Discussion Paper No. 607

DEBT, R&D INVESTMENT AND TECHNOLOGICAL PROGRESS: A PANEL STUDY OF JAPANESE MANUFACTURING FIRMS IN THE 90s

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June 2004

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December 2003
Revised June 2004

Debt, R&D Investment and Technological Progress: A Panel Study of Japanese Manufacturing Firms in the 90s*

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* I am grateful to Ryuzo Miyao, Hiroyuki Odagiri, Toshitaka Sekine, Kazuyuki Suzuki, Yosuke Takeda, Fukujyu Yamazaki and the participants of the RIEB-IMF workshop and seminar at Sophia University for extremely helpful comments and suggestions. I would like to thank Junmin Wan for excellent research assistance. This research was partially supported by Grants-in-Aid for Scientific Research 12124207 of the Ministry of Education. Any remaining errors are the sole responsibility of the author.

Abstract

Based on a panel data set of Japanese manufacturing firms in research-intensive industries, we investigate quantitatively the extent to which debt outstandings in the 90s affected the firm's R&D activities. We find that massive debt outstandings had significantly negative effect on R&D investment in the 90s. We also find that investment on R&D was closely linked to the firm-level total factor productivity growth in the 90s. In fact, ten-percentage-point increase of debt-asset ratio lowered the firm-level total factor productivity growth rate by 0.72 percentage point for 1999-2001 by way of withering R&D activities, while the firm-level TFP growth rate remains almost intact for 1988-91.

JEL Classification Number: D21,D24 and O32
Keywords: R&D investment, Debt, Total factor productivity

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1. Introduction

Consensus is not yet reached on the causes to bring long stagnancy to the Japanese economy in the 90s. The supply-siders argue that stagnancy is mainly due to supply factors such as inefficiencies of the production sector as well as banking sector suffering from massive bad loans and warn that the growth potential of the Japanese economy is withering. For example, Hayashi and Prescott(2002) demonstrate, based on the standard growth model, that decline of the total factor productivity(abbreviated as TFP) growth rate and shortened working hour is responsible for the stagnancy of the Japanese economy. Convincing as their argument is, they are silent on why the TFP growth rate suddenly dropped in the 90s.

We shed light on this aspect empirically. Recently an attempt is made to find the mechanism why the *aggregate* or *industry-level* TFP growth rate declined in the 90s. Nishimura et al. (2003) and Fukao and Kwon(2003) argue that efficient firms exit from the market, while inefficient firms remain in the market, which leads to the decline of the aggregate TFP growth rate in the middle of the 90s. We are interested in the *firm-level* TFP growth and its association with the firm's R&D activities in the 90s. Based on a panel data of Japanese manufacturing firms, we examine the R&D investment of the firm and how they are linked to the firm-level TFP growth rate. Our panel data set is composed of listed firms in chemicals, machinery, electrical machinery, equipment and supplies, transport equipment and precision instrument industries all of which are quite research-intensive. Specifically we investigate the extent to which debt outstandings of the firm and bad loans burdened on banks affected the R&D investment of the firm and subsequently the TFP growth rate. To do so, comparison is made between the R&D activities of the firm in the late 80s and the late 90s. The former period is the midst of bubble booms, while the latter period is characterized by heavy debt overhang in the corporate sector and mounting bad loans in the banking sector.

We preview our main findings. The ratio of debt to total assets has significantly negative effect on R&D investment in the late 90s, while the effect of debt-asset ratio on R&D investment is insignificant in the late 80s on the whole. Therefore it is massive debt outstandings of the firm that inactivated R&D activities in the late 90s. We also find that the TFP growth rate is positively linked to R&D investment, which implies that debt overhang in the 90s is responsible for lowering the firm-level TFP growth rate. Furthermore, it is found that larger dispersion of debt-asset ratio across firms leads to more dispersed distribution of R&D investment in the 90s.

The paper is organized as follows. The next section shows salient characteristics of R&D activities of the Japanese manufacturing industry as a whole as well as individual firm in our panel data set in the 90s. Section 3 estimates the investment function of R&D and Section 4 examines the association of investment on R&D with the firm-level TFP growth rate. Section 5 concludes the paper.

2. Characteristics of R&D Activities and the TFP Growth of the Japanese Manufacturing Firms in the 90s

We uncover some salient characteristics of R&D activities of the Japanese manufacturing industry as a whole in the 90s as well as individual firms in our panel data set. First of all, R&D activities of Japanese manufacturing industry had been stagnant in the 90s. This can be confirmed by the following three figures. Figure 1 shows the rate of change in intramural expenditures on R&D of large firms in the manufacturing sector from 1981 to 2002. Large firms are defined as those whose equity capital is over 1 billion yen. In the 80s the rate of change in intramural expenditures on R&D exceeded 10 % per annum for most of the period, but it fell sharply in 1993 and stayed low thereafter. The average annual growth rate of intramural expenditures on R&D during 1981-1990 is 13.5 %, but it is only 2.46 % during 1991-2002. The rate of change in persons engaged in R&D activities, shown in Figure2, also exhibits the same tendency. The rate of change in persons engaged in R&D activities fell sharply in 1994 and hovered around zero thereafter. The average annual growth rate of persons engaged in R&D activities during 1981-1990 is 6.27 %, while it is nearly zero (0.2 %) during 1991-2002. Reflecting low rate of change in intramural expenditures on R&D, the ratio of intramural expenditure on R&D to sales remained stagnant in the 90s, as is shown in Figure 3.

The second feature is a tilt toward development research from basic research.

Figure 4 shows the proportions of expenditures appropriated for basic R&D research. In the 80s the proportion of expenditures on basic research increased steadily from 5.18 % in 1980 to 7.07 % in 1992. However, it declined gradually in the 90s and the proportion of development research rose steeply. The share of development research increased from 1992 to 2000 by 3-percentage point. This might reflect myopic R&D behavior of manufacturing firms under increasing uncertainty over the investment outcome since it takes more time for the development research to bear fruit.

Next we characterize the R&D activities of individual firms in our panel data set. All the firm-level data series are taken from Development Bank of Japan Corporate Database. Our sampled firms belong to the following five industries: chemicals, machinery, electrical machinery, equipment and supplies, transport equipment and precision instrument. These industries are quite research-intensive in the sense that the ratio of expenditure on R&D to sales is relatively high. The number of firms as well as total observations for each industry is shown in Table 1. All the firms do not report the figures of expenditures on R&D for every year, so that our panel data set is unbalanced. Table 2 compares the averaged ratio of expenditure on R&D to sales for each industry between the two periods: 1988-91 and 1999-2001. This ratio falls drastically in the 90s for electrical machinery, equipment and supplies industry that is most research-intensive. It should be noted that even the R&D activities of research-intensive firms became stagnant in the 90s.

Now we see how the firm-level TFP growth rate has changed in the 90s. Based on the panel data set described above, we compare the average TFP growth rates of five industries between the late 80s and the late 90s. The TFP growth rate is calculated in two different ways. One way is to subtract the contribution of labor input growth and capital stock growth from the growth rate of real value-added.[1] In other words, the firm-level TFP growth rate is calculated as

$$TFP_{it} = \Delta \log(Y_{it}) - s_{L,it}\Delta \log(L_{it}) - (1 - s_{L,it})\Delta \log(K_{it}) \qquad (1)$$

where TFP_{it}: TFP growth rate of the i-th firm in year t

Y_{it} : real value-added of the i-th firm in year t

L_{it} : labor input of the i-th firm in year t

K_{it} : capital stock of the i-th firm at the end of year t

$s_{L,it}$: labor share of the i-th firm in year t

The firm-level TFP growth rate thus calculated is averaged out for each industry.

Alternative way to obtain the industry-level TFP growth rate is to estimate the Cobb-Douglas production function of value-added type by industry with labor, capital stock and time trend as regressors and identify the estimated coefficient of time trend as the industry-level TFP growth rate. The production function is estimated by either fixed effects model or variance components model, depending on the Hausman test statistics.

The estimated TFP growth rates for the two periods: 1988-91 and 1999-2001 are shown in Table 3. The firm-level TFP growth rates constructed by the first method are given in the first column (1988-91) and second column (1999-2001). Unexpectedly the TFP growth rates are higher in the late 90s except for chemicals and precision instrument industries. However, as for the statistical significance of the estimates, the average TFP growth rate is significantly positive for all the industries in the late 80s, while the average TFP growth rate is significantly positive only for electrical machinery, equipment and supplies and transport equipment. This reflects higher standard deviation of the TFP growth rate in the late 90s. It implies that the distribution of the firm-level TFP growth rate is more dispersed in the late 90s than in the late 80s. Statistically the average TFP growth rate is higher for electrical machinery, equipment and supplies in the late 90s than in the late 80s. For the rest of industries, there is no statistical difference in the average TFP growth rate between the two periods.

The third and fourth columns show the estimates of TFP growth rate obtained from regression results of the Cobb-Douglas production function for 1988-91 and 1999-2001, respectively.[2] Although the TFP growth rate is significantly positive for all the industries in 1988-91, it is only for electrical machinery, equipment and supplies that it is significantly positive in 1999-2001. To sum up, it is likely that the TFP growth rate slowed down in the late 90s except for electrical machinery, equipment and supplies industry.

3. Determinants of Investment on R&D

We investigate the determinants of R&D activities of the Japanese manufacturing firms by estimating the investment function of R&D. In particular, we are interested in the extent to which the firm's debt outstandings and the bank's bad loans affected the R&D activities of the firm in the 90s.

Our empirical strategy is to estimate the investment function of the same specification, using the two panel data sets in different periods: 1988-91 and 1999-2001. Two periods are quite contrasted in terms of the phase of business cycles. The former period is the midst of bubble booms, while the Japanese economy was in the middle of prolonged depression in the latter period. We use the panel data set introduced in the previous section that consists of listed firms in research-intensive industries.

Now we specify the investment function of R&D. We choose three factors to determine R&D investment.[3] One is the growth opportunity of the firm. The more abundant the growth opportunities are, the more active the investment on R&D will be. We measure the growth opportunities of the firm by the average growth rate of real sales in the current and past three years ($GSALES$). Second, there has been a long debate on the Schumpeterian hypothesis that large firms are more active in creative activities such as R&D investment. To account for this hypothesis in our specification, we add the logarithm of real sales ($RSALES$) to the list of explanatory variables.

Last but not least, we examine the effect of debt outstandings of the firm and bad loans of the bank on investment on R&D. Debt outstandings exert negative effect on investment in a variety of channels. One channel is through external finance premium the firm may face. When there is asymmetric information between debtors and creditors, it will drive a wedge between the cost of external finance and internal finance, called external finance premium. Note that the external finance premium is inversely associated with the borrower's collateralizable net worth relative to the debt outstandings. Therefore debt increase raises the external finance premium and thus reduces investment.[4] Moreover, spending on R&D produces fewer collateralizable assets and R&D activities have knowledge externalities, all of which tends to raise the external finance premium.

The second channel through which corporate debt affects investment is by creating debt overhang. Debt overhang is defined as deterrence of new investment by debt outstanding. It occurs when the debt outstanding is greater than the net present value of investment project since the benefits from new investment will go to the existing creditors rather than to the new investors.[5]

In the third channel, debt plays a disciplinary role for managers. Increase of debt raises the probability of bankruptcy. Managers are more concerned with bankruptcy than shareholders, since it is highly likely in case of bankruptcy that the managers are fired. Therefore, faced with increasing debt, managers will make every effort to cut back investment to raise efficiency. The ratio of debt to total assets ($DEBT$) can be used to capture the effect of debt on investment of R&D.

Recently attention has been also paid to the conditions of the bank's balance sheet as one of the important determinants to affect firm's investment. It is noted that a number of large firms in Japan belong to industry groups known as *keiretsu*, where main bank plays a vital role in mitigating the informational asymmetry between lenders and borrowers. Information of borrowers has been accumulated in main banks through long-term, stable relationships of firms with their main banks. Moreover, bank employees often hold management positions in financially troubled firms for the purpose of direct monitoring.[6] Therefore, once the bank's balance sheet deteriorates, say by mounting bad loans, it will have an adverse effect on intermediary role of banks and thus the associated firm's investment activities. Furthermore, if deterioration of bank's balance sheet affects lending negatively, it will also lead to a decrease of investment of bank-dependent firms.[7] We measure the health of the firm's main bank by the ratio of bad loans to total loans ($BADLOAN$).[8] Main bank of a firm is identified as the top shareholder among bank shareholders.[9] Unfortunately, the bad loans ratio is not available for the period of 1988-1991. Therefore we adopt alternative measure to represent the bank's health that is available for both 1988-91 and 1999-2001. That is the diffusion index of 'banks' willingness to lend' ($LEND$) reported in the Bank of Japan *Tankan* (Short-term Economic Survey of Corporations). The diffusion index represents the proportion of entrepreneurs feeling the present lending attitude of financial institutions to be “accommodative” minus those feeling the present lending attitude of financial institutions to be “severe”. It is tacitly assumed that this index can reflect the bank health closely. The diffusion index is available by industry.[10]

The investment function to be estimated is written as [11] [12]

$$\frac{RD_{it}}{Y_{it}} = \alpha_0 + \alpha_1 GSALES_{it} + \alpha_2 \log(RSALES)_{it} + \alpha_3 DEBT_{it-1} + \alpha_4 BADLOAN_{it} + \sum_{j=1}^{m} d_j YDUMMY_{jt} + v_i + u_{it} \qquad (2)$$

where RD_{it} : real expenditure on R&D

Y_{it} : real value-added

$YDUMMY_{jt}$: year dummies

v_i : firm-specific term

u_{it} : disturbance term

In alternative specification the *BADLOAN* variable is replaced by the *LEND* variable. In eq.(2) the dependent variable as well as cash flow variable is divided by the real sales to allow for heteroscedasticity. [13]

Three types of estimation method are used to estimate eq.(2). One is to estimate eq.(2) both by fixed effects model and random effects model and choose the most appropriate one by the Hausman test. The second is to estimate the first-difference form of eq.(2) by pooled OLS. The third is to estimate the first-difference form of eq.(2) by instrumental variable method to handle possible correlations between the firm-specific explanatory variables and the disturbance term. In estimation we discard the observations whose ratio of R&D expenditures to real value-added, average growth rate of sales and debt-asset ratio are above or below their mean values by four times of their standard deviations.

Table 4 and 5 report the estimation results of eq.(2) for 1999-2001 and 1988-91, respectively. The estimation results of fixed effects model are quite similar to those by pooled OLS in first-differenced form. The estimation results by the instrumental variable method in first differenced form are somewhat less precise in the sense that the coefficient estimate of debt-asset ratio has larger standard errors. This might be due to poor choice of instruments for debt-asset ratio, leading to low correlation of instruments with the debt-asset ratio.

It turns out that three variables are significant determinants of investment on R&D for 1999-2001. First, the average growth rate of sales has positive effect on investment on R&D. Second, real sales exert negative effect on the ratio of R&D investment to value-added. This is contrary to the Schumpeterian hypothesis. Third, debt-asset ratio has negative effect on R&D investment, implying that massive debt outstandings deter R&D activities. Contrasted with the significantly negative effect of debt on R&D investment, the effect of bank health on R&D investment is insignificant as a whole. It implies that even if the bank's balance sheet deteriorates, it will not necessarily aggravate real activities of the firm by reducing lending. Banks' lending attitude is insignificantly positive in the fixed effects model, while it exhibits a wrong sign in the first-difference model.

Contrary to significantly negative effects of debt-asset ratio on R&D investment for 1999-2001, the effect of debt-asset ratio on R&D investment is insignificant for 1988-91, irrespective of estimation method, as is seen in Table 5. To sum up, it is only in the 90s that debt was a heavy burden for the firm in implementing R&D investment.

4. Does R&D Investment Matter in Raising the Firm-level TFP Growth?

Given our findings that debt had negative effects on R&D activities of the Japanese research-intensive firms in the 90s, the question to be posed is "Does R&D matter in raising the firm-level TFP growth?" If the answer is yes, then we can conclude that massive debt outstandings of the firm in the 90s led to a decrease in the firm-level TFP growth by deterring R&D investment. We examine this link between R&D investment and the firm-level TFP growth in this section.

First we derive the regression equation to relate the firm-level TFP growth rate given by eq.(1) to R&D investment with market structure of individual industry into consideration.[14] [15] Let us denote the value-added production function by

$$Y_{it} = F_i(K_{it}, L_{it}, t) \tag{3}$$

where Y_{it} : real value-added of the i-th firm in year t

K_{it} : capital stock of the i-th firm in year t

L_{it} :labor input of the i-th firm in year t

t :time trend

Differentiating eq.(3) with respect to time and expressing in terms of the rate of change, we obtain the following equation.

$$\Delta y_{it} = \left(\frac{K}{Y}\right)_{it} \frac{\partial F_i}{\partial K_{it}} \Delta k_{it} + \left(\frac{L}{Y}\right)_{it} \frac{\partial F_i}{\partial L_{it}} \Delta l_{it} + \frac{1}{Y_{it}} \frac{\partial F_i}{\partial t} \tag{4}$$

where $\Delta y_{it}, \Delta k_{it}, \Delta l_{it}$: rate of change in value-added, capital stock and labor of the i-th firm in year t, respectively

The last term of the right-hand-side of eq.(4) is Solow's residual or the TFP growth rate, denoted by $\Delta \varepsilon_{it}^{*}$. Given output, the demand for inputs is determined by static cost minimization as follows: [16]

$$\lambda_{it} \frac{\partial F_i}{\partial K_{it}} = r_{k,it}$$

$$\lambda_{it} \frac{\partial F_i}{\partial L_{it}} = w_{it} \tag{5}$$

where $r_{k,it}$: rental price of capital of the i-th firm in year t

w_{it} : wage rate of the i-th firm in year t

λ_{it} : marginal cost of the i-th firm in year t

Substituting eqs.(5) into eq.(4) and arranging terms, we have

$$\Delta y_{it} = \left(\frac{r_k K}{\lambda Y}\right)_{it} \Delta k_{it} + \left(\frac{wL}{\lambda Y}\right)_{it} \Delta l_{it} + \Delta \varepsilon_{it}^{*} \qquad (6)$$

Under the homogeneity assumption of the production function, the following equation is obtained.

$$1 = \left(\frac{r_k K}{\lambda Y}\right)_{it} + \left(\frac{wL}{\lambda Y}\right)_{it} \qquad (7)$$

Substitution of eq.(7) into eq.(6) yields the following expression.

$$\Delta y_{it} - \Delta k_{it} = \alpha_{L,it}\mu\left(\Delta l_{it} - \Delta k_{it}\right) + \Delta \varepsilon_{it}^{*} \qquad (8)$$

where $\alpha_{L,it} = \left(\frac{wL}{pY}\right)_{it}$: labor share of value-added of the i-th firm in year t

$\mu = \left(\frac{p}{\lambda}\right)_{it}$: ratio of output price to marginal cost or mark-up ratio.

We assume that the value of μ , mark-up ratio, is constant over time for each industry. It exceeds unity under imperfect competition of the product market, while it is unity under perfect competition. We specify the TFP growth rate as a function of the ratio of investment on R&D to value-added in the previous year. Linearizing this relationship, we have the final expression to be estimated as follows:

$$\Delta y_{it} - \Delta k_{it} = \beta_0 + \beta_1 \alpha_{L,it}\left(\Delta l_{it} - \Delta k_{it}\right) + \beta_2 \left(\frac{RD_{it-1}}{Y_{it-1}}\right) + v_i + u_{it} \qquad (9)$$

where $\beta_1 = \mu$

v_i :firm-specific term

u_{it} : disturbance term

Based on the panel data set used in the previous sections, we estimate eq.(9) that takes account of the differences in market structure of individual industry. Specifically, we replace the second term of the right-hand-side of eq.(9) by the dummy variable for each industry multiplied by $\alpha_{L,it}(\Delta l_{it} - \Delta k_{it})$. The coefficient estimate of $\left(RD_{it-1} / Y_{it-1} \right)$ can measure the extent to which investment on R&D affects the firm-level TFP growth rate or the marginal rate of return on R&D investment. [17]

Equation (9) is estimated for the two periods: 1988-91 and 1999-2001 by three estimation procedures. One is to estimate it both by fixed effects model and random effects model and choose the most appropriate one by the Hausman test. The second is to estimate the first-difference form by pooled OLS. The third is to estimate the first-difference form by instrumental variable method. Table 6 and 7 show the estimation results of eq.(9) for 1999-2001 and 1988-91, respectively. The effect of development and research investment on the firm-level TFP growth rate is significantly positive for 1999-2001 as well as for 1988-91. However, the impact of R&D investment on the TFP growth rate for 1999-2001 is 2.1 to 23.0 times as large as that for 1988-91. [18]A ten-percentage-point increase of debt-asset ratio lowers the firm-level TFP growth rate by 0.72 percentage point for 1999-2001 by way of withering R&D activities, while the firm-level TFP growth rate remains almost intact for 1988-91.[19]

Combining the findings in the previous section that debt-asset ratio affects R&D investment in significantly negative manner in the period of 1999-2001, but not in the period of 1988-91 with more important role of R&D activities in the firm-level TFP growth rate in the period of 1999-2001, we may conclude that the firm-level TFP growth rate is much more affected by debt for 1999-2001.

Furthermore, we can explain why the distribution of the firm-level TFP growth rate became more dispersed in the late 90s, as was seen in Section 2. First, let us note that the distribution of debt-asset ratio is also more dispersed for 1999-2001. In fact the standard deviation of the debt-asset ratio of our panel data set is 0.2057 and 0.1688 for 1999-2001 and 1988-91, respectively.[20] Use of the estimation results of investment functions of R&D and the firm-level TFP growth rate equations enables us to compare the firm-level TFP growth rate between the two firms with the same attributes but debt-asset ratio. Consider a firm with the debt-asset ratio on the 1st quartile, and another with the debt-asset ratio on the 3rd quartile. Using the interquartile value of debt-asset ratio, we can compute the difference between the firm-level TFP growth rates of the two firms. The interquartile value of debt-asset ratio is 0.3079 and 0.2500 for 1999-2001 and 1988-91, respectively. Therefore the TFP growth rate of the 3rd quartile firm is lower than that of the 1st quartile firm by 2.2 percentage points for 1999-2001 and is higher only by 0.001 percentage points for 1988-91.[21] To sum up, massive debt outstandings in the 90s give rise to more dispersed distribution of the firm-level TFP growth rate across firms.

5. Concluding Remarks

Based on the panel data of Japanese research-intensive manufacturing firms, we investigated the R&D activities in the 90s. Main findings are follows. First, massive debt accumulation had a negative effect on R&D investment in the late 90s, although debt outstandings had little effect on R&D investment in the late 80s. Second, investment on R&D was closely linked to the firm-level TFP growth rate in the late 90s, while the link was much weaker in the late 80s.

Our findings suggest that lingering debt outstandings are in part responsible for slowdown of the firm-level TFP growth rate in the 90s. Moreover, we have important implications for the distributional aspect of the firm-level TFP growth rate. The distribution of the firm-level TFP growth rate across firms is more dispersed in the 90s, which is due to more dispersed distribution of the debt-asset ratio across firms in the 90s. It is true that the *average* debt-asset ratio of Japanese large manufacturing firms is declining over the 90s, but there still remain a number of firms that have massive debt outstandings to be cleaned up. Policy actions to prompt the clean-up of the debt outstandings in the corporate sector will be an urgent agenda for policy makers to recover higher growth potentials of the Japanese economy.

Footnotes

[1] See Data Appendix for the procedures to construct the variables used in the text.

[2] All the parameters estimates of the Cobb-Douglas production function as well as the related statistics are shown in Table Appendix.

[3] See Cohen and Levin (1989) and Cohen (1995) for comprehensive survey of the determinants of R&D activities in empirical context.

[4] Empirical support for negative effect of firm leverage on fixed investment is seen in Lang et al. (1996). Cantor(1990) and Calomiris et al.(1997) show in a slightly different context that investment of leverage firm is more responsive to sales and cash flow. For negative effects of leverage on investment on R&D, see Bronwyn Hall(1990, 1992).

[5] See Myers(1977) and Hart(1995) for more detailed discussion on debt overhang.

[6] Hoshi et al. (1991) is a pioneering work to show that the firms affiliated with main bank enjoy lower external finance premium than independent firms using the micro data of firms.

[7] Gibson(1995 and 1997) and Kang and Stulz(2000) examine the effect of bank health on investment behavior of the Japanese firms based on micro data of firms.

[8] The bad loan is defined as the sum of bankrupt loans, delayed loans, and loans delayed more than three months and mitigated loans. The data is taken from *Analysis of Financial Statements of All Banks* (Japanese Bankers Association).

[9] We assume that main bank of a firm holds more than 2 % of total shares of the firm, so that banks with less than 2 % share of the firm is not identified as the firm's main bank even if the bank is top shareholder among bank shareholders.

[10] For empirical studies to use the Bank of Japan diffusion index of 'banks' willingness to lend,' see Motonishi and Yoshikawa (1999) and Ogawa (2003a,b). Using the aggregate data, Motonishi and Yoshikawa obtain the evidence that bank lending is a significant determinant of business investment of small firms, but not large firms. On the other hand, Ogawa(2003a,b), using the firm's micro data, found that lending attitude of financial institutions affected fixed investment and employment adversely.

[11] The subscript i and t refer to the i-th firm and fiscal year t, respectively.

[12] Year dummies are also added as explanatory variables to capture the yearly shocks common to individual firms.

[13] An attempt was made to capture the effect of liquidity constraints on R&D investment by adding cash flow variable to the list of explanatory variables to. It turns out that the coefficient estimate of cash flow was significantly negative, possibly due to multicollinearity with real sales. Thus cash flow was dropped from the equation. Empirically the effect of cash flow on R&D investment is inconclusive in Japan. For example, it is significantly positive in Goto et al.(2002) and insignificantly positive in Hall et al.(1999), while it is insignificantly negative in Bhagat and Welch(1995).

[14] The following discussion originates from Solow(1957) and Robert Hall(1988,1990). For empirical analysis to follow Hall's approach to estimate the mark-up ratios in Japan, see Ariga et al.(1992) and Baba(1995).

[15] Alternative way to estimate the impact of R&D investment on productivity is to specify functional form of production function. The empirical analysis along this line based on Japanese firm data is Odagiri and Iwata(1986), Goto and Suzuki(1989), Griliches and Mairesse(1990) and Kwon and Inui(2003).

[16] Basu and Kimball(1997) extend the analysis along this line to the dynamic cost minimization case with adjustment cost of quasi-fixed factors taken into consideration.

[17] The above model is extended to account for non-unitary homogeneity of production function. It turns out that the estimates of marginal rate of return on R&D are essentially unaltered, while the estimates of mark-up ratios and homogeneity parameters are estimated less precisely. Therefore we report only the estimation results under linear homogeneous technology assumption.

[18] Branstetter and Nakamura(2003) find that Japanese R&D productivity growth slowed down in the 90s. Their findings are related to *average* productivity, while what we are concerned here is an increase of *marginal* rate of return on R&D investment in the 90s.

[19] The figures are computed on the basis of parameters obtained from fixed effects model with banks' willingness to lend as banks' health variable for R&D investment function and fixed effects model for TFP growth rate regression for 1999-2001 and 1988-91.

[20] When we measure the dispersion of the distribution of debt-asset ratio by coefficient of variation, it is 0.3895 and 0.2721 for 1999-2001 and 1988-91, respectively.

[21] For the models used for computing the differences of the TFP growth rate, see footnote 19.

Data Appendix

We give brief explanations of the data construction procedures with special emphasis on capital stock.

Construction of Capital Stock

Our basic strategy to construct a series of the physical depreciable capital stock is to follow the perpetual inventory method, as discussed in Hayashi and Inoue(1991) . The capital stock series is constructed each for six types of assets: nonresidential buildings, structures, machinery, vessels, transportation equipment except vessels, instruments and tools to add up the total capital stock. Our benchmark year is the fiscal year of 1985 and 1995 for 1988-91 and 1999-2001, respectively. Benchmark stock is converted into the real value by dividing the book-valued stock by the investment goods deflator in benchmark year minus the average years elapsed since installation. The information of the average years elapsed since installation is available from *1970 National Wealth Survey* for each type of physical depreciable assets. The investment goods deflator is constructed for each industry and each type of physical asset by making use of the Fixed Capital Formation Matrix in the *1995 Input-Output tables.*

Nominal investment is constructed for each type of physical asset as follows:

$$\begin{aligned} NI_{it} &= INC_{it} - \left(SR_{it} - DD_{it}\right) \\ &= INC_{it} - \left\{\left(KG_{it-1} + INC_{it} - KG_{it}\right) - \left(AD_{it-1} + DEP_{it} - AD_{it}\right)\right\} \qquad \text{(A-1)} \\ &= \left(KG_{it} - KG_{it-1}\right) - \left(AD_{it} - AD_{it-1}\right) + DEP_{it} \end{aligned}$$

where NI_{it} : nominal investment of the i-th firm in year t

INC_{it} : increment of physical asset of the i-th firm in year t

SR_{it} : value of the i-th firm's physical asset scrapped in year t

DD_{it} : value of the i-th firm's physical asset scrapped in year t out of the accumulated depreciation

KG_{it} : i-th firm's physical asset at the end of year t at purchase value

AD_{it} : accumulated depreciation of the i-th firm in year t
DEP_{it} : depreciation of the i-th firm in year t

Nominal investment is divided by the corresponding investment goods deflator to obtain real investment (I_{it}). The physical depreciation rates (δ) are based on those reported in Hayashi and Inoue(1991). They show the rates for five categories of assets, which were derived from Hulten and Wykoff(1979,1981). They are 4.7 % per annum for nonresidential buildings, 5.64 % for structures, 9.489 % for machinery, 14.7 % for transportation equipment, and 8.8838 % for instruments and tools. We use the depreciation rate of transportation equipment for that of vessels.

Given the benchmark value of depreciable stock, real investment series, and depreciation rate, we obtain the capital stock of each type from the following formula. For detailed explanations see Hayashi and Inoue(1991).

$$K_{it} = (1-\delta)K_{it-1} + I_{it} \qquad \text{(A-2)}$$

where K_{it} : i-th firm's capital stock at the end of year t

Finally, the capital stock is multiplied by the capacity utilization rate index reported by Ministry of Economy, Trade and Industry.

<u>Value-added</u>

Value-added = (Ordinary Income – Corporate Taxes – Enterprise Tax – Residential Tax + Compensations to Directors + Wages and Salaries to Employees + Welfare Expenses + Reserve Fund for Bonuses + Retirement Allowance + Reserve Fund for Retirement Allowance + Company Pension + Taxes + Rental Fees + Royalties + Interest and Discount paid + Depreciation Allowances).

<u>Labor inputs</u>

The number of employees is multiplied by the Hours Worked Indices (Total Hours Worked) reported in *Monthly Labour Survey* (Ministry of Health, Labour and

Welfare).

Labor Share

Labor share = (Compensations to Directors + Wages and Salaries to Employees + Welfare Expenses + Reserve Fund for Bonuses + Retirement Allowance + Reserve Fund for Retirement Allowance + Company Pension)/Value-added.

Investment on R&D

Total expenditure on R&D.

Real sales

Nominal sales are divided by the Corporate Goods Price Indexes of each industry (The Bank of Japan).

Cash flow

Cash flow = (ordinary income + depreciation allowance – corporate tax – dividends paid – compensations and bonus to directors).

Debt-asset ratio

Liabilities are divided by total assets.

Bad loans ratio

Bad loans ratio of the firm's main bank is defined as the ratio of bad loans to total loans. Main bank of the firm is identified as the top shareholder among bank shareholders. The bad loan is defined as the sum of bankrupt loans, delayed loans, and loans delayed more than three months and mitigated loans. The data of bad loans comes from *Analysis of Financial Statements of All Banks* (Japanese Bankers Association).

The diffusion index of 'banks' willingness to lend'

The diffusion index is the proportion of entrepreneurs feeling the present lending attitude of financial institutions to be “accommodative” minus those feeling the present lending attitude of financial institutions to be “severe”. It is reported by the Bank of Japan *Tankan* (Short-term Economic Survey of Corporations).

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Table 1 Number of Firms and Total Observations in Panel Data Set
in 1988-91 and 1999-2001:

	1988-91		1999-2001	
	(1)	(2)	(1)	(2)
Chemicals	75	284	141	419
Machinery	83	307	147	433
Electrical machinery, equipment and supplies	78	290	133	390
Transport equipment	55	208	102	305
Precision instrument	17	67	32	94
Total	308	1156	555	1641

Data Source: Development Bank of Japan Corporate Database

(1): number of firms

(2): number of total observations

Table 2 Comparison of R&D Activities between 1988-91 and 1999-2001: Mean Ratio of Expenditures on R&D to Sales

	1988-91	1999-2001
Chemicals	0.0589	0.0528
	(0.05)	(0.04)
Machinery	0.0253	0.0275
	(0.02)	(0.02)
Electrical machinery, equipment and supplies	0.0809	0.0481
	(0.09)	(0.04)
Transport equipment	0.0326	0.0274
	(0.03)	(0.03)
Precision instrument	0.0487	0.0505
	(0.03)	(0.03)

Data Source: Development Bank of Japan Corporate Database

The values in parentheses are standard deviations.

Table 3 Comparison of the TFP Growth Rate by Industry between 1988-91 and 1999-2001:

	TFP growth rate as Solow's residual		TFP growth rate estimated by Cobb-Douglas production function	
	1988-91	1999-01	1988-91	1999-01
Chemicals	0.0162***	0.0057	0.0553***	0.0034
	(0.10)	(0.14)	(8.57)	(0.43)
Machinery	0.0174**	0.0226	0.0432***	0.0201
	(0.14)	(0.32)	(6.20)	(1.20)
Electrical machinery,	0.0814***	0.1102***	0.0961***	0.1208***
equipment and supplies	(0.10)	(0.21)	(19.33)	(11.32)
Transport equipment	0.0398***	0.0613***	0.1088***	0.0128
	(0.15)	(0.16)	(8.02)	(1.17)
Precision instrument	0.0398***	0.0223	0.0330***	0.0153
	(0.11)	(0.17)	(3.93)	(0.94)

Data Source: Development Bank of Japan Corporate Database

*** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis in the first and second column are standard deviations.

The values in parenthesis in the third and fourth column are t-ratios.

The production function of chemicals, machinery, electrical machinery, equipment and supplies and transport equipment for the period of 1988-91 and chemicals, machinery, transport equipment for the period of 1999-2001 is estimated by fixed effects model.

On the other hand, the production function of precision instrument for the period of 1988-91 and electrical machinery, equipment and supplies and precision instrument for the period of 1999-2001 is estimated by variance components model.

Table 4 Estimation Results of R&D Investment Function: 1999-2001

Estimation method	Growth rate of sales	Real sales	Debt-asset ratio	Ratio of bad loans	Banks' willingness to lend	S.E. Number of observations
1. Fixed effects model	0.1145** (2.30)	-0.1003*** (-6.41)	-0.0452* (-1.82)		0.0266 (0.77)	0.0338 1618
2.Fixed effects model	0.1296*** (2.57)	-0.1064*** (-6.47)	-0.0660** (-2.43)	0.0462 (1.34)		0.0342 1494
3.First difference (Pooled OLS)	0.1302*** (2.86)	-0.1073*** (-7.35)	-0.0440* (-1.73)		-0.0427*** (-2.61)	0.0431 1068
4.First difference (Pooled OLS)	0.1660*** (3.62)	-0.1237*** (-8.65)	-0.0482* (-1.74)	0.0667* (1.89)		0.0440 975
5. First difference (Instrumental variables)	0.2134*** (2.70)	-0.1130*** (-3.62)	-0.0397 (-0.28)		-0.0393* (-1.84)	0.0432 1068
6. First difference (Instrumental variables)	0.2012** (2.21)	-0.1480*** (-6.06)	0.0547 (0.37)	0.0578 (1.60)		0.0445 975

Notes: *** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis are t-ratios.

Instruments for the 5-th and 6-th row are constant, year dummies, first-lagged and second-lagged debt-asset ratios, second-lagged and third-lagged average growth rates of sales and logarithm of real sales. It is assumed that banks' willingness to lend is exogenous in the 5-th equation and that the bank's bad loan ratio is exogenous in the 6-th equations.

Table 5 Estimation Results of R&D Investment Function: 1988-91

Estimation method	Growth rate of sales	Real sales	Debt-asset ratio	Banks' willingness to lend	S.E. Number of observations
1. Fixed effects model	0.1361** (2.10)	-0.0834** (-2.66)	-0.0006 (-0.02)	0.0334 (0.86)	0.0541 1135
2.First difference (Pooled OLS)	0.0939 (0.70)	-0.0708 (-1.23)	-0.0243 (-0.34)	-0.0125 (-0.25)	0.1202 827
3.First difference (Instrumental variables	0.2366 (0.92)	-0.4105 (-1.61)	-0.6151 (-1.44)	-0.0102 (-0.18)	0.1400 556

Notes: *** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis are t-ratios.

Instruments for the 3-rd row are constant, year dummies, first-lagged and second-lagged debt-asset ratios, second-lagged average growth rates of sales and second-lagged and third-lagged logarithm of real sales. It is assumed that banks' willingness to lend is exogenous.

Table 6 Link of the Firm-level TFP Growth Rate to R&D Investment: 1999-2001

Estimation method	Effect of research and development	Mark-up ratio Chemicals	Machinery	Electrical machinery	Transport equipment	Precision instrument	S.E. Number of observations
1. Fixed effects model	1.5871*** (7.64)	1.6026*** (9.92)	0.7729*** (6.28)	1.0811*** (7.85)	0.8465*** (4.58)	0.8526** (1.99)	0.1591 1068
2.First difference (Pooled OLS)	0.8053*** (15.38)	1.6105*** (9.60)	0.5265*** (4.53)	0.7379*** (5.75)	0.9914*** (5.26)	0.9304** (2.09)	0.2338 523
3.First Difference (Instrumental Variables)	0.7085*** (10.29)	0.8115 (0.56)	0.1472 (0.80)	0.9298*** (5.17)	2.8803*** (5.96)	3.6346* (1.86)	0.2705 523

Notes: *** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis are t-ratios.

Instruments for the 3-rd row are constant, industry dummies, second-lagged ratio of R&D to value-added, second-lagged and third-lagged growth rate of capital stock and growth rate of labor-capital ratio multiplied by labor share.

Table 7 Link of the Firm-level TFP Growth Rate to R&D Investment: 1988-91

Estimation method	Effect of research and development	Mark-up ratio Chemicals	Machinery	Electrical machinery	Transport equipment	Precision instrument	S.E. Number of observations
1. Fixed effects model	0.0691* (1.82)	1.6960*** (16.96)	1.3386*** (23.05)	1.5325*** (14.30)	1.8415*** (9.51)	1.5520*** (8.87)	0.0878 827
2.First difference (Pooled OLS)	0.0758* (1.86)	1.8001*** (16.67)	1.5123*** (22.82)	1.7424*** (21.11)	2.0558*** (9.10)	1.6807*** (9.11)	0.1338 535
3.First Difference (Instrumental Variables)	0.3442** (2.50)	1.8682*** (3.57)	1.5826*** (7.34)	1.8089*** (5.58)	2.9260*** (4.47)	2.1810*** (7.29)	0.1422 535

Notes: *** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis are t-ratios.

Instruments for the 3-rd row are constant, industry dummies, second-lagged ratio of R&D to value-added, second-lagged and third-lagged growth rate of capital stock and growth rate of labor-capital ratio multiplied by labor share.

Table Appendix

Estimation Results of the Cobb-Douglas Production Function by Industry

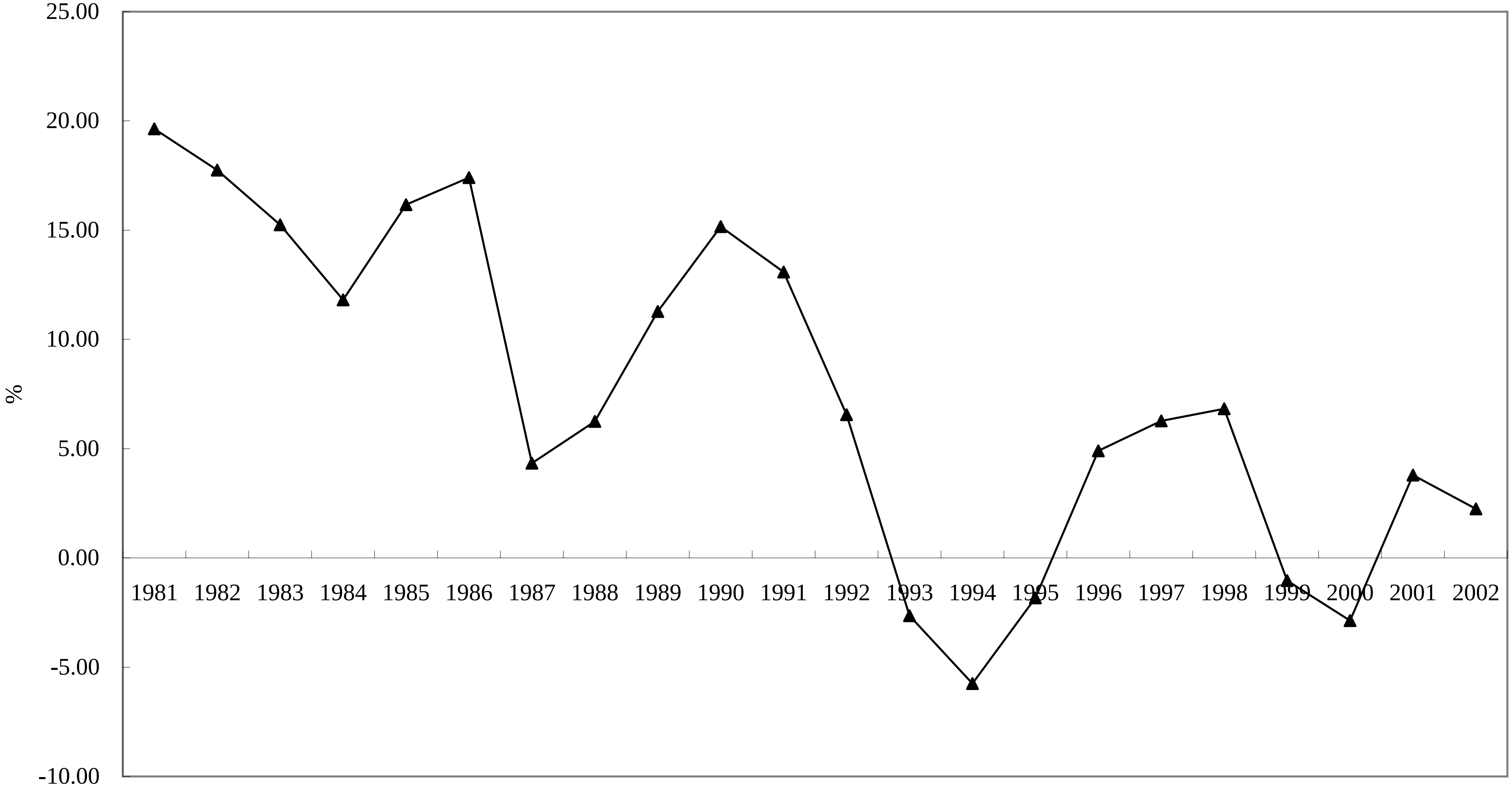
	1988-91				1999-2001			
	Labor elasticity	Capital elasticity	Time trend	S.E.	Labor elasticity	Capital elasticity	Time trend	S.E.
Chemicals	0.5894***	0.1940***	0.0553***	0.0743	0.4301***	0.2326***	0.0034	0.1181
	(6.34)	(4.38)	(8.57)		(4.13)	(3.81)	(0.43)	
Machinery	0.3520***	0.1519***	0.0432***	0.0931	0.2702	0.3654**	0.0201	0.2533
	(2.93)	(4.07)	(6.20)		(1.61)	(2.52)	(1.20)	
Electrical machinery,	0.9530***	0.1535***	0.0961***	0.0663	0.6770***	0.3511***	0.1208***	0.2682
equipment and supplies	(12.25)	(5.96)	(19.33)		(17.30)	(11.25)	(11.32)	
Transport equipment	1.1336***	-0.1327	0.1088***	0.0973	0.4609***	0.3003***	0.0128	0.0968
	(7.73)	(-1.50)	(8.02)		(7.12)	(2.94)	(1.17)	
Precision instrument	0.7193***	0.2311***	0.0330***	0.1568	0.7119***	0.3138***	0.0153	0.2619
	(9.18)	(4.21)	(3.93)		(6.92)	(4.25)	(0.94)	

*** ** * : significant at the 1 %, 5 % and 10% level, respectively

The values in parenthesis are t-ratios.

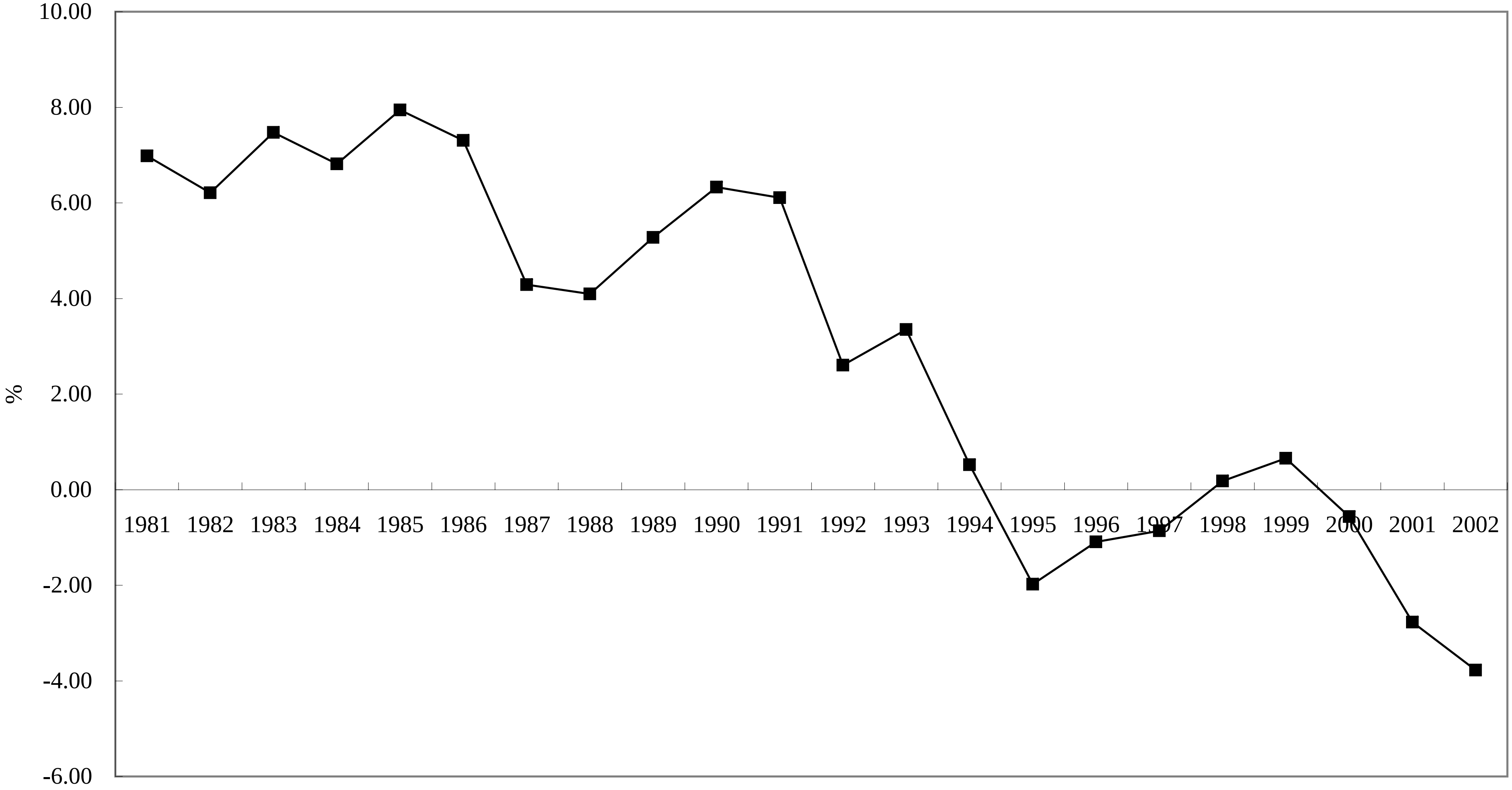
The production function of chemicals, machinery, electrical machinery, equipment and supplies and transport equipment for the period of 1988-91 and chemicals, machinery, transport equipment for the period of 1999-2001 is estimated by fixed effects model. On the other hand, the production function of precision instrument for the period of 1988-91 and electrical machinery, equipment and supplies and precision instrument for the period of 1999-2001 is estimated by variance components model.

Figure 1 Rate of Change in Intramural Expenditures on R&D:
Large Firms in Manufacturing Sector



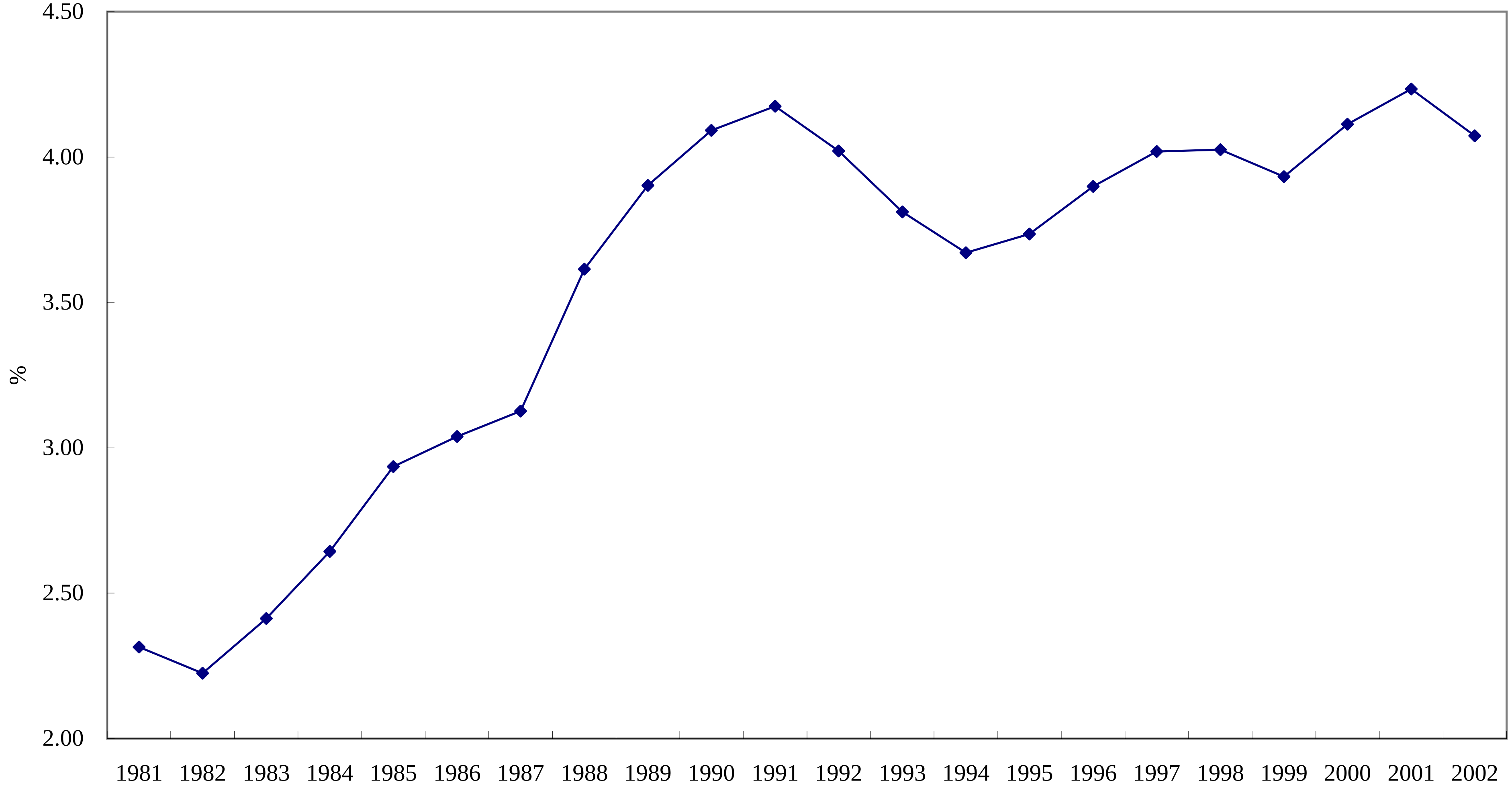
Data Source: Survey of Research and Development (Statistics Bureau of Ministry of Public Management, Home Affairs, Posts and Telecommunications)

Figure 2 Rate of Change in Persons Engaged in R&D Activities:
Large Firms in Manufacturing Sector



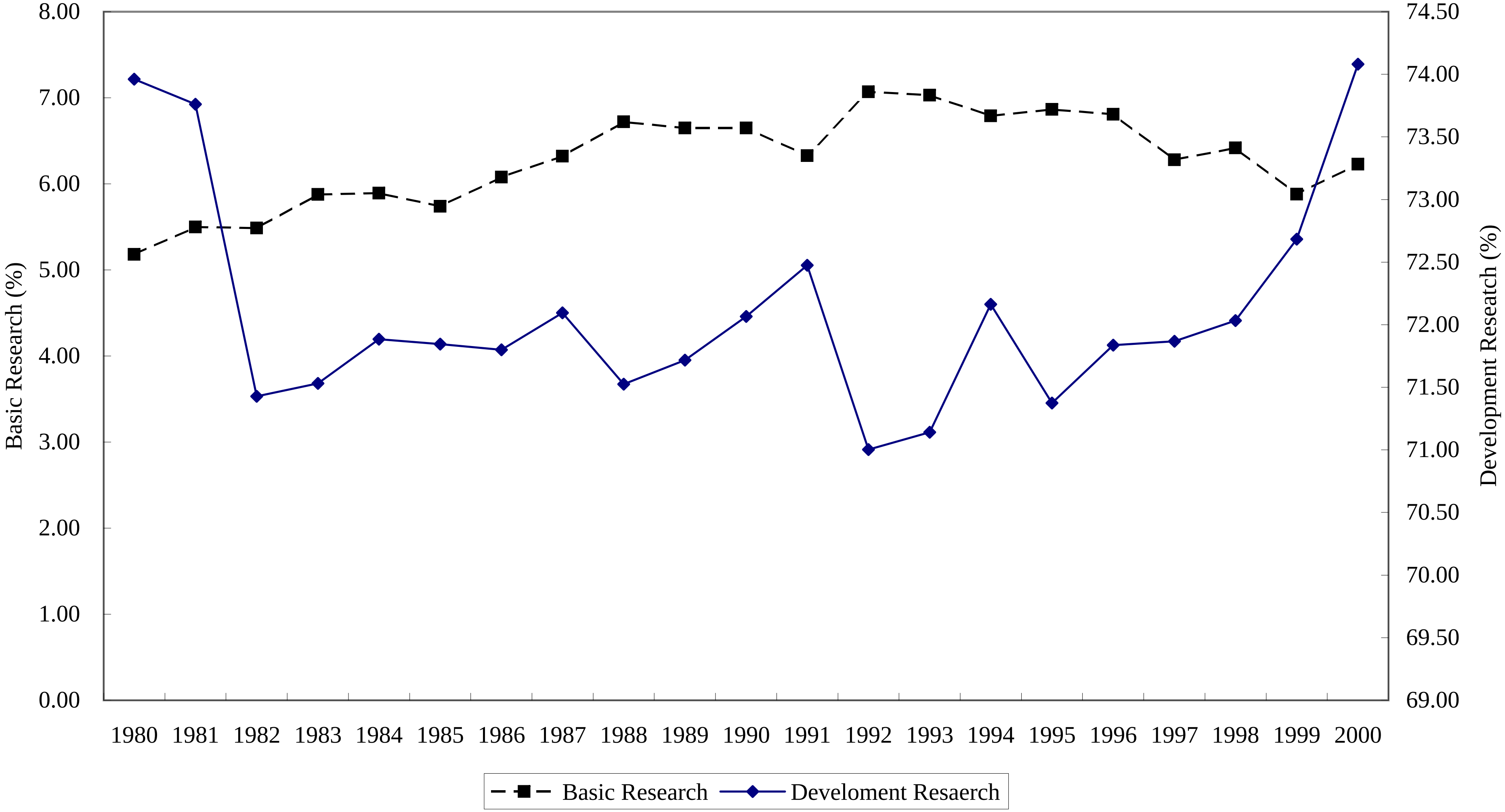
Data Source: Survey of Research and Development (Statistics Bureau of Ministry of Public Management, Home Affairs, Posts and Telecommunications)

Figure 3 Ratio of Intramural Exprnditures on R&D to Sales:
Large Firms in Manufacturing Sector



Data Source: Survey of Research and Development (Statistics Bureau of Ministry of Public Management, Home Affairs, Posts and Telecommunications)

Figure 4 Intramural Expenditure on R&D by Types:
Large Firms in Manufacturing Sector



Data Source: Survey of Research and Development (Statistics Bureau of Ministry of Public Management, Home Affairs, Posts and Telecommunications