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ABSTRACT

This paper estimates the contribution of R&D spillovers to four high-tech industries in Japan -- general machinery, electrical machinery, transportation machinery, and chemicals. The candidate spillover source industries are selected on the basis of large R&D flow or R&D proximity. R&D flow measures the spillovers embodied in purchased intermediate goods using the input-output coefficients. R&D proximity measures the extent of similarity between a pair of industries of the distribution of R&D expenditures across research fields, and is considered to show the likelihood of spillovers at the R&D stage. The contribution of spillovers was estimated by applying a translog cost function that includes the R&D stock variable of one of the source industries. The results suggest that electrical machinery benefitted from spillovers mainly through the purchase of intermediate goods whereas transportation machinery benefitted from R&D proximity. General machinery benefitted from both R&D flow and R&D proximity but none of the spillovers to chemicals was significant. These results clearly imply that the contribution as well as the channels of R&D spillovers is diverse depending on source industries and receiving industries, casting doubt on the earlier studies that used a weighted sum of R&D expenditures (or stocks) of other industries as a spillover variable.

1. Introduction

Increasingly, the contribution of technological spillovers in raising the productivity of industries and, thereby, the rate of economic growth is recognized. Several studies have investigated the consequence of these spillovers, mostly by estimating the impact of weighted R&D outlays of other industries on the productivity or the costs: see the survey by Griliches (1992). Yet, neither the mechanism (i.e., how the technology spills over) nor the direction (i.e., from which industry to which) of the spillovers has been fully understood.

We purport to study these questions using the data on the Japanese high-tech industries. To our knowledge, only three studies have estimated the contribution of R&D spillovers in Japan. Odagiri (1985) and Goto and Suzuki (1989) both used the measure of R&D spillovers embodied in purchased intermediate goods and capital goods in the manner of Terleckyj (1980). Odagiri found the effect of this variable on the rate of growth of labour productivity or of total factor productivity (TFP) positive after the 1973 oil crisis, although only the effect on labour productivity increase was significant. Goto and Suzuki found the effect significantly positive to total factor productivity growth in 1978-1983.

Suzuki (1993) estimated the cost function of major firms in the Japanese electrical machinery industry during the 1980s and found that the spillovers from other core firms in the industry and from own subcontracting firms reduce costs. These studies suggest that both inter-industry and intra-industry R&D spillovers have had productivity-enhancing or cost-reducing effect in Japan since the oil crisis.

In the present paper, we confine our analysis to the estimation of inter-industry R&D spillovers. However, instead of aggregating the spillovers from all other industries as in Odagiri, and Goto and Suzuki, we follow Bernstein and Nadiri's (1988) and Bernstein's (1989) cost function approach to separate the spillovers from each of the other industries to examine which source industry has a significant cost-reducing effect. Furthermore, we select source industries on the basis of the magnitude of R&D flow embodied in intermediate goods and the extent of R&D proximity with the target industry. The latter is expected to approximate the intensity of technological spillovers at the R&D stage, for instance, through the dissemination of technical papers. If the source industry selected on the criterion of R&D flow (resp. R&D proximity) is found to have a cost-reducing effect, it is inferred that technology spills over mainly through intermediate goods (resp. at the R&D stage).

Four industries will be studied here: general machinery, electrical machinery (including electronics and communications equipment), transportation machinery (including automobiles), and chemicals (including pharmaceuticals). These are the so-called high-tech industries, with higher-than-average R&D-sales ratios.[1] For each of the industries, we will estimate a translog cost function using the 1966-1993 time-series data.

In Section 2, we will measure R&D flow, that is, R&D embodied in purchased intermediate goods and, in Section 3, R&D proximity, that is, the extent that the distribution of R&D efforts across research fields is similar between a pair of industries. The estimation model is discussed in Section 4. Estimation will be made in two stages; first, without any spillover variable (in Section 5) and, second, with the R&D variable of one of the spillover source industries included (in Section 6). Section 7 gives a summary and conclusion. The details on the data are in Data Appendix.

2. R&D Flow: Spillovers through Purchased Goods

An important channel through which technology spills over across industries is the purchase of intermediate and capital goods. When the capacity or other quality measures of a machine are increased through product development, the industry using the machine will be able to increase the productivity and reduce costs. Actually, if the price of the machine is also increased, reflecting fully the increase in quality, TFP would stay the same and the cost function unaffected. However, to the extent that the price increase is not so large as to offset the quality increase, the cost curve would shift down. Thus, the cost-reducing effect of R&D spillovers would take place through purchased inputs. The extent of this effect would be affected by market conditions that determine how much the sellers of the improved materials or machines would be able to raise their prices.

Let us hereafter call the technological spillovers occurring in this fashion the *R&D flow* and measure it as follows, following Terleckyj (1974) and others:

$$t_{ij} = a_{ji} \cdot E_j, \qquad j \neq i \tag{1}$$

where t_{ij} is the R&D flow from industry *j* (hereafter called the source industry) to industry *i* (hereafter called the target industry or the receiving industry), a_{ji} is the proportion of sales to *i* among the total sales of *j*, and E_j is the R&D expenditure of industry *j*.

We calculated R&D flow to the four industries in our study -- general machinery, electrical machinery, transportation machinery, and chemicals -- from each of 13 manufacturing industries using the Input-Output Table and R&D data in 1985. Table 1 lists three source industries with the highest R&D flow to the four target industries.

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

Electrical machinery is the largest source of R&D flow to any of the other three industries, reflecting the weight of electrical equipment and machinery as capital inputs and the R&D intensity of the industry. To the three machinery-related industries, primary metals appear as the second or third most important source. Electrical machinery is benefitted from the R&D in chemicals, through the purchase of plastics, silicon, and other chemical materials.

In the fifth column of the table is shown the total amount of R&D flow that each of the four industries received, that is the sum of t_{ij} for all j ($\neq i$). Clearly, transportation machinery is gaining most from R&D flow, closely followed by general machinery. The majority of the flow in these industries comes from electrical machinery. By contrast, the flow to electrical machinery and chemicals are more evenly distributed across source industries. Although these industries are the largest sources of flow to each other, the proportion to total flow is only about a quarter in either industry.

In view also of the proportion to own R&D, as shown in the last column, transportation machinery and general machinery are big beneficiaries. General machinery, in particular, receives R&D flow worth 77 per cent of the own R&D expenditure. In electrical machinery and chemicals by contrast, the proportion is less than 10 per cent. However, the smaller amount or proportion of R&D flow need not imply that it is unimportant. We will examine this issue in Section 6.

3. R&D Proximity as a Measure of Spillovers at the R&D Stage

Technological knowledge may spill over without purchase of intermediate goods. Most likely, such spillovers take place at the R&D stage. Researchers may obtain new knowledge from journals and presentations at conferences, which can be applied to their own research. They may learn that a certain research is in progress in another company and ask for the latter's collaboration to solve bottlenecks in their R&D. The likelihood for such spillovers, diffusion, or collaboration must be higher the nearer the research subjects of the two parties are (and the less likely the two parties compete with each other in markets because, if they do expect to be rivals, they would be unwilling to share the knowledge).

Following Jaffe (1986), we measure the likelihood of R&D spillovers at the R&D stage by the similarity of the distribution of R&D expenditures across research fields. Denote by F_{ik} the R&D Expenditure made by the i-th industry to the k-th research field and by F_i the vector of F_{ik} across 26 fields, that is, $F_i = (F_{i1}, F_{i2}, \ldots, F_{i26})$. We call the distance between two vectors, F_i and F_j, as R&D proximity and denote it by P_{ij}:

$$P_{ij} = \frac{F_i F'_j}{\sqrt{(F_i F'_i)(F_j F'_j)}} \tag{2}$$

P_{ij} is between 0 and 1, taking the value of 1 if and only if the distribution of R&D expenditures across fields is identical between the two industries. It is symmetric, that is, $P_{ij} = P_{ji}$.

Table 2 shows the names and the values of P_{ij} of the three industries (j) with highest P_{ij} for each of the four industries (i) to be studied in this paper.

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

The difference from Table 1 is evident. Now, electrical machinery is not in the top three any more in either general machinery, transportation machinery, or chemicals, and chemicals is not in the top three in electrical machinery. Instead, non-ferrous metals appear among the top three of two machinery-related industries and so does metal products. The proximity between chemicals and textiles is perhaps due to the presence of several synthetic fibre producers in the textiles industry, and the proximity between chemicals and food processing took place because a number of food processing companies, most notably beer brewers, are making research in biotechnology to develop drugs.

In the following, these industries that appeared in Tables 1 and 2, that is, the top three industries with the largest R&D flow and the top three industries with the largest R&D proximity will be examined as the candidate spillover source industries. The exceptions are, firstly, plastics which was omitted because the Japanese R&D data started to separate plastics from general chemicals only in 1984 and, secondly, publishing and printing which was omitted because the magnitude of R&D proximity with EM was relatively small and technological spillovers from publishing and printing to electrical machinery appears quite unlikely (as opposed to the spillovers in the other direction which may result from the use of electronic publishing technology).

The model to be used to test if the R&D spillovers from these source industries significantly reduced the costs of the four high-tech industries will be explained in the next section.

4. The Model

Following Bernstein and Nadiri (1988) and Bernstein (1989), we assume a translog cost function including R&D stocks. It is assumed that capital and labour are variable, while R&D stocks, either those of own industries or of other industries, are fixed in the short run. Hence, utilizing the linear-homogeneity condition regarding prices and costs, and taking value added as the output measure, the cost function (without R&D spillovers) is written as follows for the i-th industry:

$$\begin{aligned}\log(C^i/w_1) = {} & a_0 + a_y \log y^i + a_k \log\omega + a_i \log x^i + (1/2) b_{yy} (\log y^i)^2 \\ & + b_{yk} \log y^i \cdot \log\omega + b_{yi} \log y^i \cdot \log x^i + (1/2) b_{kk} (\log\omega)^2 + b_{ki} \log\omega \cdot \log x^i \\ & + (1/2) b_{ii} (\log x^i)^2 + u_c^i \end{aligned} \tag{3}$$

where C^i is the total cost, y^i is value added, w_1 is labour price, ω is capital-labour price ratio, x^i is the stock of own R&D, and u_c^i is the error term.

By differentiating this equation with respect to $\log\omega$ and using Shepherd's Lemma, we obtain the following cost share function:

$$s_k^i = a_k + b_{kk} \log\omega + b_{yk} \log y^i + b_{ki} \log x^i + u_k^i \tag{4}$$

where s_k^i is the share of capital in costs and u_k^i is disturbance.

Equations (3) and (4) are jointly estimated using the seemingly unrelated regression (SUR) method. In the actual estimation, the first difference form of these equations was used in order to reduce the risk of auto-correlation and multi-collinearity.[2] Since many of the variables have an increasing trend (except for the capital-labour relative price, ω, which shows a decreasing trend), the correlation among the explanatory variables tended to be high. By taking the first differences, such correlation was significantly reduced.

The constant term (a_0) of equation (3) vanishes when the first difference is taken. However, we found that the constant term added in the first-difference equation was significant (in electrical machinery and transportation machinery) or at least had the estimates with the t-values greater than unity (in general machinery and chemicals). We will thus report the results with constant terms. The presence of a constant term in the first difference form in effect implies that, in the original equation (3), a positive trend term must have been present.

In the estimation of the cost and share equations with R&D spillovers, the squared term for value added, the cross terms between value added and (own and spillover) R&D stocks, and the cross term between own R&D stock and spillover R&D stock were omitted to save on degrees of freedom. Thus, the *truncated* translog cost function with R&D spillovers (from j-th industry) is as follows:

$$\log(C^i/w_l) = a_0 + a_y \log y^i + a_k \log\omega + a_i \log x^i + a_j \log x^j + b_{yk} \log y^i \cdot \log\omega + (1/2) b_{kk} (\log\omega)^2$$
$$+ b_{ki} \log\omega \cdot \log x^i + (1/2) b_{ii} (\log x^i)^2 + b_{kj} \log\omega \cdot \log x^j + (1/2) b_{jj} (\log x^j)^2 + u_c^i \tag{5}$$

The corresponding share equation is

$$s_k^i = a_k + b_{yk} \log y^i + b_{kk} \log\omega + b_{ki} \log x^i + b_{kj} \log x^j + u_k^i \tag{6}$$

We have also estimated the *full* cost function (as opposed to the truncated function) and confirmed that the coefficients of the terms omitted in the truncated function were generally insignificant and that most of the coefficients of other terms were insensitive to the exclusion of these terms. Thus we report only the results of the truncated functions as defined in equations (5) and (6). An exception is the spillovers from the precision instrument industry to general machinery. In this case, the linear-term spillover coefficient, a_j, was significantly negative in the full model but was insignificantly positive (inconsistently with the spillover hypothesis) in the truncated model. Thus, in this case only, we report the result of the full model though, as will be later shown in Table 5, the results will be shown only for the coefficients included in the truncated function.

The estimation was made with the time-series data of 1966-1993. With the loss of one observation due to the use of a first-difference form, the number of observations is 27. The results of the estimation without R&D spillover variable, that is, equations (3) and (4), will be presented in Section 5, and the estimation results with an R&D spillover variable, that is equations (5) and (6), will be presented in Section 6.

The detailed definition of the variables and the sources of the data are in the data appendix. R&D stock was calculated by means of the perpetual inventory method.

5. Estimation Results without Spillovers

The results are in Table 3. The coefficients for the linear terms on output and on capital price are strongly significantly positive as expected, with the exception of a_y in chemicals. In this industry, both the estimated coefficients and t-values on linear and squared terms of capital-labour price are much larger than in other industries, and this strong explanatory power of the relative factor price may have somehow deprived the value added variable of its explanatory power.

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

In any of the four industries, b_{ki} is significantly positive, indicating that an increase in R&D stock raises capital share in costs. That is, R&D is capital-using and labour-saving in the four industries.

a_i is negative in any of the industries and significant in electrical machinery and transportation machinery. To interpret this result, let us define the elasticity of costs with respect to R&D stock as follows:

$$\eta \equiv - \frac{\partial \log C^i}{\partial \log x^i} = - (a_i + b_{yi} \log y^i + b_{ki} \log \omega + b_{ii} \log x^i) \tag{7}$$

Note that η is defined so that it is positive when an increase in R&D stock *decreases* costs.

Since y^i, ω, and x^i are normalized so that they equal one in 1985 (see the data appendix), $-a_i$ gives the value of elasticity in 1985. Therefore, the results indicate that, at least in 1985, R&D stock had the effect of reducing the costs of own industry in any of the four industries, although this effect is not significant in two industries. For other years, η is calculated and shown in Table 4.

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

In electrical machinery, the elasticity is around 0.44 throughout the period, implying that a one-percent increase in R&D stock tended to decrease the costs by 0.44 per cent. In transportation machinery, the elasticity had a strong increasing trend from 0.14 in 1967 (not shown in Table 4) to 0.76 in 1993. It is therefore inferred that the cost-reducing effect of R&D stock, as measured by the elasticity, has lately become more prominent and is now greater than in electrical machinery. The effect is more modest in general machinery and chemicals. In fact, the elasticities are estimated to be negative in the early period. They turned positive in 1971 in general machinery and in 1978 in chemicals. In both industries, there is an increasing trend similarly to the transportation machinery industry and the elasticities are now around 0.2.

One may explain why the elasticity turned to be positive only lately in chemicals. As shown in the data appendix, the lag in R&D is longest in chemicals, indicating that the accumulation of technological stock requires a long gestation period after R&D. Furthermore, in this industry, particularly in pharmaceuticals, Japan has long been an importer of technology and started to intensify own R&D efforts later than in assembly industries (Odagiri and Goto, 1996). This later start, combined with the longer gestation period, would explain why the cost-reducing effect started to take effect later than in other industries.

A remark is in order, however, concerning the problem of double counting of R&D inputs. As shown in the data appendix, our cost variable, C^i, includes the costs of labour and capital employed in R&D. Hence, even if C^i is increased with R&D stock as in the early years in the chemical industry, the costs employed purely for production, that is, C^i less R&D costs, may have been decreased. In other words, the elasticities calculated in Table 4 are biased downward in the sense that the elasticity of *production* cost with R&D stock must have been larger. One may thus conjecture that, even in the chemical industry, this elasticity must have turned positive earlier than in 1978.

6. Estimation Results with Spillovers

Equations (5) and (6) were estimated for each of the candidate source industries discussed in Section 3. Unlike Bernstein and Nadiri (1988), we did not estimate the equations including the R&D variables of two or more source industries because of limited degrees of freedom.

We only accepted the equations with negative a_j. Since

$$-\frac{\partial \log C^i}{\partial \log x^j} = -(a_j + b_{kj}\log\omega + b_{jj}\log x^j) \tag{8}$$

and both ω and x^j are normalized to equal unity in 1985, the negativity condition on a_j is tantamount to the requirement that the elasticity is positive in 1985. It is also noted that, unlike the effect of own R&D, x^j is not a part of C^i and, hence, double counting cannot take place; that is, one may assume that R&D spillovers have the effect of reducing production costs (as well as total costs) if the elasticity as defined in (8) is positive.

As shown in Table 5, 10 cases of R&D spillovers satisfied this criterion although a_j was statistically significant only in three cases -- electrical machinery and precision instrument to general machinery, and chemicals to electrical machinery. In addition, the t-values exceeded a modest criterion of one in three cases -- metal products to general machinery and to transportation machinery, and transportation machinery to general machinery. The effect to chemicals from petroleum and coal products is negligible.

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

Based on these estimates, the elasticities as defined in (8) were calculated and shown in Table 6.

**** TABLE 6 ABOUT HERE ****

The largest cost-reducing effect of R&D spillovers is found in that of electrical machinery from chemicals. The effect is also most significant in terms of the t-value to the coefficient a_j. Although the elasticity was negative in the beginning, it rapidly increased, turned positive in 1970, and exceeded unity in 1981. In the most recent year of 1993, it implies that a one-percent increase in the R&D stock of chemicals decrease the costs in the electrical machinery industry by 1.7 per cent. As shown in Table 1, chemicals is the largest source of R&D flow to electrical machinery via intermediate goods while it is not among the top three in R&D proximity. Hence, it is conjectured that R&D stock in chemicals has improved the quality of materials, say, silicon and plastics, that the electrical machinery industry purchases, without an offsetting increase in the price of these materials, thereby reducing the production costs in electrical machinery.

Electrical machinery also benefitted from the R&D stocks in primary metals (ferrous and non-ferrous metals) and general machinery, although the coefficients are not statistically significant. It is noteworthy that, like chemicals, these industries were chosen on the basis of R&D flow. Quite likely, higher-quality materials (say, steel) and investment goods (say, machine tools) developed in these industries were purchased by the electrical machinery industry and contributed to its cost reduction. The industry does not appear to have benefitted from the spillover at the R&D stage through the proximity of research fields with other industries.

This makes a good contrast to the general machinery industry which benefitted from all the five industries chosen on the basis of R&D flow and/or R&D proximity. The magnitude of elasticity is in the range of 0.23 to 0.47 for any source industry and for any year. The conjecture, therefore, is that the industry benefitted not only from better materials, components, and equipment but also from spillovers at the R&D stage owing to the proximity of research topics with the precision instruments, metal products, and transportation machinery industries.

In the transportation machinery industry, the only source of spillovers, albeit insignificantly, was metal products, which had the highest R&D proximity with the industry. Many of the largest firms in metal products are the producers of bridges, towers, and pipes which a number of shipbuilding companies also produce. Technological knowledge may thus have been exchanged (intentionally or not) among them.

To chemicals, petroleum and coal products had a spillover effect. This industry was selected mainly because of its large R&D flow to chemicals, but R&D proximity is also large (fourth largest). Hence, spillovers may be taking place not only through the purchase of materials but also at the R&D stage, particularly because the research on petrochemicals must be closely related to that on petroleum refining, and many petroleum refiners also started research on petrochemicals and biotechnology. However, the a_j coefficient is not at all significant and the cost-reducing effect as measured by the elasticity has been weakening over time. In recent years, the elasticity is negative, indicating the lack of cost-reducing effect.

Often it has been suggested that the widespread use of computers and other electronic devices in production sites decreased production costs in many industries. However, the cost-reducing effect of spillovers from electrical machinery was confirmed only in general machinery whereas the effects to transportation machinery and chemicals failed to satisfy the positive elasticity condition despite the large values of R&D flow. The result is consistent with the finding of Goto and Suzuki (1989) that the R&D expenditure of electronics-related industries (weighted with input-output coefficients) had no significant effect of increasing the rate of TFP increase of other industries. However, they found a significant effect when electronics R&D was weighted by R&D proximity, which disagrees with our results that electrical machinery is not among the top three regarding R&D proximity to the three other industries. Our result also indicates that the spillovers from electrical machinery differ according to the receiving industry, casting doubt on Goto and Suzuki's methodology that assumed a common spillover effect across receiving industries.

The signs of b_{Kj} in Table 5 suggest that the effects of spillovers to general machinery and chemicals are capital-saving but the effects to electrical machinery and transportation machinery are capital-using. Not all of them are significant, however.

7. Conclusion

In this paper, the contribution of R&D spillovers to four high-tech industries -- general machinery, electrical machinery, transportation machinery, and chemicals -- in Japan was estimated. The novelty here is the choice of candidate spillover source industries based on R&D flow and R&D proximity. R&D flow was measured using the input-output coefficient on the assumption that technology developed by the source industry must be embodied in the intermediate goods that this industry supplies. R&D proximity measures the extent of similarity of the distribution of industries' R&D expenditures across research fields. It was expected that technological spillovers, mainly at the R&D stage, would take place more easily between the industries with similar distributions.

Whether the spillovers from these candidate source industries in fact contributed to the productivity of a receiving industry was investigated by the estimation of a translog cost function that includes the R&D stock variable of one of the source industries. The results suggested that electrical machinery benefitted from spillovers mainly through the purchase of intermediate goods from chemicals and others, whereas transportation machinery benefitted from its R&D proximity with the metal products industry. General machinery, on the other hand, benefitted both from R&D flow and R&D proximity from all the candidate source industries including primary metals, metal products, and three assembly industries (electrical machinery, transportation machinery, and precision instruments). To chemicals, only the spillovers from petroleum and coal products had a cost-reducing effect but this effect was insignificant and has turned negative in recent years.

The most important finding, therefore, was the diversity of the effects of R&D spillovers and of the channels through which these spillovers take place. Depending on the source industry and depending on the receiving industry, the spillovers may take place through the purchase of materials and capital goods or through the exchange of information at the R&D stage, or through both. Some of the spillovers significantly contribute in cost reduction but others do not. One may doubt, therefore, that a reasonable aggregate measure of R&D spillovers may be constructed at all: the results of some of the earlier studies that used a weighted sum of R&D expenditures (or stocks) of other industries as a spillover variable may be questioned.

Technological spillovers across industries, across firms, and across nations have been an important source of industrial development and structural changes.[3] More studies are desperately in need to investigate not just the contributions but also the mechanism and channels of spillovers.

NOTES

1. These industries are four of the six industries with the highest R&D-sales ratios in Japan. The other two are precision instruments and rubber products. These industries were excluded in the estimation because some of the data were not available for the entire estimation period.

2. In fact, the Durbin-Watson statistics greatly improved when first differences were taken.

3. See Odagiri and Goto (1996) for the Japanese experience.

DATA APPENDIX

1. The Construction of R&D Stock

Denote R&D stock by x_t, R&D outcome in the flow sense (to be defined presently) by R_t, and R&D expenditure by E_t, all in year t. (the subscript or superscript i to indicate the i-th industry is suppressed). Then, the stock is defined as follows:

$$x_t = R_t + (1-\delta)\, x_{t-1} \tag{A1}$$

where δ is the rate of obsolesence. By iteration, we get

$$x_t = R_t + (1-\delta)R_{t-1} + (1-\delta)^2 R_{t-2} + \cdots + (1-\delta)^{t-s-1} R_{s+1} + x_s \tag{A2}$$

Assuming that R_t had increased at a constant rate until year s ($< t$), we approximate x_s as follows:

$$x_s = \frac{R_{s+1}}{\delta + g} \tag{A3}$$

x_t is the stock of technological knowledge and, hence, R_t should be the outcome (and not input) of R&D. Usually, there is a lag between the time R&D expenditure is made and the time a certain outcome is obtained from the research. If this lag is k years, $R_t = E_{t-k}$. However the lag, k, is not necessarily an integer. Write the integer part of k by ki, and the decimal part by kd; that is, k = ki + kd, with kd $\in$ [0, 1). Then,

$$R_t = (1 - kd) \cdot E_{t-ki} + kd \cdot E_{t-ki-1} \tag{A4}$$

x_t is thus computed using (A2), (A3), and (A4). The rate of obsolesence and the length of lag are taken from *Kagaku Gijutsu Hakusho* [White Paper on Science and Technology], 1960, which is based on the questionnaire study conducted by Science and Technology Agency to private firms. They are shown in the following table:

Industry	Years of lag	Rate of obsolesence
Electrical Machinery	3.336	0.139
Transportation Machinery	3.226	0.113
General Machinery	2.960	0.072
Chemicals	5.942	0.092

2. Data Source

The data on R&D expenditure was taken from *Kagaku Gijutsu Kenkyu Chousa Houkoku* [Report on the Survey of Research and Development] (Management and Coordination Agency) and were converted to real values using the R&D deflator in the same source.

The value added was from *Kougyou Toukei Hyo* [Census of Manufactures] (Ministry of International Trade and Industry) and deflated with the GDE deflator in the *Kokumin Keizai Keisan Nenpo* [Annual Report on National Accounts] (Economic Planning Agency).

Labour input and labour price were taken from *Roudou Toukei Nenpo* [Year Book of Labour Statistics] (Ministry of Labour). Labour input was calculated by multiplying the end-of-month number of workers by the number of hours worked per worker. Average monthly compensation was used as the labour price.

Capital price, p_t, was computed using the following Jorgenson formula:

$$p_t = q_t(r_t + \theta_t)$$

where q_t is the index of investment-goods price taken from *Bukka Shisu Geppo* [Price Indexes Monthly] (Bank of Japan), r_t is the rate of interest, taken from the long-term prime rate in *Keizai Toukei Geppo* [Economic Statistics Monthly] (Economic Planning Agency), and θ_t is the depreciation rate, calculated with the following formula:

$$K_t = (1 - \theta_t) K_{t-1} + I_t$$

where K_t is the real stock of gross capital taken from *Shihanki-betsu Minkan Kigyo Sutokku* [Quarterly Fixed Capital Stock of Private Non-Financial Enterprises] (Economic Planning Agency), and I_t is the real value of new capital investment taken from the same source.

Total cost, C_t, is the sum of labour cost (labour input times labour price) and capital cost. The latter was calculated as the sum of capital price this year and capital stock last year, that is, $p_t K_{t-1}$, assuming that the input of capital service this year is proportional to the capital stock at the end of the previous year.

In the estimation, all the variables were normalized so that they are unity in 1985.

Finally, it is noted that labour input as calculated above includes the workers in R&D sector and capital input, those used in laboratories. Hence, the total cost includes the costs for these R&D-related inputs. This fact is discussed in detail in Section 5 of the text.

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Table 1. R&D Flow: Top Three Sources,Total, and Its Ratio to Own R&D Expenditure

Industry	1st Source	2nd Source	3rd Source	Total (a)	Own R&D (b)	(a)/(b) (%)
General Machinery	Electrical Mach. 187231.79 (63.9%)	Primary Metals 35831.70 (12.2%)	Precision Inst. 24471.64 (8.4%)	292961.1 (100.0%)	382698	76.55
Electrical Machinery	Chemicals 33459.44 (27.4%)	Primary Metals 25547.81 (20.9%)	General Mach. 23569.23 (19.3%)	122249.2 (100.0%)	1938183	6.31
Transportation Machinery	Electrical Mach. 152855.69 (50.6%)	General Mach. 85926.34 (28.4%)	Primary Metals 23536.45 (7.8%)	302330.3 (100.0%)	935661	32.31
Chemicals	Electrical Mach. 8930.68 (25.7%)	Petroleum and Coal Products 7515.37 (21.6%)	General Mach. 4805.07 (13.8%)	34761.86 (100.0%)	936360	3.71

Notes: The name of the source industry is in the top row, the amount (in million yen) in the second, and the percentage to the total R&D flow received by the industry in the third (in parentheses).

Table 2. R&D Proximity: The Top Three

Industry	1st	2nd	3rd
General Machinery	Precision Instruments 0.341	Metal Products 0.264	Transportation Machinery 0.221
Electrical Machinery	Non-ferrous Metals 0.482	Precision Instruments 0.306	Publishing and Printing 0.229
Transporation Machinery	Metal Products 0.553	General Machinery 0.221	Non-ferrous Metals 0.118
Chemicals	Plastics 0.628	Textiles 0.520	Food Processing 0.356

Notes: In the upper row is the name of the industry: in the lower row is the amount of R&D proximity as defined in the text.

Table 3. Estimation Results without Spillovers

	General machinery	Electrical machinery	Transportation machinery	Chemicals
constant	.0304 (1.334)	.0736*** (4.222)	.0707*** (3.751)	.0303 (1.511)
a_y	.243** (2.674)	.343*** (3.292)	.234** (2.769)	-.0054 (-0.047)
a_k	.418*** (8.950)	.289*** (6.835)	.395*** (8.750)	.541*** (18.903)
a_i	-.149 (-0.546)	-.442*** (-2.917)	-.593** (-2.765)	-.0745 (-0.291)
b_{yy}	.680 (1.386)	.140 (0.500)	-.350 (-0.736)	.608 (0.857)
b_{yk}	-.0493* (-1.903)	-.089*** (-3.831)	-.0836** (-2.592)	-.0491* (-1.931)
b_{yi}	-.332 (-1.596)	-.111 (-0.676)	.0363 (0.178)	-.276 (-0.895)
b_{kk}	.196*** (11.702)	.204*** (13.077)	.182*** (7.547)	.244*** (20.963)
b_{ki}	.191*** (6.587)	.185*** (7.274)	.179*** (5.547)	.239*** (9.823)
b_{ii}	.134 (0.808)	.173 (1.481)	-.120 (-0.934)	.116 (0.676)
R^2:				
cost	.902	.891	.896	.938
share	.868	.871	.680	.944

Notes:

- In parentheses are t-values. ***, **, and * indicates signigicance at, respectively, 1, 5, and 10 per-cent levels.
- Constant terms are those for the cost equations in the first-difference form.

Table 4. Estimated Elasticities of Costs with Own R&D Stock

Year	General Machinery	Electrical Machinery	Transportation Manchinery	Chemicals
1968	-.120	.425	.166	-.229
1973	.011	.452	.323	-.036
1978	.024	.450	.508	.008
1983	.078	.436	.542	.040
1988	.176	.456	.651	.167
1993	.200	.425	.761	.185
Mean	.063	.436	.478	.013

Table 5. Estimation Results with Spillover Variables

Industry:	General Machinery				
Spillover Source:	Primary Metals	Metal Products	Electrical Machinery	Transportation Machinery	Precision Instruments
constant	.104*** (3.446)	.0892*** (3.747)	.0624** (2.570)	.0879*** (3.739)	.178*** (5.566)
a_y	.153** (2.158)	.123* (1.987)	.167** (2.420)	.119* (1.831)	.110* (1.916)
a_k	.471*** (11.304)	.489*** (12.930)	.475*** (11.249)	.468*** (11.857)	.439*** (12.289)
a_i	-.556 (-1.558)	-.440* (-1.850)	-.0656 (-0.170)	-.255 (-0.965)	-1.385*** (-5.324)
b_{yk}	-.0400 (-1.536)	-.0289 (-1.048)	-.0448 (-1.690)	-.0478* (-1.786)	-.0472* (-1.854)
b_{kk}	.193*** (10.945)	.190*** (10.126)	.195*** (11.018)	.195*** (10.917)	.197*** (11.901)
b_{ki}	.179*** (6.085)	.184*** (5.896)	.200*** (6.522)	.186*** (6.155)	.165*** (5.361)
b_{ii}	-.751** (-2.729)	-.639** (2.816)	-.480 (-1.496)	-.496* (-1.995)	-1.274 (-4.473)
a_j	-.436 (-0.741)	-.262 (-1.264)	-.322* (-1.856)	-.386 (-1.662)	-.267* (-1.963)
b_{kj}	-.0297* (-1.849)	-.0374*** (-2.992)	-.0311** (-2.709)	-.0218 (-1.642)	.0171 (1.048)
b_{jj}	-.103*** (-3.772)	-.0397** (-2.778)	-.0483** (-2.289)	-.0342** (-2.109)	.0196 (0.266)
R^2:					
cost	.946	.950	.938	.948	.962
share	.870	.862	.869	.867	.871

Note: See Notes to Table 3.

Table 5. Estimation Results with Spillover Variables - Continued

Industry:	Electrical Machinery			Transportation Machinery	Chemicals
Spillover Source:	Chemicals	Primary Metals	General Machinery	Metal Products	Petroleum and Coal Products
constant	.122***	.0958**	.0839**	.0631***	.0284*
	(5.890)	(2.667)	(2.761)	(3.113)	(1.886)
a_y	.271***	.366***	.283***	.284***	-.0871
	(4.013)	(5.091)	(3.965)	(4.054)	(-1.581)
a_k	.299***	.293***	.303***	.415***	.548***
	(7.724)	(7.051)	(7.269)	(8.557)	(24.263)
a_i	-.070	-.271	-.311	-.151	.0443
	(-0.399)	(-0.756)	(-1.180)	(-0.469)	(0.209)
b_{yk}	-.103***	-.107***	-.0923***	-.129***	-.07946***
	(-4.067)	(4.365)	(-3.948)	(-3.633)	(-2.858)
b_{kk}	.208***	.209***	.205***	.189***	.247***
	(13.258)	(13.998)	(13.133)	(8.311)	(19.656)
b_{ki}	.134**	.0217	.179***	.0283	.293***
	(2.291)	(0.238)	(7.019)	(0.339)	(5.067)
b_{ii}	.463***	-.0289	.351	.195	-.241
	(3.466)	(-0.086)	(1.148)	(1.043)	(-1.641)
a_j	-1.224***	-.590	-.292	-.385	-.0303
	(-3.629)	(-0.661)	(-0.746)	(-1.202)	(-0.190)
b_{kj}	.077	.289*	.00464	.163*	-.0657
	(.955)	(1.801)	(0.206)	(1.949)	(-1.310)
b_{jj}	-.838***	-.346	-.393*	-.309*	.330**
	(-3.459)	(0.398)	(-1.817)	(-1.895)	(2.424)
R^2:					
cost	.897	.885	.889	.905	.963
share	.875	.887	.873	.715	.947

Note: See Notes to Table 3.

Table 6. Estimated Elasticities of Costs with R&D Spillovers

Industry:	General Machinery					Electrical Machinery			Transportation Machinery	Chemicals
Spillover Source:	Primary Metals	Metal Products	Electrical Machinery	Transportation Machinery	Precision Instruments	Chemicals	Primary Metals	General Machinery	Metal Products	Petroleum and Coal Products
1968	.357	.230	.279	.349	.253	-.135	.682	-.410	-.454	.612
1973	.380	.242	.294	.359	.269	.342	.689	-.091	-.126	.457
1978	.403	.247	.308	.372	.244	.884	.729	.111	.167	.218
1983	.428	.264	.320	.384	.255	1.128	.610	.238	.307	.117
1988	.449	.264	.332	.390	.262	1.397	.616	.383	.490	-.049
1993	.471	.261	.346	.395	.248	1.736	.612	.544	.646	-.188
Mean	.414	.253	.313	.375	.260	.865	.645	.115	.154	.208