DEPRECIATION RATE OF R&D CAPITAL: PANEL DATA ANALYSIS OF LISTED FIRMS IN JAPANESE R&D-INTENSIVE INDUSTRIES

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ABSTRACT
Research and development (R&D) capital is thought to be at the core of technological progress. To measure the effect of R&D capital correctly, the knowledge of its depreciation rate is required. However, few studies have paid attention to the depreciation rate of R&D capital for recent Japanese firms. This study estimates the depreciation rate of R&D capital by two methods using panel data of listed Japanese firms in R&D-intensive industries. The results show that the rates are higher than the conventionally accepted 15 percent and those estimated by previous studies for Japanese firms.

Keywords: Research and Development (R&D), depreciation rate of R&D capital, Japanese firms, panel data, Q model of investment, multiple capital assets, instrumental variable.

JEL Classification: O30; C81

Contribution/ Originality
This study contributes in the existing literature in that it compares the results by two methods which have different assumptions. Another contribution of this study is to find that the depreciation rates of R&D capital for recent Japanese firms in R&D-intensive industries are higher than the conventionally accepted rate.

1. INTRODUCTION
The expected rate of potential growth in Japan is declining because of a rapidly aging population. Therefore, it is necessary to increase total factor productivity growth by technological progress to raise the rate of potential growth. Since Research and development (R&D) capital is thought to be at the core of technological progress, it is important to analyse the effect of R&D correctly.

To measure the R&D effect, it is necessary to know the correct depreciation rate of R&D capital and construct the R&D capital series. Nevertheless, few studies have paid attention to the depreciation rate of R&D capital. Most of the previous studies, including Griliches and Mairesse (1984) used a constant depreciation rate (usually 15%).

However, whether the depreciation rate of R&D capital is constant across countries and industries has not been verified. The main objective of this paper is to measure the depreciation rate of R&D capital of Japanese R&D-
intensive industries by applying the two methods: the market value approach, and the R&D-earnings approach. We
correct the panel data of listed Japanese firms in four industries, namely, the pharmaceutical, electric and electronic
manufacturing, chemical, and machinery industries, for the period 1986 to 2010.

The rest of this paper is organized as follows. In Section 2, previous studies are reviewed. Next section of the
paper considers the estimation method of the depreciation rate of R&D capital. Estimation results are shown in
Section 4. Section 5 concludes the paper with suggestions for future research.

2. PREVIOUS STUDIES MEASURING THE DEPRECIATION RATE OF R&D CAPITAL

2.1. Patent Renewal Data Method

Bosworth (1978) estimates the technological knowledge obsolescence rate using patent renewal data. Pakes and
Schankerman (1984); Goto et al. (1986) the Development Bank of Japan (2005) and Sakai (2013) also apply this
method. For example, Bosworth (1978) uses U.K. patent data from the 1930s to the 1940s and estimates that the rate
of obsolescence is 10 to 15 percent. Goto et al. (1986) and the DBJ (2005) both use Japanese patent data. Goto et al.
(1986) estimate the depreciation rate of R&D capital to be 7 to 10 percent in the 1960s, and the DBJ (2005) estimates
it to be 13 to 22 percent in the 1980s. Similarly, Sakai (2013) estimates the depreciation rate using Japanese patent
data from 1996 to 1999 and reports the rate to be 13 to 22 percent. Pakes and Schankerman (1984) use the patent data
of European countries from the 1930s and find the rate to be 25 percent.

However, estimating the depreciation rate of R&D capital using this method has a weakness. Although the
statistics covers a wide variety of patents, it covers only certain kinds of knowledge that can be patented. Moreover,
patent renewal depends on the patent policies of each firm. Pakes and Schankerman (1984) identify sample selection
bias resulting from the differences in the depreciation rate of patented innovations and that of other type of
innovations. In addition, Goto and Suzuki (1989) show that Japanese patent holders tend to keep their patents even
though they may no longer represent valuable knowledge because the renewal fee is relatively low. Therefore, the
estimates of R&D depreciation rate using patent renewal data may be biased downward.

2.2. Market Value Method

Hall (2007) applies the idea proposed by Griliches (1981) and Hayashi and Inoue (1991) and estimates the
depreciation rates of R&D capital assuming that R&D and physical capital are valued equally in the market. This
method is forward looking in that it relies on the financial market’s assessment of firm value. Hall (2007) estimates
the rates to be 14.9 percent for pharmaceutical and 35.7 percent for electric manufacturing firms in the U.S. during

<table>
<thead>
<tr>
<th>Study</th>
<th>Estimation type</th>
<th>Sample</th>
<th>Period</th>
<th>Depreciation rate of R&amp;D capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sakai (2013)</td>
<td>Patent renewal</td>
<td>Japan patents</td>
<td>1982–1999</td>
<td>12.6–21.6% Chemicals: 19.4% Drugs: 14.9% Electrical: 35.7% Computers: 30.6% Current 11.4% Preceding 17.7% ... (Length of lags: 7 years)</td>
</tr>
</tbody>
</table>

Source: Prepared by author.
2.3. The R&D-Earnings Method

The estimation of R&D amortization rates proposed by Lev and Sougiannis (1996) is based on the fundamental relation between R&D and the earnings. They define the R&D amortization rate in year k as the ratio of that year’s expired benefits to the total benefits generated by R&D for x periods. Lev and Sougiannis (1996) estimate the rate of amortization on current R&D to be 11.4 percent, and the preceding year’s R&D to be 17.7 percent.

3. METHODS OF ESTIMATING THE DEPRECIATION RATE OF R&D CAPITAL

3.1. Estimation Using the Market Value Method

3.1.1. Model

Hall (2007), which is based on the theoretical Q model of investment with multiple capital assets proposed by Hayashi and Inoue (1991), is applied in this section.

The model has two capitals—physical capital ($K_p$) and R&D capital ($K_r$)—with the corresponding investments $I$ and $R$, prices $p^i$ and $p^k$, and depreciation rates $\delta_c$ and $\delta_k$. The expectation operator $E_i$ is based on the information at period $t$ and $\beta$ is a constant discount rate.

Firm $i$ maximize the following value function:

$$
\text{max } V_i = E_i \sum_{j=t}^{\infty} \beta^j [\Pi(K_{R_{i+j}}, K_{R_{i+j-1}}, K_{R_{i+j-2}}, \ldots; p^k) - p^i I_{i+j} - p^k R_{i+j}]
$$

s.t. $K_{R_{i+j}} = (1 - \delta_k)K_{R_{i+j-1}} + R_{i+j}$

$$
E_i \sum_{j=t}^{\infty} \beta^j [\Pi(K_{P_{i+j}}, K_{P_{i+j-1}}, K_{P_{i+j-2}}, \ldots; p^j) - p^i I_{i+j} - p^k R_{i+j}]
$$

To solve Equation (1) using the condition where the cost of capital equals the marginal profit, following Jorgensen-type cost of capital functions are derived:

$$
C^c_p = p^i - E_i [\beta(1 - \delta_c) p^i]
$$

$$
C^k_p = p^k - E_i [\beta(1 - \delta_k) p^k]
$$

Now, Equation (1) can be rewritten as Equation (4):

$$
V_i = E_i \sum_{j=t}^{\infty} \beta^j [\Pi(K_{P_{i+j}}, K_{R_{i+j}}, K_{R_{i+j-1}}, K_{R_{i+j-2}}, \ldots; p^k) - C^p_i I_{i+j} - C^k_i R_{i+j}]
$$

$$
= E_i \sum_{j=t}^{\infty} \beta^j [\Pi(K_{P_{i+j}}, K_{R_{i+j}}, K_{R_{i+j-1}}, K_{R_{i+j-2}}, \ldots; p^k) - C^p_i K_{P_{i+j}} - C^k_i K_{R_{i+j}}]
$$

$$
+ (1 - \delta_c) p^i K_{P_{i+j}} + (1 - \delta_k) p^k K_{R_{i+j}}
$$

We assume the firm’s supernormal rent ($W$) to be

$$
W_i = E_i \sum_{j=t}^{\infty} \beta^j [\Pi(K_{P_{i+j}}, K_{R_{i+j}}, K_{R_{i+j-1}}, K_{R_{i+j-2}}, \ldots; p^k) - C^p_i K_{P_{i+j}} - C^k_i K_{R_{i+j}}]
$$

Thus, Equation (6) is obtained from Equation (4) and (5).

$$
V_i = (1 - \delta_c) p^i K_{P_{i+j}} + (1 - \delta_k) p^k K_{R_{i+j}} + W_i
$$

By using Equation (6), conventionally measured Tobin’s q can be shown as follows:

$$
q_i = V_i / (1 - \delta_c) p^i K_{P_{i+j}} + W_i / (1 - \delta_c) p^i K_{P_{i+j}}
$$

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However, the correct depreciation rate is not known beforehand. Assuming that the depreciation rate δ is tentative, the regression result will be biased by  \( \hat{\gamma} \).

\[
\ln q_{it} = \ln \left[ 1 + \gamma \left( (1 - \delta) p_{it}^g K_{R,i}^*/(1 - \delta_c) p_{it}^c K_{P,i}^* \right) \right] + W_i + (1 - \delta_c) p_{it}^c K_{P,i}^* \right] + \varepsilon_{it} \tag{8}
\]

If \( K_{R,i}^* \) is assumed to be the true R&D capital, where ‘true’ indicates that the R&D capital is computed using the correct depreciation rate \( \delta \), Equation (9) holds:

\[
\ln q_{it} = \ln \left[ 1 + (1 - \delta) p_{it}^g K_{R,i}^*/(1 - \delta_c) p_{it}^c K_{P,i}^* \right] + \varepsilon_{it} \tag{9}
\]

By defining \( \hat{\gamma}(1 - \delta)/((1 - \delta_c)) = \hat{\Theta} \), following equation holds:

\[
\ln q_{it} = \ln \left[ 1 + \hat{\gamma}(1 - \delta) p_{it}^g K_{R,i}^*/(1 - \delta_c) p_{it}^c K_{P,i}^* \right] + \varepsilon_{it} = \ln \left[ 1 + \hat{\Theta}(p_{it}^g K_{R,i}^*/ p_{it}^c K_{P,i}^*) \right] + \varepsilon_{it} \tag{10}
\]

From Equations (9) and (10), Equation (11) is obtained.

\[
(1 - \delta) p_{it}^g K_{R,i}^*/(1 - \delta_c) p_{it}^c K_{P,i}^* = \hat{\Theta}(p_{it}^g K_{R,i}^*/ p_{it}^c K_{P,i}^*) \tag{11}
\]

Assuming that R&D expenditure grows at a constant rate \( g \), the following relation holds:

\[
K_{R,i} = K_{R,i}^*(\delta + g)/(\delta_g + g) \tag{12}
\]

Equation (13) follows from Equations (11) and (12):

\[
(1 - \delta) p_{it}^g K_{R,i}^*/(1 - \delta_c) p_{it}^c K_{P,i}^* = \hat{\Theta}(p_{it}^g K_{R,i}^*/ p_{it}^c K_{P,i}^*) = \hat{\Theta}(p_{it}^g / p_{it}^c) \left[ K_{R,i}^*(\delta + g)/(\delta_g + g) \right] \tag{13}
\]

Thus, the correct depreciation rate \( \delta \) can be given in Equation (14), where we assume that \( \delta_R = 15 \) percent as a starting value.

\[
\delta = \left[ (\delta_R + g) - (1 - \delta_c) g \hat{\Theta} \right]/\left[ (\delta_R + g) + (1 - \delta_c) \hat{\Theta} \right] \tag{14}
\]

3.1.2. Variables

Variable \( V_{it} \) denotes firm \( i \)'s market value, that is, its stock price multiplied by the number of stocks issued by firm \( i \) at time \( t \); \( \delta_c \) is the depreciation rate of physical capital, for which the rates of depreciation of goods proposed by Hayashi and Inoue (1991) are applied. Variables \( p_{it}^c K_{P,i} \) and \( p_{it}^g K_{R,i} \) are the nominal physical capital and R&D capital, respectively. Tentative R&D capital \( K_{R} \) is calculated by using \( \delta_R \) and \( R_i \), where \( R_i \) is R&D expenditure.

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3 If \( K_{R} \) and \( K_{R}^* \) are at their optimal level and the marginal shadow value of both capitals are equal, \( \gamma \) should be one and \( W \) should be zero.

4 Hall (2007) tried to add capital aggregator term \( \phi(K_{R}^*/K_{R}) \) as an explanatory variable in Equation (10) to capture possible supranormal rents. However, the capital aggregator term and \( \hat{\Theta}(p_{it}^g K_{R,i}^*/ p_{it}^c K_{P,i}^*) \) will be highly correlated across firms. Assuming that financial markets are efficient and firms quickly achieve equilibrium, Equation (10) is estimated without including the capital aggregator term.
Following the method used by Goto and Suzuki (1989) and Hall and Mairesse (1995) Equation (15) is used for setting the starting value of R&D capital ($R_{K}$), where $g$ is assumed to be constant for the estimation period.

$$
K_{R;1} = R_0 + (1 - \delta) R_{-1} + (1 - \delta)^2 R_{-2} + \ldots = R_0 \sum_{t=0}^{\infty} [(1 - \delta)/(1 + g)]^t = R_0 (g + \delta) \tag{15}
$$

### 3.1.3. Data

Panel data of listed firms used in this paper is on the NEEDS-Financial QUEST files between fiscal years 1986 and 2010. The sample, which satisfies all the necessary variables, includes 45 pharmaceutical, 271 electric and electronic manufacturing, 176 chemical, and 328 machinery firms.

### 3.2. Estimation Using the R&D-Earnings Method

#### 3.2.1. Model

Applying Lev and Sougiannis (1996) Equation (16) where logarithms mitigate heteroscedasticity is estimated by using the instrumental variables and the Almon lag procedure:

$$
\ln OI_t = \alpha_0 + \alpha_1 \ln TA_{t-1} + \sum_{k=0}^{x} \alpha_2, k \ln RD_{t-k} + \alpha_3 \ln AD_{t-1} + \epsilon_t \tag{16}
$$

Where $OI$ is the operating income before depreciation, advertising and R&D expenses; $TA$ is value of tangible assets; $RD_{i,t}$ is R&D expenditure with $k$ lags; and $AD$ is advertising capital. R&D amortization rate in year $k$ is defined as the ratio of that year’s expired benefits, $\hat{a}_{2,k}$ to the total benefits R&D generated.

$$
\hat{a}_{2,k} = \frac{\hat{\alpha}_{2,k}}{\sum_{k} \hat{\alpha}_{2,k}} \tag{17}
$$

The length of lag is set by $x$, and $\hat{\alpha}_{2,k}$ is the last significant coefficient.

#### 3.2.2. Variables

Average R&D expenditure of other firms is used as instrument for $RD$, as followed by Lev and Sougiannis (1996). Moreover, advertising expenditure is used instead of advertising capital for $AD$, because their effect on subsequent earnings is short-lived.

#### 3.2.3. Data

Panel data of listed firms used in this paper is on the NEEDS-Financial QUEST files between fiscal years 1986 and 2010. The sample, which satisfies all the necessary variables, includes 38 pharmaceutical, 207 electric and electronic manufacturing, 145 chemical and 223 machinery firms.

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1 It is assumed that we follow a perpetual inventory method to construct the R&D capital.

2 Lev and Sougiannis (1996). do not take logarithms, but scale by total sales to mitigate heteroscedasticity.


4 This means that if $\hat{a}_{2,1}$ is insignificant while $\hat{a}_{2,x}$ is significant in Equation (16), then $x$ is the last significant coefficient. In that, $x$ is considered the useful life of R&D capital. However, finding the reasonable length of lags that affect the estimation result is quite difficult.

5 An association between a firm’s R&D expenditures and those of average R&D of other firms is induced by spillover. Cohen and Levinthal (1989) show that R&D develops the firm’s absorptive capacity, the ability to assimilate and exploit others’ knowledge.
4. RESULTS

4.1. Market Value Method

Table-2 shows the estimation results by market value method. Equation (10) is estimated by using nonlinear least squares with year and firm dummies, and \(\delta\) is obtained by Equation (14). The rate ranges from 19.5 to 29.3 percent, which are found to be higher than the conventionally accepted 15 percent. Among them, the depreciation rate of R&D capital was the highest for electric and electronic manufacturing firms.

Table-2. Estimation results using the market value method

<table>
<thead>
<tr>
<th>1996 to 2010</th>
<th>pharmaceutical</th>
<th>electric and electronic</th>
<th>chemical</th>
<th>machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tilde{\alpha}) (Standard errors)</td>
<td>0.663 (0.114)</td>
<td>0.462 (0.036)</td>
<td>0.573 (0.073)</td>
<td>0.706 (0.057)</td>
</tr>
<tr>
<td>(\delta) Estimated depreciation rate of R&amp;D</td>
<td>20.9%</td>
<td>9.7%</td>
<td>21.6%</td>
<td>19.5%</td>
</tr>
<tr>
<td>Samples</td>
<td>926</td>
<td>4,545</td>
<td>3,353</td>
<td>5,751</td>
</tr>
</tbody>
</table>

Source: Author’s calculation.

4.2. R&D-Earnings Method

Table-3 shows the estimation results of annual depreciation rate \(\delta_k\) using Equation (16) with year and firm dummies. The length of the statistically significant lagged R&D coefficient, \(\alpha_{2,k}\), indicates the useful life of R&D capital. Thus, the average useful life is the shortest in electric and electronic manufacturing, seven years, followed by chemicals and pharmaceuticals, and the longest in machineries, ten years. R&D capital depreciates very quickly especially for electric and electronic manufacturing firms such that the amortization rate of current R&D was 22.4 percent, preceding year’s R&D was 20.3 percent, and so on.

Table-3. Estimation results using the R&D-earnings method

<table>
<thead>
<tr>
<th>1996 to 2010</th>
<th>pharmaceutical</th>
<th>electric and electronic</th>
<th>chemical</th>
<th>machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>const.</td>
<td>-2.120 (3.797)</td>
<td>0.949 (0.280)</td>
<td>0.019 (0.005)</td>
<td>-0.164 (0.019)</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>-0.016 (0.023)</td>
<td>0.018 (0.003)</td>
<td>0.741 (0.031)</td>
<td>0.340 (0.043)</td>
</tr>
<tr>
<td>(\alpha_{2,k})</td>
<td>0.144 (0.045)</td>
<td>0.493 (0.033)</td>
<td>0.201 (0.016)</td>
<td>0.254 (0.025)</td>
</tr>
<tr>
<td>(\alpha_{3,k})</td>
<td>0.138 (0.072)</td>
<td>11.8%</td>
<td>0.034 (0.010)</td>
<td>22.4%</td>
</tr>
<tr>
<td>(\alpha_{4,k})</td>
<td>0.155 (0.063)</td>
<td>13.2%</td>
<td>0.031 (0.006)</td>
<td>20.3%</td>
</tr>
<tr>
<td>(\alpha_{5,k})</td>
<td>0.163 (0.063)</td>
<td>14.0%</td>
<td>0.027 (0.006)</td>
<td>17.9%</td>
</tr>
<tr>
<td>(\alpha_{6,k})</td>
<td>0.164 (0.066)</td>
<td>14.0%</td>
<td>0.023 (0.007)</td>
<td>15.0%</td>
</tr>
<tr>
<td>(\alpha_{7,k})</td>
<td>0.156 (0.067)</td>
<td>13.4%</td>
<td>0.018 (0.007)</td>
<td>11.8%</td>
</tr>
<tr>
<td>(\alpha_{8,k})</td>
<td>0.141 (0.065)</td>
<td>12.1%</td>
<td>0.012 (0.006)</td>
<td>8.2%</td>
</tr>
<tr>
<td>(\alpha_{9,k})</td>
<td>0.118 (0.057)</td>
<td>10.1%</td>
<td>0.007 (0.004)</td>
<td>4.3%</td>
</tr>
<tr>
<td>(\alpha_{10,k})</td>
<td>0.086 (0.044)</td>
<td>7.4%</td>
<td>0.000 (0.000)</td>
<td>5.2%</td>
</tr>
<tr>
<td>(\alpha_{11,k})</td>
<td>0.047 (0.025)</td>
<td>4.0%</td>
<td>0.256 (0.023)</td>
<td>12.374 (1.686)</td>
</tr>
<tr>
<td>(\alpha_{12,k})</td>
<td>0.141 (0.022)</td>
<td>0.134 (0.023)</td>
<td>2.9%</td>
<td></td>
</tr>
<tr>
<td>(\alpha_{13,k})</td>
<td>0.256 (0.023)</td>
<td>0.134 (0.023)</td>
<td>2.9%</td>
<td></td>
</tr>
<tr>
<td>(\alpha_{14,k})</td>
<td>12.374 (1.686)</td>
<td>0.141 (0.022)</td>
<td>2.5%</td>
<td></td>
</tr>
<tr>
<td>(\alpha_{15,k})</td>
<td>0.881</td>
<td>0.950</td>
<td>0.845</td>
<td></td>
</tr>
<tr>
<td>(\alpha_{16,k})</td>
<td>2.932</td>
<td>2.036</td>
<td>2.593</td>
<td></td>
</tr>
<tr>
<td>(\alpha_{17,k})</td>
<td>0.963</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| \(\alpha_{18,k}\) | Source: Author’s calculation.

Note: Standard errors are in parentheses.

4.3. Comparison of Annual Depreciation of R&D Capital

Hall (2007), and Lev and Sougiannis (1996), are modified in estimating Equations (10) and (16) in that firm dummies are included to control for firm effects.
Figure-1 shows how the R&D capital at period zero depreciates annually by using the market value (red line) and R&D-earnings (blue line) methods, and compares them with the conventionally accepted depreciation rate of 15 percent (green dotted line).

The estimated rates are found to be higher than 15 percent for all four industries, while the rates estimated by both methods follow a similar trend.

![Comparison of annual depreciation of R&D capital](image)

**Source:** Calculated and prepared by author.

**5. DISCUSSION**

In this paper, depreciation rates of R&D capital for Japanese firms in R&D-intensive industries are measured by using two methods with recent data. The estimated depreciation rates are found to be higher than the conventionally accepted 15 percent and the rates estimated by previous studies for Japanese firms, such as Goto *et al.* (1986). Since the depreciation rate reflects technological progress, rapid technological progress can be inferred especially for Japanese electric and electronic manufacturing firms.

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11 Estimated R&D depreciation rate for electric and electronic manufacturing firms also far exceed the rate estimated by the DBJ (2005) and Sakai (2013), while the estimated rate for other industries are around the upper limit of the results by these previous studies.

12 All the previous studies introduced in this paper on Japanese firms are using the data before the year 2000. Therefore, it can be inferred from our results that rapid technological progress occurs after the year 2000.
The Japanese government will replace the System of National Accounts (SNA) from ‘1993 SNA’ to ‘2008 SNA’ in 2016. According to this change, R&D expenditures will be capitalized,\(^{13}\) and the depreciation rate of R&D to estimate the R&D capital is necessary. Bureau of Economic Analysis (BEA) in U.S. Department of Commerce developed an R&D satellite account as a prelude to this change, and calculated R&D capital by using the R&D depreciation rate of 11 percent for chemicals and 15 percent for all other industries according to Mead (2007) which are far below the estimated result of this paper. In addition, there are no reasons to believe that the depreciation rates of R&D capital are identical by industries and will not change in the future. Applying the methods presented in this paper will be helpful to calculate the R&D capital correctly.

Two methods are used to estimate the depreciation rate of R&D capital in this paper. Each method is based on different assumptions and has different strengths and weaknesses. The first one is the market value method, which has a firm theoretical background. However, the assumptions for this method is strict. It assumes that financial market is efficient and that the firm can optimize its choice of R&D capital smoothly. If the adjustment cost in R&D capital is not negligible, then the method will not work well. The second one is the R&D-earnings method. It is intuitively comprehensible in that it focuses on the fundamental relation between R&D expenditures and subsequent benefits. However, it does not have a theoretical background. In addition, setting the reasonable length of lags in estimating Equation (16) is somewhat arbitrary.

Following two tasks remain to be solved for future research. Firstly, further test is needed for robustness checks based on the thorough review of other alternative methods. There are also other methods with different assumptions to estimate the rate of depreciation. Secondly, enlarge the sample size to unlisted firms is desirable. In this paper, we limit the sample to listed firms, while some unlisted small and medium-sized firms are actively promoting R&D.

6. ACKNOWLEDGEMENTS

I would like to thank Professor Hiroshi Teruyama of the Institute of Economic Research, Kyoto University, for especially helpful suggestions. All remaining errors are mine.

Appendix
Descriptive statistics

<table>
<thead>
<tr>
<th>1986 to 2010</th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>depreciation rate of physical capital</td>
<td>5.83%</td>
<td>0.88%</td>
<td>0.21%</td>
<td>13.85%</td>
<td>933</td>
</tr>
<tr>
<td>nominal physical capital (one mil. yen)</td>
<td>28,827.5</td>
<td>37,642.4</td>
<td>397.0</td>
<td>293,590.3</td>
<td>979</td>
</tr>
<tr>
<td>nominal R&amp;D capital (one mil. yen)</td>
<td>53,412.2</td>
<td>90,651.6</td>
<td>4.4</td>
<td>806,987.4</td>
<td>979</td>
</tr>
<tr>
<td>Q</td>
<td>6.47</td>
<td>4.64</td>
<td>0.02</td>
<td>21.62</td>
<td>926</td>
</tr>
<tr>
<td>real operating income (one mil. yen)</td>
<td>35,275.4</td>
<td>65,999.8</td>
<td>-638.4</td>
<td>578,154.6</td>
<td>848</td>
</tr>
<tr>
<td>real tangible fixed assets (one mil. yen)</td>
<td>23,997.3</td>
<td>31,009.2</td>
<td>1.1</td>
<td>322,428.6</td>
<td>1,133</td>
</tr>
<tr>
<td>real advertisement expenses (one mil. yen)</td>
<td>2,956.6</td>
<td>4,323.1</td>
<td>1.7</td>
<td>32,908.7</td>
<td>927</td>
</tr>
<tr>
<td>real R&amp;D expenditure (one mil. yen)</td>
<td>13,763.1</td>
<td>29,390.8</td>
<td>0.9</td>
<td>280,748.8</td>
<td>1,028</td>
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</tbody>
</table>

\(^{13}\) R&D expenditures are treated as intermediate consumption in the 1993 SNA.
2. Electric and electronic manufacturing

<table>
<thead>
<tr>
<th>1986 to 2010</th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>depreciation rate of physical capital</td>
<td>6.51%</td>
<td>0.92%</td>
<td>4.72%</td>
<td>13.72%</td>
<td>5,032</td>
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<tr>
<td>nominal physical capital (one mil. yen)</td>
<td>58,934.1</td>
<td>203,389.8</td>
<td>61.7</td>
<td>1,891,353.0</td>
<td>5,723</td>
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<tr>
<td>nominal R&amp;D capital (one mil. yen)</td>
<td>45,499.9</td>
<td>196,881.9</td>
<td>2.7</td>
<td>1,905,625.0</td>
<td>4,724</td>
</tr>
<tr>
<td>Q</td>
<td>3.43</td>
<td>2.81</td>
<td>0.00</td>
<td>13.00</td>
<td>4,545</td>
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<tr>
<td>real operating income (one mil. yen)</td>
<td>18,789.7</td>
<td>63,079.0</td>
<td>-43,339.9</td>
<td>821,238.8</td>
<td>3,914</td>
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<tr>
<td>real tangible fixed assets (one mil. yen)</td>
<td>24,013.0</td>
<td>74,754.9</td>
<td>0.8</td>
<td>895,604.8</td>
<td>6,068</td>
</tr>
<tr>
<td>real advertisement expenses (one mil. yen)</td>
<td>1,157.0</td>
<td>4,966.5</td>
<td>0.6</td>
<td>89,300.0</td>
<td>4,822</td>
</tr>
<tr>
<td>real R&amp;D expenditure (one mil. yen)</td>
<td>7,488.4</td>
<td>29,265.0</td>
<td>0.6</td>
<td>295,877.6</td>
<td>4,756</td>
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</table>

3. Chemical

<table>
<thead>
<tr>
<th>1986 to 2010</th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>depreciation rate of physical capital</td>
<td>7.00%</td>
<td>0.72%</td>
<td>4.86%</td>
<td>10.65%</td>
<td>4,197</td>
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<tr>
<td>nominal physical capital (one mil. yen)</td>
<td>27,494.7</td>
<td>55,820.1</td>
<td>0.6</td>
<td>555,396.0</td>
<td>4,571</td>
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<tr>
<td>nominal R&amp;D capital (one mil. yen)</td>
<td>15,644.9</td>
<td>41,185.7</td>
<td>0.5</td>
<td>483,894.9</td>
<td>3,651</td>
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<tr>
<td>Q</td>
<td>2.50</td>
<td>1.64</td>
<td>0.10</td>
<td>6.79</td>
<td>3,353</td>
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<tr>
<td>real operating income (one mil. yen)</td>
<td>14,705.4</td>
<td>33,096.7</td>
<td>-1,241.9</td>
<td>274,977.1</td>
<td>2,700</td>
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<tr>
<td>real tangible fixed assets (one mil. yen)</td>
<td>33,496.2</td>
<td>63,699.2</td>
<td>1.2</td>
<td>535,629.8</td>
<td>4,576</td>
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<tr>
<td>real advertisement expenses (one mil. yen)</td>
<td>1,590.3</td>
<td>6,478.1</td>
<td>0.8</td>
<td>69,232.9</td>
<td>3,370</td>
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<tr>
<td>real R&amp;D expenditure (one mil. yen)</td>
<td>3,574.1</td>
<td>8,993.2</td>
<td>0.8</td>
<td>96,399.9</td>
<td>3,572</td>
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</table>

4. Machinery

<table>
<thead>
<tr>
<th>1986 to 2010</th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>depreciation rate of physical capital</td>
<td>6.86%</td>
<td>0.26%</td>
<td>6.16%</td>
<td>7.30%</td>
<td>7,414</td>
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<tr>
<td>nominal physical capital (one mil. yen)</td>
<td>40,349.8</td>
<td>165,890.2</td>
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<td>3,387,446.0</td>
<td>8,572</td>
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<tr>
<td>nominal R&amp;D capital (one mil. yen)</td>
<td>14,254.2</td>
<td>98,132.0</td>
<td>1.2</td>
<td>2,953,277.0</td>
<td>6,290</td>
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<tr>
<td>Q</td>
<td>2.34</td>
<td>1.59</td>
<td>0.03</td>
<td>6.32</td>
<td>5,751</td>
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<tr>
<td>real operating income (one mil. yen)</td>
<td>11,819.0</td>
<td>41,610.0</td>
<td>-55,174.4</td>
<td>852,088.9</td>
<td>4,573</td>
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<tr>
<td>real tangible fixed assets (one mil. yen)</td>
<td>29,737.3</td>
<td>96,152.3</td>
<td>1.8</td>
<td>1,410,652.0</td>
<td>8,570</td>
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<td>real advertisement expenses (one mil. yen)</td>
<td>1,275.5</td>
<td>6,549.4</td>
<td>0.9</td>
<td>113,333.1</td>
<td>6,589</td>
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<td>real R&amp;D expenditure (one mil. yen)</td>
<td>3,137.9</td>
<td>21,677.0</td>
<td>0.9</td>
<td>555,302.9</td>
<td>5,947</td>
</tr>
</tbody>
</table>

Note: Nominal R&D capital is used in Equation (10). So, it is calculated by using the depreciation rate of 15 percent.

REFERENCES


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