

# **Public R&D, Government Support, and R&D Expenditure in Industrial Sector: An Analysis Focusing on Correlation Among Industries**

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## **1 Introduction**

One of the tools that constitute national science and technology policy in a country is the government expenditure for various R&D activities. Governmental support for technological activities in companies and R&D activities in research institutions and universities is included here. This paper empirically examines the effect that a variety of R&D expenditures by government and other public organizations exert on technological innovations in industries through promoting their R&D activities.

In order to consider the determination factor of R&D expenditures in industries, we focus on the technological opportunity that they have. In this paper, as technological opportunity to promote technological innovation in industries, we examine (i) transfer and spillover of research output produced by the public sector and (ii) technology transfer through introduction of technological know-hows from foreign countries. Technological innovation of an industry is influenced also by the demand for its physical output, which enables it to spend more resources for its R&D activities. Thus, we suspect that both factors jointly determine the actual level of R&D effort. If the scale of R&D activity is determined based on relationship between supply and demand

for R&D, the technological opportunity influences the supply side of R&D and the demand factor influences the demand side of R&D. Thus, both factors could be regarded as important in determining actual R&D quantity.

This paper tries to examine the hypothesis that R&D expenditure in the public sector in Japan and its support for the private industrial sector in Japan do promote R&D supply in industries. We try to demonstrate the positive relationship between the activity of the public sector, such as government-and-industry joint research and technology transfer of research output, and the activity and performance of technological innovation in industries. The method adopted here is to estimate the relationship by using time-series data aggregated by industry, assuming that such a relationship varies across industries. Previously, we estimated the relationship by using macro-data in Japan and showed some evidence for significant effect of the government expenditure on industry R&D. In this paper, we try to examine whether the relationship holds at individual industry level as well.<sup>(1)</sup>

However, we cannot avoid confronting a problem of simultaneity when we conduct the analysis at the level of individual industry. That is, as a result that the increase of R&D expenditures in individual industries has positive effect on the amount of government R&D expenditure in the country and the government R&D influences the amount of private R&D in individual industries in turn, R&D activity in one industry may be influenced by other industries' R&D activities. Thus, it is expected that the relationship between public and private industrial R&D expenditures is correlative among industries through the channel of government R&D policies. Any empirical analysis using econometric method must take this problem into consideration.

In this paper, we use the term 'public' as expressing 'not profit-oriented'. For example, public R&D includes various R&D activities in the universities

and institutions which don't have profit-oriented objectives (for example, national research institutions, private non-profit research institutions, and public and private universities and colleges).

## **2 Determinants of Industrial R&D: Technological Opportunity and Aggregate Demand**

In discussing the factor determining the level of R&D in the industrial sector, the following two hypotheses are often presented in relation to the Schumpeter hypothesis. One hypothesis emphasizes the technological opportunity which each firm faces in conducting R&D activity. Another hypothesis focuses on the influence of demand factor at the stage of practical application of R&D output.

According to Kamien and Schwartz[1982] that studies the Schumpeter hypotheses, the former is called the 'Technology-Push Hypothesis.' It places major emphasis on the role of underlying scientific knowledge in innovation.<sup>(2)</sup> This regards the amount of R&D activity as related to the technological opportunity inside the firm. In this case, it is emphasized that the speed of technological innovation depends on the progress of this scientific base and that a larger-scale research organization can study the base of fundamental science with a larger view. In this sense, this viewpoint is consistent with that of the Schumpeter-Galbraith hypothesis that relates technological innovation to the scale and the monopolistic nature of a firm.

On the other hand, the latter is referred to as the 'Demand-Pull Hypothesis' in Kamien and Schwartz[1982]. This emphasizes the role of economic opportunity in innovation.<sup>(3)</sup> This is attributed to Schmookler[1966], which relates innovative activities of a firm to the size of demand it faces in the

market. This hypothesis relates innovative activities to several market factors outside the firm such as aggregate demand, investment demand and state of expectations. It regards innovative output in a firm as a reaction to the profit opportunity of that firm; therefore, market supposedly grasps the hegemony of technological innovation. According to this hypothesis, in order for the technological innovation in a firm to be successful, not only available technological opportunity but also sufficient demand to the new product or process that makes R&D activity profitable enough is needed.

Relating to these hypotheses, Griliches[1989] states “in the longer run, supply forces in the form of new discoveries and the steady contribution of new scientific knowledge surely have an important role to play. ... In general at the level of annual fluctuations demand forces are likely to be more important and easier to detect than the much slower supply forces, whose effects take longer to accumulate.”<sup>(4)</sup> According to Kamien and Schwartz[1982], “the technology-push and demand-pull hypotheses may be viewed as complementary rather than as competing explanations of innovation, with the former being more of a long-run theory and the latter, a short-run theory.”<sup>(5)</sup> Thus, in this paper, we empirically test these hypotheses by selecting several variables to represent technological opportunity and demand factor affecting Japanese industries’ technological activity so as to assess the direction and volume of their effects.

### **3 Interactive Relationship Between Public R&D and Industrial R&D**

#### **3.1 Complementarity between public and private R&D**

It is supposed that not only R&D expenditures in government organizations

but also non-financial assistance and regulatory policies do influence R&D expenditures in the private industrial sector. One of the rationale for the government spending money on R&D activity directly and supporting industrial R&D activity indirectly is the existence of the gap between the social and private rate of return of technological innovation, and many studies have shown the existence of this gap (for example, Mansfield et al.[1977]) .

There is a view that these direct and indirect R&D spending policies have a positive effect of producing new knowledge and technology that raise the profitability of R&D of private enterprises and stimulating their R&D activities. According to the 'Technology-Push' hypothesis, this effect could be interpreted as promoting R&D in the industrial sector through formation of its scientific base.

On the other hand, from a viewpoint of the scarcity of resources needed for performing R&D, an increase in government expenditures for R&D, especially direct spending, may increase the relative scarcity of the resources and raise the R&D cost for the private industrial sector. As a result, private sector industrial R&D may be crowded out by the government expenditure, that is, they may be substitute goods in the long run. In addition, since the capacity of a firm to perform R&D may be limited in the short run, the firm contracting R&D with the government may cut its own R&D budget. Moreover, as a result of the government research substituting for basic research by the private firms which shift their own resources to applied and development research, there may exist a trade-off relationship between basic research in the public sector and that in the private industrial sector although complementarity between public and industrial R&D activities may exceed this substitutability on the whole.<sup>(6)</sup>

### 3.2 Technology transfer and utilization in the industrial sector

With respect to the technology push hypothesis, a part of the technological output in non-profit research institutions and universities can spread through the private industrial sector by way of several channels of technology-transfer organizations and joint research projects. Thus, it may contribute to the technological innovation and productivity growth in the private industrial sector. Assuming the existence of the technology production function that models an activity of producing technological output from several technological inputs in the private industrial sector, we can regard these public R&D expenditures and knowledge stock coming from public R&D as a separate input factor of the technology production activities along with industrial R&D and technology import.<sup>(7)</sup> Thus, public R&D may be presumed to contribute to the improvement of economic performance such as productivity growth in the industrial sector through the technology production function.

On the other hand, it is often pointed out that private R&D has two faces. That is, R&D activity in a firm improves not only its own technological knowledge but also its capability to absorb knowledge and information from outside the firm. According to Cohen and Levinthal[1989], "While R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment. ... Absorptive capacity also includes the firm's ability to exploit outside knowledge of a more intermediate sort, such as basic research findings that provide the basis for subsequent applied research and development."<sup>(8)</sup> Therefore, it is expected that private R&D plays a complementary role in utilizing public R&D and its output. This means that public R&D and private R&D may be complements rather than substitutes. In addition, this interrelationship between public and private R&D can be analyzed by focusing on their geographic accessibility and

similarity of areas of research. For example, Jaffe[1989] points out that industrial R&D is affected by the public R&D activity that stands close regionally or has a similar theme by way of joint research between firms and universities or research institutions.<sup>(9)</sup>

## 4 The Model

### 4.1 Demand function and supply function for R&D and interpretation of the parameters

To the relationship stated above, in this paper, we apply the following specification derived from the demand function and supply function for industrial R&D that is based on Lichtenberg[1987] and try to estimate and interpret its parameters.

Lichtenberg[1987] assumes the existence of a demand function and a supply function behind the actual relationship between public and private R&D and treats technological opportunity and demand factor as the factors affecting them. At first, for simplicity, he lumps all factors other than R&D together and write it as the variable *SALES* expressing demand factor. Thus, the common linear expression of the model linking public and private R&D is written as:

$$(1) \quad CRD = \beta_0 + \beta_1 FRD + \beta_2 SALES,$$

*CRD* : R&D in the private sector by its own capital,

*FRD* : R&D in the private sector funded by the government,

*SALES* : aggregate demand.

In equation (1), the coefficient  $\beta_1$  of the variable *FRD* shows the relationship between private R&D funded by the government and R&D by its own fund.

Then, Lichtenberg[1987] treats the actual amount of R&D as the equilibrium amount of R&D demand and R&D supply and interprets the estimated

coefficients as derived from the following demand function and supply function.

That is, he assumes:

$$(2) \quad P_S = a_0 + a_1 CRD + a_2 FRD \quad (\text{supply curve}),$$

$$(3) \quad P_D = b_0 + b_1 CRD + b_2 SALES \quad (\text{demand curve}),$$

$P_S$  : supply price of R&D,

$P_D$  : demand price of R&D.

In equation (2), it is assumed that an entry of the government to the R&D market influences the price level of R&D resources and moves the private R&D supply curve upward. In equation (3), it is assumed that an increase of aggregate demand provides firms with incentives to spend more money for R&D activities, and the private R&D demand curve shifts upward.

Finally, in estimating equation (1), Lichtenberg[1987] specifies the model as linear function and divides the aggregate demand variable into two parts; demand from the public sector and demand from the private sector. Using this specification, he compares the effects of these two demand factors on private R&D spending and examines the effect of including these factors on the value of the coefficient of  $FRD$ .<sup>(10)</sup>

We can interpret this model as follows: (i) the technology-push hypothesis focuses on the shift of the R&D supply curve and the demand-pull hypothesis focuses on the shift of the R&D demand curve, (ii) the former determines the actual amount of R&D in the long run and the latter determines it in the short run. Assuming that the equilibrium situation holds in actual market and  $P_S = P_D$ , we obtain the following expression:

$$(4) \quad CRD = \frac{b_0 - a_0}{a_1 - b_1} + \frac{-a_2}{a_1 - b_1} FRD + \frac{b_2}{a_1 - b_1} SALES.$$

As is the case with ordinary supply function and demand function, we assume that the increasing marginal cost and the decreasing marginal return hold true



for R&D, so that  $a_1 - b_1 > 0$  holds true in equation (4). Thus, we guess the sign of the coefficient of *FRD* in equation (2) and that of *SALES* in equation (3) from the sign condition of the coefficient in equation (4). This enables us to recognize the direction of the effect of these factors on supply curve and demand curve. For example, if  $-a_2/(a_1 - b_1) > 0$ , then  $a_2 < 0$ , and this means that public R&D reduces R&D cost and stimulates private industrial R&D activity (the technology-push effect). In contrast, if  $-a_2/(a_1 - b_1) < 0$ , public R&D raises R&D cost and has negative effect on private industrial R&D activity (crowding-out effect). Though Lichtenberg[1987] does not mention this interpretation of the coefficients explicitly, it seems that his article tries to explain the change of the actual amount of R&D in terms of the shift of the curves stated above, so we follow the above interpretation of the model.

In Lichtenberg[1987], his method was applied only to investigate the effect of R&D money flow coming from government to industry. We extend his model so as to include all R&D activities conducted by the public sector (research institutions and universities, for example). Thus, in this paper, we take R&D spending in the public sector as a whole into consideration and treat it as one of the variables of the model explicitly.

#### 4.2 Simultaneous relationship and correlation among industries

On the other hand, as pointed out in Jaffe[1989], industrial R&D also affects public R&D activity. If we solely focus on the relationship between national level of industrial R&D and public research, this problem of simultaneity could be avoided by assuming suitable time lag between the two R&D variables or by using a proper estimation procedure for a simultaneous equations model like a two stage least square method or instrumental variable method. However, if we analyze this relationship for each industry separately, we must consider the

phenomenon that this relationship correlates between industries. That is, because of this simultaneity, even the public R&D expenditure that is not related directly to the R&D for individual industries can be influenced by the R&D in each industry through this relation of cause and effect. As a result, the amount of R&D in one industry may be influenced by the amount of R&D in other industries. This brings about the situation where the relationship between public R&D and industrial R&D influences mutually among industries. Moreover, since R&D activity raises national income through productivity growth and an increase in aggregate demand caused by this increase in national income growth raises the amount of R&D in turn, the same relationship is also assumed to exist between the R&D in each industry and aggregate demand.

Meanwhile, Fernald[1999] used time-series data aggregated by industry and confronted the same problem of simultaneity as stated above. In his estimation of the relationship between social capital (interstate highway network in the U.S.) and productivity growth, he focused on the phenomenon that the error term of each industry's regression correlates each other. In order to obtain more accurate estimates for the effect of social capital, Fernald[1999] dealt with the problem by applying the seemingly unrelated regression (SUR) method. In this paper, we follow Fernald's method and analyze the interactive relationship between aggregate public R&D expenditure and individual R&D expenditure in each industry.

## **5 Empirical Analysis**

### **5.1 Model specification and data**

In this paper, based on Lichtenberg[1987], we conduct an empirical analysis

on the effect of public R&D activity as a determinant of industrial R&D using time-series data, disaggregated by manufacturing industry in Japan. We consider public R&D expenditures in research institutions and universities as well as industrial R&D funds provided by central and local governments as government research activity, and we try to estimate their technology-push effect on private industrial R&D effort. In addition, we consider the effect of technology import as a separate independent variable concerning technological opportunity for the industrial sector. Furthermore, following Lichtenberg[1987] that divides aggregate demand into private and public demand, we focus on the investment demand that is especially influential on private R&D in Japan. In this attempt, we test the hypothesis that the increase of investment embodying new technologies stimulates R&D expenditure.

The coefficients of these new variables can be interpreted in the same manner as Lichtenberg's original variables. Thus, supply function and demand function for industrial R&D are specified as:

$$(5) \quad P_S = a_0 + a_1 CRD + a_2 FRD1 + a_3 FRD2 + a_4 TIM$$

(supply curve),

$$(6) \quad P_D = b_0 + b_1 CRD + b_2 (OTH + (1 + \theta) INV) + b_3 FRD1 + b_4 FRD2$$

(demand curve).

In equation (5),  $FRD1$  is the amount of private firms' R&D funds received from central and local governments,  $FRD2$  is the amount of R&D expenditures at research institutions and universities, and  $TIM$  is the amount of payment for technology import. In equation (6),  $INV$  is the gross fixed capital formation,  $OTH$  is calculated as  $SALES - INV$ , and  $\theta$  means the weight or premium of  $INV$  relative to  $OTH$ . Here, the variable  $OTH + (1 + \theta) INV$  is transformed into  $SALES (1 + \theta INV/SALES)$ . The variables  $FRD1$  and  $FRD2$  in equation (6) consider that these public R&D expenditures may stimulate the demand

side of industrial R&D activity by providing technological incentives to R&D in addition to the technology-push effect at the supply side shown in equation (5).

Using equation (5) and (6), we obtain:

$$(7) \quad CRD = \frac{b_0 - a_0}{a_1 - b_1} + \frac{b_3 - a_2}{a_1 - b_1} FRD1 + \frac{b_4 - a_3}{a_1 - b_1} FRD2 + \frac{-a_4}{a_1 - b_1} TIM \\ + \frac{b_2}{a_1 - b_1} SALES \left[ 1 + \theta \frac{INV}{SALES} \right].$$

From equation (7), we obtain the sign of the coefficient of each variable in equation (5) and (6). Then, assuming  $\theta (INV/SALES) < 1$ , taking natural logarithm of the last term of the right-hand side, we obtain as an approximation:

$$\log SALES (1 + \theta INV/SALES) = \log SALES + \theta INV/SALES.$$

In this paper, instead of using common linear specification as expressed in equation (7), we assume the following log-linear specification of the model:

$$(8) \quad \log CRD = \frac{b_0 - a_0}{a_1 - b_1} + \frac{b_3 - a_2}{a_1 - b_1} \log FRD1 + \frac{b_4 - a_3}{a_1 - b_1} \log FRD2 \\ + \frac{-a_4}{a_1 - b_1} \log TIM + \frac{b_2}{a_1 - b_1} \log SALES + \frac{b_2}{a_1 - b_1} \theta \left[ \frac{INV}{SALES} \right].$$

If  $b_2/(a_1 - b_1)$  is not equal to zero and  $b_2/(a_1 - b_1) \theta = 0$ , we can guess  $\theta = 0$ . This means the factor  $INV$  and  $OTH$  have the same effect on industrial R&D. If  $(b_3 - a_2)/(a_1 - b_1) > 0$ , then we can guess that the government R&D has positive effect on R&D supply (that is,  $a_2 < 0$ ) or its positive effect on demand-side is greater than its negative effect on supply-side (that is,  $0 < a_2 < b_3$ ).

Estimation is conducted using annual data for the period of 1976-1997, for which investment data in the industries listed below are available. As a result, the data in the period of the first oil shock (the early and middle of 1970s) during which the trend of economic growth in Japan was heavily disturbed are

excluded, so that we can avoid the problem of structural change in the relationship in those years.<sup>(11)</sup> The industries used in this estimation are the following 10 Japanese manufacturing industries; textiles manufacturing, chemical products manufacturing, petroleum and coal products manufacturing, ceramics, basic metals manufacturing (including iron and steel manufacturing and non-ferrous metals and products manufacturing), fabricated metal products manufacturing, general machinery manufacturing, electrical machinery manufacturing, transportation equipment manufacturing, and precision instruments manufacturing.<sup>(12)</sup> These industries are selected from the category in the Statistics Bureau's R&D survey according to the availability of received R&D data during the period and account for about 76% of the total amount of GDP in manufacturing (in 1997).

On the other hand, since the linear or log-linear specification of the model such as equation (7) or (8) may suffer from the possibility of serial correlation of the error term, these specifications are not suitable for time-series analysis. For that reason, we take the first difference of equation (8) and convert variables into rates of change. Thus, the estimated equation corresponding to the log-differential form of equation (8) in the  $i$ th industry in the year  $t$  is written as follows:

$$(9) \quad GPRD_{i,t} = \alpha_0 + \alpha_1 GRRD_{i,t} + \alpha_2 GGRD_t + \alpha_3 GGDP_{i,t} + \alpha_4 GTIM_{i,t} \\ + \alpha_5 DINV_{i,t} + u_{i,t} ,$$

$GPRD_{i,t}$  : annual rate of change in real intramural expenditure on R&D in the  $i$ th industry (except for funds received from central and local governments),

$GRRD_{i,t}$  : annual rate of change in real R&D funds received from central and local governments in the  $i$ th industry,

$GGRD_t$  : annual rate of change in real intramural expenditure on R&D in research institutions and universities,

$GTIM_{i,t}$  : annual rate of change in real payment of technology imports in the  $i$ th industry (expressed in yen),

$GGDP_{i,t}$  : annual rate of change in real GDP classified by economic activities in the  $i$ th industry,

$DINV_{i,t}$  : annual change in the ratio of investment in fixed assets (progress base) relative to GDP classified by economic activities in the  $i$ th industry.

These data are calculated from the data on *Report on the Survey of Research and Development* (Statistics Bureau, Ministry of Public Management, Home Affairs, Posts and Telecommunications), *Annual Report on National Accounts* and *Gross Capital Stock of Private Enterprises* (Economic and Social Research Institute, Cabinet Office). R&D deflator in company, research institution, and university are derived from *White Paper on Science and Technology* (Ministry of Education, Science, Sports and Culture).

Along with this estimation, we estimate the following equation as well:

$$(10) \quad GPRD_{i,t} = \alpha_0 + \alpha_1 GRRD_{i,t} + \alpha_2 SR_{i,t} \times GGRD_t + \alpha_3 GGDP_{i,t} \\ + \alpha_4 GTIM_{i,t} + \alpha_5 DINV_{i,t} + u_{i,t} .$$

In this equation,  $SR_{i,t} \times GGRD_t$  is the product of  $GGRD_t$  and percentage of R&D in sales in the  $i$ th industry,  $SR_{i,t}$  (based on the R&D statistics stated above). Assuming that the R&D intensity in each industry reflects the degree of utilization of public R&D outputs in that industry, we assume this variable to be an approximation of the amount of public R&D used in that industry.

## 5.2 Results of estimation

### (a) *Industrial R&D, government support, and public R&D*

First, assuming that each industry uses the same amount of public R&D outputs, the simultaneous equations model expressed as equation (9) was examined by using SUR method. The estimated coefficients and other statistics are shown in Table 1. The results may be summarized as follows<sup>(13)</sup>:

- (i) The estimated coefficient of the variable *GRRD* is positive and statistically significant at least at the 10% level for textiles, basic metals, fabricated metal products, and electrical machinery manufacturing. The coefficient is negative and significant for the ceramics industry. For other industries, the coefficient is not significant. Thus, R&D funds received from central and local governments seems to have had positive effect on industrial R&D expenditures at least for several industries in Japan. On the other hand, the estimated coefficient of the variable *GGRD* is positive and statistically significant, at least at the 10% level, for textiles and transport equipment manufacturing. These results seem to show that public and industrial R&D expenditures are complements rather than substitutes for these industries. That is, even though the cost-reducing effect of the government support for R&D is not obvious, we can guess that its positive effect on technological incentives is greater than its cost-raising effect.
- (ii) Technology import as a separate technological opportunity variable seems to play a complementary role with domestic R&D in many industries.
- (iii) The investment ratio variable *DINV* as demand factor has significant and positive sign in textiles, chemical products, petroleum and coal products, ceramics, basic metals, and transportation equipment manufacturing. Except for transportation equipment, they are traditional process industries. On the other hand, the investment ratio does not have such a significant effect on R&D in electrical machinery and precision instruments manufacturing.

**Table 1. Government funded R&D and industrial R&D**Dependent variable: *GPRD*

Period of estimation: 1976~1997

Method of estimation: SUR (Seemingly Unrelated Regression)

Industry	textiles	chemical	petroleum and coal	ceramics	basic metals
constant	-0.114* (-2.476)	0.0331** (2.595)	0.0350 (0.521)	0.0328 (1.098)	-0.0199 (-0.990)
<i>GRRD</i>	0.00716* (2.278)	-0.00475 (-0.342)	-0.00221 (-0.126)	-0.0447* (-2.305)	0.0686** (5.191)
<i>GGRD</i>	2.741** (3.298)	0.140 (0.685)	-0.537 (-0.428)	0.346 (0.639)	0.992** (2.619)
<i>GTIM</i>	0.123** (6.618)	0.120* (2.537)	0.296** (3.265)	0.0273 (1.475)	-0.0261+ (-1.708)
<i>GGDP</i>	0.144 (0.412)	0.227* (2.090)	0.716* (2.550)	0.591+ (1.656)	0.221* (1.905)
<i>DINV</i>	1.451* (2.285)	0.162** (3.766)	3.436+ (1.945)	1.180* (2.173)	1.440** (4.010)
$R^2$	0.576	0.269	0.481	0.333	0.473
<i>s</i>	0.140	0.0355	0.215	0.0908	0.0593
<i>DW</i>	2.420	1.096	2.406	2.022	2.074

industry	fabricated metal	general machinery	electrical machinery	transportation equipment	precision instruments
constant	-0.0123 (-0.284)	0.0818** (4.441)	-0.00140 (0.0656)	0.0101 (0.472)	0.0463* (1.987)
<i>GRRD</i>	0.0347** (1.956)	-0.00216 (-0.109)	0.0542* (1.849)	-0.0200 (-0.889)	-0.000844 (-0.109)
<i>GGRD</i>	0.154 (0.214)	-0.532 (-1.589)	0.500+ (1.862)	0.672+ (1.784)	0.335 (0.800)
<i>GTIM</i>	-0.0681 (-0.620)	0.128+ (1.946)	0.0850 (1.410)	0.138* (2.066)	0.00514 (0.121)
<i>GGDP</i>	0.875+ (1.832)	0.117 (1.055)	0.383** (4.229)	0.316+ (1.729)	0.516** (4.822)
<i>DINV</i>	1.295 (1.223)	0.147 (0.159)	0.247 (0.660)	2.400** (5.991)	0.211 (0.495)
$R^2$	0.260	0.331	0.546	0.486	0.416
<i>s</i>	0.116	0.0524	0.0465	0.0612	0.0694
<i>DW</i>	2.639	2.058	1.687	3.004	3.042

The estimation was conducted by using TSP ver. 4.2.

*t*-values are in parentheses. *DW* is Durbin-Watson statistics. *s* is standard error of regression.

\*\* significant at the 1% level.

\* significant at the 5% level.

+ significant at the 10% level.



Second, based on the two-faced nature of R&D stressed by Cohen and Levinthal[1989] and the concept of technology production function referred to in Link[1987], equation (10) was examined, where each industry was assumed to use public R&D according to the size of its R&D intensity. The results of estimation are shown in Table 2. This is based on the assumption that the influence received from public R&D activity is higher in the industry or in the period where R&D intensity is relatively high.<sup>(14)</sup> However, estimated results were similar to the results shown in Table 1 in which R&D intensity was not considered. Thus, in the following estimation that examines the above relationship from the viewpoint of types of R&D, we adopt the specification based on equation (9).

*(b) Type of R&D activity and public R&D*

Then, we examine the relationship between private industrial R&D and public R&D focusing on the type of R&D activity; basic research and applied research and development in the industrial sector. We use the intramural expenditure on R&D in industries including R&D funded by the government as a dependent variable and divide this into two parts; basic research expenditure in the industry and applied research plus development expenditure in the industry. This is because industrial R&D funded by the government is not classified by type of R&D activity in the statistics of intramural expenditure on R&D in Japan and, as a result, we cannot distinguish government support for basic research in industries from other R&D supports. For that reason, the independent variable  $GRRD_{i,t}$  in section 5.2(a) is omitted from the estimation here. Estimated equations are written as:

$$(11) \quad GRD_{i,t} = a_0 + a_2 GGRD_t + a_3 GGDP_{i,t} + a_4 GTIM_{i,t} + a_5 DINV_{i,t} \\ + e_{i,t} .$$

**Table 2. Government funded R&D and industrial R&D  
(considering percentage of R&D in sales)**

Dependent variable: *GPRD*

Period of estimation: 1976~1997

Method of estimation: SUR

Industry	textiles	chemical	petroleum and coal	ceramics	basic metals
constant	-0.105* (-2.425)	0.0351** (2.731)	0.0168 (0.274)	0.0440 (1.558)	0.000799 (0.0393)
<i>GRRD</i>	0.00881** (2.816)	-0.00406 (-0.291)	-0.000800 (-0.0470)	-0.0421* (-2.177)	0.0614** (4.366)
<i>SR</i> × <i>GGRD</i>	164.811** (3.359)	0.955 (0.223)	-32.351 (-0.155)	3.735 (0.170)	27.891 (1.492)
<i>GTIM</i>	0.136** (7.662)	0.112* (2.375)	0.303** (3.490)	0.0244 (1.274)	-0.0221 (-1.443)
<i>GGDP</i>	-0.146 (-0.424)	0.255* (2.349)	0.739** (2.636)	0.557 (1.477)	0.150 (1.242)
<i>DINV</i>	1.253* (1.998)	0.166** (3.846)	3.616* (2.037)	1.034+ (1.860)	1.207** (3.455)
<i>R</i> <sup>2</sup>	0.544	0.264	0.479	0.315	0.357
<i>s</i>	0.145	0.0356	0.215	0.0920	0.0655
<i>DW</i>	2.342	1.094	2.475	2.003	1.948
average <i>SR</i>	1.344%	4.074%	0.454%	2.184%	1.824%

industry	fabricated metal	general machinery	electrical machinery	transportation equipment	precision instruments
constant	0.00276 (0.0639)	0.0759** (4.065)	0.0123 (0.556)	0.0114 (0.567)	0.0511* (2.190)
<i>GRRD</i>	0.0323+ (1.818)	-0.00790 (-0.390)	0.0576+ (1.859)	-0.0174 (-0.757)	0.00108 (0.140)
<i>SR</i> × <i>GGRD</i>	-13.306 (-0.254)	-14.097 (-1.199)	5.404 (1.052)	22.487* (1.969)	4.936 (0.542)
<i>GTIM</i>	-0.0646 (-0.589)	0.132+ (1.940)	0.0678 (1.099)	0.164* (2.418)	0.00366 (0.0806)
<i>GGDP</i>	0.863+ (1.811)	0.134 (1.147)	0.349** (3.724)	0.312+ (1.689)	0.504** (4.408)
<i>DINV</i>	1.163 (1.073)	0.368 (0.388)	0.165 (0.446)	2.316** (5.772)	0.143 (0.332)
<i>R</i> <sup>2</sup>	0.255	0.311	0.505	0.495	0.411
<i>s</i>	0.116	0.0532	0.0490	0.0605	0.0699
<i>DW</i>	2.686	2.090	1.707	2.993	3.011
average <i>SR</i>	1.378%	2.670%	5.075%	2.997%	4.495%

See Table 1 for notation.

"average *SR*" is the average percentage of R&D in sales during 1976 to 1997.

$$(12) \quad GBRD_{i,t} = a_0 + a_2 GGRD_t + a_3 GGDP_{i,t} + a_4 GTIM_{i,t} + a_5 DINV_{i,t} \\ + e_{i,t} .$$

$$(13) \quad GARD_{i,t} = a_0 + a_2 GGRD_t + a_3 GGDP_{i,t} + a_4 GTIM_{i,t} + a_5 DINV_{i,t} \\ + e_{i,t} .$$

$GRD_{i,t}$  is the annual growth rate of real intramural expenditure on R&D in the  $i$ th industry (including R&D funds received from central and local governments),  $GBRD_{i,t}$  is the growth rate of intramural R&D expenditure for basic research in the  $i$ th industry, and  $GARD_{i,t}$  is that for applied research and development (each variable is deflated by private R&D deflator).

The results of estimation of equation (11), (12), and (13) are shown in Tables 3, 4, and 5, respectively.<sup>(15)</sup> According to Table 3, public R&D in research institutions and universities has a positive effect on intramural R&D expenditures in private companies. This is consistent with the results shown in Tables 1 and 2, even when R&D funds received from the government are included in company R&D. According to the result shown in Table 4, the coefficient of the variable  $GGRD$  has a positive sign and it is significant at least at the 10% level in ceramics, electrical machinery, and precision instruments manufacturing. This means that public R&D expenditures seem to have a complementary relationship with basic research activity in these industries.

Furthermore, the results shown in Table 5 indicate that the relationship between applied research and development in companies and R&D expenditure in research institutions and universities is similar to the relationship between the whole R&D expenditure in companies and public R&D.

**Table 3. Public R&D and overall R&D in industry**

Dependent variable: *GRD*  
 Method of estimation: SUR

Period of estimation: 1976~1997

Industry	textiles	chemical	petroleum and coal	ceramics	basic metals
constant	-0.0951* (-2.053)	0.0329** (2.650)	0.0300 (0.440)	0.0250 (0.818)	0.000528 (0.0284)
<i>GGRD</i>	2.586** (3.010)	0.137 (0.677)	-0.495 (-0.391)	0.228 (0.418)	0.911* (2.074)
<i>GTIM</i>	0.125** (6.377)	0.123** (2.797)	0.309** (4.389)	0.0242 (1.181)	-0.0319 (-1.568)
<i>GGDP</i>	0.114 (0.338)	0.224* (2.216)	0.772** (3.121)	0.725+ (1.852)	0.293* (2.090)
<i>DINV</i>	1.347* (2.024)	0.163** (4.056)	4.147* (2.386)	1.297* (2.200)	1.755** (4.095)
$R^2$	0.552	0.276	0.494	0.323	0.375
<i>s</i>	0.145	0.0352	0.220	0.0908	0.0657
<i>DW</i>	2.264	1.110	2.356	2.108	1.445

industry	fabricated metal	general machinery	electrical machinery	transportation equipment	precision instruments
constant	-0.00439 (-0.101)	0.0765** (4.159)	0.00521 (0.220)	0.0112 (0.549)	0.0484** (2.108)
<i>GGRD</i>	0.161 (0.219)	-0.482 (-1.486)	0.479+ (1.663)	0.679+ (1.907)	0.297 (0.726)
<i>GTIM</i>	-0.0861 (-0.798)	0.123+ (1.918)	0.0758 (1.100)	0.168** (2.680)	0.0253 (0.752)
<i>GGDP</i>	1.023* (2.157)	0.165 (1.553)	0.398** (4.098)	0.215 (1.419)	0.492** (4.908)
<i>DINV</i>	2.000+ (1.925)	0.191 (0.215)	0.531 (1.401)	2.348** (6.353)	-0.0852 (-0.282)
$R^2$	0.241	0.322	0.504	0.521	0.445
<i>s</i>	0.118	0.0519	0.0492	0.0589	0.0680
<i>DW</i>	2.811	2.088	1.623	3.006	2.985

See Table 1 for notation.

**Table 4. Public R&D and basic research in industry**Dependent variable: *GBRD*

Period of estimation: 1976~1997

Method of estimation: SUR

Industry	textiles	chemical	petroleum and coal	ceramics	basic metals
constant	0.422* ( 2.209)	0.0456 ( 1.220)	0.115 ( 0.872)	- 0.0357 ( - 0.697)	0.0270 ( 0.592)
<i>GGRD</i>	- 0.869 ( - 0.244)	- 0.0935 ( - 0.165)	0.779 ( 0.318)	2.425** ( 2.685)	0.809 ( 0.904)
<i>GTIM</i>	- 0.180** ( - 2.927)	0.0457 ( 0.288)	0.227 ( 1.493)	0.0382* ( 2.309)	- 0.0707 ( - 1.626)
<i>GGDP</i>	8.352** ( 7.255)	0.604+ ( 1.673)	0.560 ( 1.071)	0.923 ( 1.319)	0.373 ( 1.250)
<i>DINV</i>	6.955** ( 2.989)	0.178 ( 1.260)	7.561* ( 2.051)	3.488** ( 3.271)	4.005** ( 4.281)
$R^2$	0.449	0.0461	0.417	0.457	0.464
<i>s</i>	0.611	0.0962	0.425	0.147	0.132
<i>DW</i>	2.184	2.745	2.472	1.926	1.908
basic R&D ratio	7.032%	11.818%	8.5%	7.564%	7.037%

industry	fabricated metal	general machinery	electrical machinery	transportation equipment	precision instruments
constant	- 0.0564 ( - 0.235)	0.181 ( 1.093)	0.0866* ( 2.240)	- 0.0588 ( - 0.833)	- 0.0416 ( - 0.499)
<i>GGRD</i>	2.561 ( 0.641)	- 1.695 ( - 0.591)	0.816+ ( 1.682)	1.176 ( 0.967)	2.842+ ( 1.919)
<i>GTIM</i>	- 0.752 ( - 1.263)	0.565 ( 0.944)	0.0280 ( 0.249)	- 0.540* ( - 2.407)	0.248 ( 1.399)
<i>GGDP</i>	3.552 ( 1.311)	1.499 ( 1.450)	- 0.0767 ( - 0.482)	1.326* ( 2.467)	0.380 ( 0.891)
<i>DINV</i>	7.731 ( 1.302)	- 16.375* ( - 1.972)	2.225** ( 3.300)	3.390* ( 2.422)	1.547 ( 1.074)
$R^2$	0.107	0.0986	0.257	0.232	0.294
<i>s</i>	0.636	0.451	0.0784	0.198	0.229
<i>DW</i>	2.688	2.094	1.375	2.078	2.199
basic R&D ratio	2.905%	3.673%	4.127%	3.936%	3.705%

See Table 1 for notation.

"basic R&amp;D ratio" is the average percentage of basic research in overall R&amp;D expenditure during 1976 to 1997.

**Table 5. Public R&D and applied R&D in industry**Dependent variable: *GARD*

Period of estimation: 1976~1997

Method of estimation: SUR

Industry	textiles	chemical	petroleum and coal	ceramics	basic metals
constant	- 0.104* (- 2.291)	0.0278* ( 2.157)	0.0324 ( 0.491)	0.0281 ( 0.874)	0.00231 ( 0.104)
<i>GGRD</i>	2.571** ( 3.041)	0.183 ( 0.885)	- 0.649 (- 0.530)	0.111 ( 0.195)	0.833+ ( 1.916)
<i>GTIM</i>	0.153** ( 8.533)	0.125** ( 2.634)	0.296** ( 4.283)	0.0142 ( 0.641)	- 0.0217 (- 1.086)
<i>GGDP</i>	- 0.132 (- 0.423)	0.229* ( 2.089)	0.754** ( 3.083)	0.764+ ( 1.816)	0.234+ ( 1.682)
<i>DINV</i>	0.764 ( 1.215)	0.172** ( 3.936)	4.064* ( 2.379)	1.272* ( 2.041)	1.355** ( 3.200)
$R^2$	0.615	0.272	0.511	0.261	0.325
<i>s</i>	0.141	0.0359	0.212	0.0951	0.0653
<i>DW</i>	2.132	1.276	2.333	2.074	1.345

industry	fabricated metal	general machinery	electrical machinery	transportation equipment	precision instruments
constant	- 0.00353 (- 0.0834)	0.0745** ( 4.297)	0.00101 ( 0.0436)	0.0185 ( 0.848)	0.0613** ( 2.435)
<i>GGRD</i>	0.219 ( 0.303)	- 0.408 (- 1.337)	0.483+ ( 1.691)	0.630+ ( 1.668)	0.131 ( 0.292)
<i>GTIM</i>	- 0.0954 (- 0.953)	0.141* ( 2.257)	0.0597 ( 0.890)	0.178* ( 2.512)	0.0103 ( 0.260)
<i>GGDP</i>	0.908* ( 2.078)	0.120 ( 1.170)	0.431** ( 4.479)	0.0902 ( 0.538)	0.434** ( 3.796)
<i>DINV</i>	2.206* ( 2.205)	0.237 ( 0.276)	0.503 ( 1.353)	2.290** ( 5.552)	- 0.255 (- 0.728)
$R^2$	0.225	0.311	0.527	0.502	0.399
<i>s</i>	0.117	0.0491	0.0485	0.0622	0.0740
<i>DW</i>	2.743	2.017	1.682	2.947	2.951

See Table 1 for notation.

## 6 Conclusion

The results of the analysis may be summarized as follows. First, according to the estimation using SUR method, public R&D expenditures and government R&D funds provided to each industry had significant positive relationship with the intramural R&D expenditure in that industry even if the interactive relationship between public and private industrial R&D was considered. This suggests that public R&D and R&D funds spent for the industrial sector play a positive role as the technological opportunity for technological innovations in the private industrial sector, which reduces R&D cost or provides technological incentives to perform R&D. In addition, this also suggests that public R&D and private R&D are complement goods. This outcome is consistent with the previous finding in Baba[1993] using macro-data. In addition, this finding also is consistent with the finding in Baba[2001] in which similar models are estimated by using regional cross-sectional data in Japan.

Second, the estimation results reveal that the relationship varies according to the industries. Not all the industries examined here revealed positive relationships between public and private R&D expenditure; that is, this relationship was not statistically significant for several industries. However, any significant negative relationship was not observed between them except in one case. This suggests that complementary relationships are found more often than substitute relationships in Japanese industries.

Third, when the industrial R&D expenditure was divided into (i) basic research and (ii) applied research and development, the relationship observed in basic research completely differed from the relationship in the case of applied research and development. In contrast with applied research and

development expenditure in the industrial sector also having complementary relationships with public R&D in the similar industries, basic research expenditure had significant relationship with public R&D in ceramics and precision instrument manufacturing, in which the whole R&D in the industry didn't have such a significant effect. However, we could not find any statistically significant negative relationship between public R&D expenditure and basic research expenditure. This suggests that complementary relationship between public and industrial R&D is predominant in some industries even in cases where industrial basic research has a possibility of substitution with public R&D activity.

In spite of the detail being different among industries or among the types of R&D activity, we may be able to conclude that public R&D activities supporting the private industrial sector and spending in research institutions and universities can stimulate private industry R&D and that they does not substitute for private industry R&D at least.



## Notes

- (1) This paper is based partly on an earlier paper, Baba[1993]. However, the method of estimation and data used are quite different from Baba[1993]. Estimated results and interpretation are also newly conducted here.
- (2) Kamien and Schwartz[1982], p.22.
- (3) Kamien and Schwartz[1982], p.23.
- (4) Griliches[1989],pp.305-307.
- (5) Kamien and Schwartz[1982],p.36.
- (6) For example, Higgins and Link[1981] found that the R&D-intensive industry was likely to have high ratio of government funds relative to the overall R&D expenditure. However, this relationship was observed mainly between applied research and development in that industry and government expenditure, and they concluded that the industry that received relatively large amount of government funds was likely to have low level of expenditure for basic research by its own capital. Higgins and Link[1981],pp.86-88.
- (7) About this type of technology production function, for example, see Link[1987].
- (8) Cohen and Levinthal[1989], pp.569-570.
- (9) For example, Baba[2001] executed empirical analysis based on Fernald[1999] and Jaffe[1989] and found (i) positive interactive relationship between public R&D and productivity growth in industries using time-series data by industry, (ii) positive interactive relationship among patent production, public R&D, and industrial R&D using regional cross-sectional data.
- (10) Lichtenberg[1987],pp.98-99.
- (11) Baba[1993] applied stepwise chow-test to the similar model and found that the significant structural change occurred at the year of 1975/76. Baba[1993], pp.47-48.
- (12) These names of industries follow the Statistics Bureau's R&D survey (except basic metals manufacturing).
- (13) These results are roughly consistent with the results of OLS estimation shown in Baba[1993], which used annual macro-data in Japan for the period of 1965-1990 and estimated the log-linear specification similar to equation (8) except the investment rate variable and the technology import variable. One of the estimation in Baba[1993] was as follows:

$$\log CRD = -12.596 + 0.006t + 0.461\log GRD + 0.874\log GNP + 8.018(OD/GNP)$$

$$(-7.422^{**}) \quad (1.139) \quad (1.863+) \quad (3.109^{**}) \quad (8.594^{**})$$

Adjusted R-squared = 0.997,  $DW = 1.787$ ,  $s = 0.0364$ .

In the equation,  $GRD$  corresponds to the sum of  $FRD1$  and  $FRD2$  in this paper,  $GNP$  is the gross national products in Japan,  $t$  is the time trend, and  $OD$  is the portion of  $GNP$  other than the government sector. Baba[1993], p.46.

- (14) Baba[2000] and Baba[2001] applied this assumption about R&D intensity to the productivity growth analysis based on Fernald[1999] and found its significant contribution to the industrial productivity performance.
- (15) As shown in footnote(13), Baba[1993] conducted similar estimation using macro-data and dividing industrial R&D into the types of R&D activity. Though the estimation method was OLS, the result was roughly similar to the one in this paper. For example, the following equation was estimated:

$$\log BRD = -6.084 + 0.01t + 2.186\log GRD - 2.183\log GNP + 27.981(OD/GNP)$$

$$(-1.083) \quad (0.551) \quad (2.669^{*}) \quad (-2.343^{*}) \quad (9.056^{**})$$

Adjusted R-squared = 0.952,  $DW = 1.704$ ,  $s = 0.121$ .

$BRD$  is basic research expenditure in companies. This suggests that basic research in industry has positive relationship with public R&D at least at macro-level. Baba[1993], p.46.

## References

Baba, Masahiro [1993], "Minkan R&D Katsudō ni Taisuru Seifu Futan Kenkyūhi no Kōka (The Effect of Government-funded Research Expenditure on Private R&D Activity)," *The Fujironsō - Studies in Economics, Business Administration and the Liberal Arts* - , Vol.38, No.1-2, Scientific Association of Fuji College, pp.37-54.

\_\_\_\_\_ [2000], "Social and Knowledge Capital Stock and Productivity Change in Industries: Estimation of the Effects Considering Associated Private Capital Input," in Sadao Suwa (ed.), *Current Issues in Economic Policy*, Institute for Research in Contemporary Political and Economic Affairs, Waseda University, pp.67-99. (in English)

\_\_\_\_\_ [2001], "Shakaiteki Kyōtsū Shihon to Sangyō Bumon no Seisansei Jōshō: Kōteki Chisiki Shihon no Kōka (Social Overhead Capital and Productivity Growth in Industrial Sectors: Some Effects of Public Knowledge Stock)," paper presented at the 58th annual conference of the Japan Economic Policy Association held at Meiji University, Tokyo, Japan. (unpublished)

Cohen, Wesley M. and Daniel A. Levinthal [1989], "Innovation and Learning: The Two Faces of R&D," *Economic Journal*, Vol.99, pp.569-596.

Fernald, John G. [1999], "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity," *American Economic Review*, Vol.89, No.3, pp.619-638.

Griliches, Zvi [1989], "Patents: Recent Trends and Puzzles," *Brookings Papers on Economic Activity: Microeconomics*, pp.291-319.

Higgins, Richard S. and Albert N. Link [1981], "Federal Support of Technological Growth in Industry: Some Evidence of Crowding Out," *IEEE Transactions on Engineering Management*, Vol. EM-28, No.4, pp.86-88.

Jaffe, Adam B. [1989], "Real Effects of Academic Research," *American Economic Review*, Vol.79, No.5, pp.957-970.

Kamien, Morton I. and Nancy L. Schwartz [1982], *Market Structure and*

*Innovation*, Cambridge University Press.

Lichtenberg, Frank R. [1987], "The Effect of Government Funding on Private Industrial Research and Development: A Re-Assessment," *Journal of Industrial Economics*, Vol.36, No.1, pp.97-104.

Link, Albert N. [1987], *Technological Change and Productivity Growth*, Harwood Academic Publishers.

Mansfield, Edwin et al. [1977], "Social and Private Rates of Return from Industrial Innovations," *Quarterly Journal of Economics*, Vol.91, No.2, pp.221-240.

Mansfield, E. and Lorne Switzer [1984], "Effects of Federal Support on Company-Financed R&D: The Case of Energy," *Management Science*, Vol.30, No.5, pp.562-571.

Schmookler, Jacob [1966], *Invention and Economic Growth*, Harvard University Press.