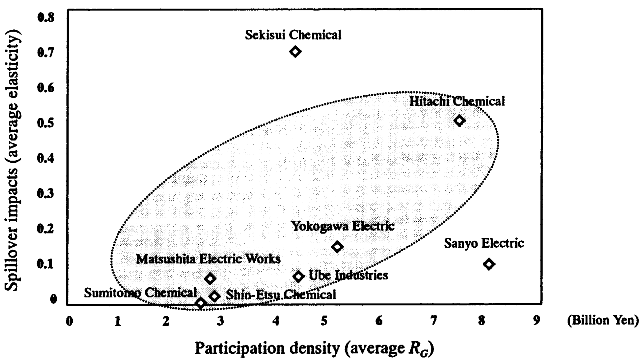


Fig. 11. Correlation between participation density and spillover effects (1986–1997).

for participation increases in accordance with the increase in SO_1 and decrease in SO_2. This is reasonable as potential participants expect benefits of participation as SO_1 increases while their expectation is small in cases where SO_2 increases. While further improvement for model construction is expected to increase R^2, these results support the hypothetical view that the benefits of technology spillover are one of the major inducing factors for firms' participation in R&D consortia.

4.3. Cyclical correlation between inducement for firms' participation In R&D consortia and their spillover effects

Analyses in the last section demonstrate that inter-firm technology spillover effects among participants in the MITI-initiated R&D consortia were one of the major inducement for firms to participate in the consortia, and this inducement functioned in stimulating firms to second qualified human resources to the consortia with an aim to take initiative in the consortia R&D and fully assimilate the results of spillover technology. This inducement led to the construction a virtuous cycle between spillover effects and quality of participants. However, the analysis in the section Spillover Effects Induced by R&D Consortia demonstrate that the effects of such spillover decreased from the latter half of the 1980s, particularly in the 1990s. Given the above cyclical correlation between spillover effects and quality of participants, a decrease in spillover effects in the 1990s inevitably decreases the inducement for firms to participate in the consortia, resulting in a change from a virtuous cycle between spillover effects and quality of participants to a vicious cycle. In order to trace the industry's expectation to the government (particularly MITI)-

Table 9
Inducing factors for firms' participation in R&D consortia in selected chemical firms (1986–1997)

Estimated coefficient					Marginal inducement effect for participation ($\partial y/\partial x$)	
Inducing factors for participation (x)	Parameter	Estimated value	t value	P value	0	1
C (constant)	á$_0$	–4.012	–1.52	(0.13)	1.237	–1.237
DA	á$_1$	0.841	0.49	(0.63)	–0.259	0.259
DS	á$_2$	–2.577	–0.87	(0.38)	0.794	–0.794
CF	á$_3$	6.082	0.41	(0.68)	–1.875	1.875
SO_1	á$_4$	1.182	1.70	(0.09)	–0.365	0.365
SO_2	á$_5$	–86.843	–1.60	(0.11)	26.777	–26.777
R^2	0.075					

$y = a_0 + a_1DA + a_2DS + a_3CF + a_4SO_1 + a_5SO_2$ where y = 1 in case of participation, and = 0 in case of non-participation.

Table 10a
Trends in expectation of technology policies (scores by evaluation) (1989)

R&D Policy	Evaluation Score
R&D consortia	72
Tax reduction	71
Information diffusion	70
Entrustment	68
Standardization	68
Patent	67
Investment	66
Basic research	64
International cooperation	62
Tie-ups between industry, government research institute and university	61
Research facility	59
Education and training	57
R&D budget	56

Scores in accordance with the appreciation by policy objectives (average score: 65). Source: Questionnaire survey conducted by Japan Federation of Economic Organization in December 1989.

Table 10b
(1999)

Policy Tool	Participants	Non Participants
Subsidy	35	(3)
Joint research, Tie-ups	17	(13)
Regulation	9	(2)
Tax reduction	7	(3)
Standardization	4	(3)
Loan	3	(2)
Investment	2	(2)
Procurement	2	(0)
Awarding	0	(0)
Others	1	(1)

Scores by identifying the most effective policy (total responses are 80). Figures indicate evaluation by responses with experiences in involving in the Government sponsored R&D projects while figures in parentheses indicate those responses without such experiences. Source: Questionnaire survey conducted by the Economic Research Institute of Japan Society for the Promotion of Machine Industry in May 1999.

initiated R&D consortia, Table 10 (a and b) analyzes trends in expectation of technology policies by comparing the results of the questionnaire surveys conducted in 1989 and 1999 by the Japan Federation of Economic Organizations (1989) and the Economic Research Institute of Japan Society for the Promotion of Machine Industry (1999), respectively. Table 10 (a and b) demonstrates that while R&D consortia were appreciated as the most effective policy by gaining the highest scores in 1989[13], such appreciation dramatically decreased in 1999. Although further in-depth analyses are expected, this contrast demonstrates the foregoing postulate with respect to a vicious cycle between inter-firm technology spillover effects of the R&D consortia and the quality of the participants in the consortia supported by the strong inducement to participation.

5. Conclusion

Originated by the enactment of the Law of Engineering Research Association (ERA) in 1961, government (particularly MITI)-initiated R&D consortia played a significant role in Japan's industrial technology leading to the high-technology miracle in the 1980s. This achievement can be attributed to a virtuous cycle between the quality of the participants in the consortia and their technology spillover effects. Notwithstanding such a conspicuous achievement in the 1970s and the 1980s, the performance of R&D consortia has declined in the 1990s and this can be attributed to a collapse of the above sophisticated virtuous cycle.

Prompted by this postulate, this paper attempted to demonstrate the following hypotheses:

1. Structural change has emerged in the effects of technology spillover derived from the governmental-initiated R&D consortia,
2. The effects of such spillover have significant relevance with inducement for firms' participation in the consortia, and
3. A virtuous cycle between the spillover effects and firms' participation in the consortia has changed to a vicious cycle in these years.

On the basis of an emprical analysis taking all consortia established over the period 1961–1997, amounting to 126, together with in-depth analysis focusing on the leading 56 participating firms in the electrical machinery and chemical industries, the following noteworthy findings were obtained:

1. Trends in spillover effects

1. While spillover effects from manufacturing industries' own technology stock to the nation's economy has been stagnating from the middle of the 1980s, spillover effects from the government-initiated R&D

[13] Such appreciation was supported also by the result of the questionnaire survey conducted by the National Institute of Science and Technology Policy (1993) in October 1993 that 65.9% of responses (83 firms) appreciated the significance of R&D consortia, while 31.0% of responses (39 firms) expressed negative appreciation.

consortia's technology stock to the nation's economy has been maintained.
2. The stagnation of spillover effects from manufacturing industries' own technology stock to the nation's economy can be attributed to the stagnation of the government support as well as the shift of consortia's R&D focus from catch-up type to basic research.
3. On the other hand, spillover effects between participants of the government-initiated consortia in the chemical industry decreased from the beginning of the 1990s. Similar trends were observed in the electrical machinery industry.
4. These results demonstrate that spillover effects through participation in the government-initiated R&D consortia were decreasing. Thus, the first hypothesis was supported.

2. Factors inducing firms' participation in R&D consortia

Numerical analysis using a probit model demonstrated that spillover effects between the participants of the consortia functioned significant inducement for firms' participation in the consortia, thereby the second hypothesis was supported.

3. A virtuous cycle between the spillover effects and firms' participation in the consortia.

The foregoing analyses demonstrate that the government-initiated R&D consortia functioned effectively in encouraging broad involvement of cross-sectoral industry in these consortia and stimulating cross-sectoral technology spillover as well as inter-technology stimulation, thereby inducing further qualified participants in the consortia leading to a virtuous cycle in the 1970s and the first half of the 1980s.

However, the analyses revealed that, in line with the stagnation of Japan's industrial R&D in the 1990s, performance of R&D consortia, particularly their spillover effects, declined. Subsequently, firms reduced their secondment of qualified human resources to the consortia, resulting ina further decrease in the consortia's performance, leading to changing a virtuous cycle to a vicious cycle. All supported the third hypothesis.

This paper focused on a mechanism of the government-initiated R&D consortia, particularly on their interfirm technology spillover, and attempted to develop a new approach for elucidation of the inside the black box of this mechanism that enabled Japan to achieve a high-technology miracle in the 1980s.

All the foregoing results demonstrate the significance of this approach. Therefore, future work should attempt to identify a trajectory to remedy the current vicious cycle and restructure a virtuous cycle between effective technology spillover and qualified participants.

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Appendix 1. R&D Consortia initiated by MITI (1961–1997)[a]

I. Research Association

1	*High Polymer Raw Materials*	1961–1977	*67*	*Conductive Inorganic Compound*	1983–1995
2	*High Grade Alcohol Industrialization*	1961–1972	*68*	*Advanced Technology for Manufacturing Resin with High Performance*	1983–1995
3	*Tenchi Research Institute*	1962–1967	*69*	*Aluminum Power Metallurgy*	1983–1995
4	*Creep Test*	1962–1977	*70*	*Shape Memory Alloy*	1983–1993
5	*Optical Industry*	1962–1969	*71*	*Fuel Alcohol Development*	1983–1994
6	*Preferential Steel Refining*	1962–1981	*72*	*Advanced Robot Technology Research Association ARTRA*	1984–1991
7	*Electronic Computer*	1962–1973	*73*	*Alkaline Battery*	1984–1987
8	*Wool Product Solvent Dyeing*	1962–1964	*74*	*Resources Remote Sensing*	1985–1989
9	*Naniwa Casting*	1963–1974	*75*	*Super Heat Pump Energy*	1985–1993
10	*Insulator*	1964–1979	*76*	*Advanced Material and Machinery for Apartment Buildings*	1985–1996
11	*Heavy Oil Kiln with Lime*	1965–1983	*77*	*Research Institute for Development of New Generation Equipment for Atomic Power Plant*	1985–exist
12	*Aluminum Surface Treatment*	1965–1980	*78*	*Toyama Prefecture Regional System Development*	1985–1991
13	*Automobile Equipment*	1971–exist	*79*	*Aqua Renaissance*	1985–1991
14	*General Automobile Safety and Pollution*	1971–exist	*80*	*Coal Based Hydrogen Production*	1986–1995
15	*Light Metals Composite Material*	1971–1976	*81*	*Coal Gasification Combined Cycle Generation*	1986–1997
16	*Super-high Performance Computer Development*	1972–1984	*82*	*Improvement of Practical Performance of Gas Turbine*	1986–exist
17	*New Computer Series*	1972–1984	*83*	*Hokkaido Advanced Wood Use*	1986–1992

[a]In addition to the above, seven consortia participated in MITI-initiated R&D projects over the period 1998-2000. They consist of six foundations: Manufacturing Science and Technology Center, Optoelectronic Industry and Technology Development Association, Materials Process Technology Center, Ishikawa Sunrise Industries Creation Organization, Japan Information Processing Development Center, and Osaka Science & Technology Center; and one private corporation: Semiconductor Technology Academic Research Center.

18	Super-high Performance Electronic Computer	1972–1984	84	Textiles Manufacturing System	1986–exist
19	Medical Equipment Safety	1973–1985	85	Advanced Material Processing and Machining System	1987–1995
20	Steel Manufacturing by Atomic Energy	1973–1981	86	Laser Concentration	1987–exist
21	De-Nox Technology for the Iron and Steel Industry	1974–1980	87	Advanced Cogeneration	1987–1998
22	Software Module for Design and Calculation	1974–1991	88	Engineering Research Association for Superconductive Generation Equipment and Materials (Super-GM)	1987–exist
23	Software Module for Office Work	1974–1991	89	Composite Material Product Development System	1987–1999
24	Calculation for Operation Research	1974–1986	90	Molten Carbonate Fuel Cell	1988–exist
25	Software Module for Business Management	1974–1991	91	Artificial Clay Synthesis	1988–1993
26	Software Module for Automatic Control	1974–1991	92	International Fuzzy Engineering Research Institute	1989–1995
27	Automatic Measurement	1974–1993	93	Technology and System Development of New Industrialized House	1989–exist
28	High Temperature Safety	1974–1985	94	Engineering Research Association for Super Transport Propulsion System	1990–exist
29	Automobile General Control	1974–1980	95	Photovoltaic Power Generation Technology Research Association (PVTEC)	1990–exist
30	Vinyl Chloride Environment	1975–1983	96	Advanced Chemical Processing Technology Research Association	1990–1997
31	Heavy Oil Chemical Materialization	1975–1983	97	Phosphoric Acid Fuel Cell	1991–1998
32	Jet Engines for Aircraft	1976–1989	98	Improvement of Small Articles Plating Environment	1991–exist
33	Super LSI	1976–1990	99	Real World Computing Partnership RWCP	1992–exist
34	Technology Research Association of Medical and Welfare Apparatus	1976–exist	100	Lithium Battery Electric Power Storage	1993–exist
35	New House Supply System	1977–1979	101	Angstrom Technology Partnership	1993–exist
36	Pattern Information Processing System	1977–1982	102	Water Plastic Casting of Ceramics	1993–1999
37	Electric Car	1978–1990	103	Association for Research and Development of House Technology	1994–exist
38	Subsea Oil Production System	1978–1985	104	Ibaraki Prefecture General Information System for Support of the Aged	1995–1998
39	Flexible Manufacturing System Complex Provided with Laser	1978–1991	105	Nippon CALS Research Partnership (NCALS)	1995–1998
40	Advanced Gas Turbine	1978–1988	106	Femtosecond Technology Research Association	1995–exist
41	Research Association for Residual Oil Processing (RAROP)	1979–1996	107	TRAMET	1996–exist
42	Electronic Computer Basis	1979–1991	108	Association of Super-Advanced Electronics Technologies (ASET)	1996–exist
43	Research Association for Petroleum Alternatives Development (RAPAD)	1980–1996	109	Solar Cell Material	1996–exist
44	Application of High Polymer	1980–1985	110	Fixing Acid Gases by High Pressure	1998–exist
45	Wastewater Treatment Machinery System for Permanent Residential Area	1980–1987			
46	C1 Chemical	1980–1988			
47	Optics Applied System	1981–1987		**II. Incorporated foundation, etc.**	
48	Mini Gas Air-conditioning	1981–1991	111	R&D Institute of Metals and Composites for Future Industries	1981–exist
49	Synthetic Dye	1981–1998	112	Japan High Polymer Center [b]	1949–exist
50	Fine Ceramics Research Association	1981–exist	113	Research and Development Association for Future Electron Devices	1981–exist
51	Research Association for Biotechnology	1981–exist	114	Information-Technology Promotion Agency	1970–exist
52	High Polymer Basis	1981–1992	115	International Superconductivity Technology Center	1988–exist
53	Scientific Computer System	1981–1990	116	Micromachine Center	1992–exist
54	Technology Research Association of Ocean Mineral Resources Mining System	1982–1998	117	Research Institute of Human Engineering for Quality Life	1991–exist
55	Research Institute for Industrial Furnace Technology	1982–exist	118	Engineering Advancement Association of Japan (ENAA)	1978–exist

[b] Japan High Polymer Center (No. 112) was restructured and renamed into Japan Chemical Innovation Institute.

56	*New Basis of Steel Refining*	1982–1992	119	*Marine Biotechnology Institute Co., Ltd.*	1988–exist
57	*Combustion using Oxygen Enrichment Film*	1982–1992	120	*The Japan Research and Development Center for Metals*	1985–exist
58	*Paper Manufacturing*	1982–1991	121	*Japan Fine Ceramics Center (JFCC)*	1985–exist
59	*Secondary and Tertiary Recovery from Crude Oil*	1982–1996	122	*Japan Bio-Industry Association*	1983–exist
60	*Surfactant for Energy Development*	1982–1989	123	*Laboratories of Image Information Science and Technology (LIST)*	1992–exist
61	*Technology Research Association of Automated Sewing System*	1982–1991	124	*Institute for New Generation Computer Technology (ICOT)*	1982–1992
62	*Coal Opencast Machinery*	1983–1995	125	*Interoperability Technology Association for Information Processing, Japan (INTAP)*	1985–exist
63	*Advanced Aluminum Refining*	1983–1987	126	*Manufacturing Science and Technology Center Institute for Photonics Engineering*	1997–exist
64	*New Application Development for Light Ingredient from Oil Refinery*	1983–1996			
65	*High Efficiency Synthesis of Textiles*	1983–1995			
66	*Advanced Manufacturing Technology for Chemical Product using Vital Function*	1983–1995			

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