International Journal of Finance and Accounting 2016, 5(5A): 49-58
DOI: 10.5923/s.ijfa.201601.04

Empirical Research on Depreciation of Business R&D Capital

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Abstract The Japanese Government is planning to change the estimation methods of the Japanese System of National Accounts (JSNA) in 2016, from the 1993 System of National Accounts (SNA) to the 2008 SNA. Following this change, research and development (R&D) expenditures will be counted as investments, and will be capitalized in GDP account. To capitalize R&D expenditures, we need to estimate R&D capital stock; hence, the methods of estimating R&D depreciation rates are critical. Consequently, this paper investigates R&D depreciation in the JSNA based on the methodology developed by Li (2012a). By adopting Li's model and using data on industry outputs and R&D investments from Japan, we estimate R&D depreciation rates for 20 Japanese industries. Our estimates are consistent with the results of prior studies and recent survey results reported by Miyagawa et al. (2014).

Keywords Intellectual property product, Intangible asset, Research and development, Depreciation rate

1. Introduction

Numerous economists have recognized the importance of intangible capital for a country's economic growth. Corrado et al. (2009) point out that, in the U.S.A., the contribution of intangible capital to economic growth has been on par with that of tangible capital after the 1990s. Moreover, McGrattan and Prescott (2010) include intangible capital in a standard real business cycle model, and the modifications to the model improve business cycle accounting for the U.S.A.

In response to these research trends, the United Nations Statistical Commission formulated a new System of National Accounts (SNA) standard, the 2008 SNA, to replace the 1993 SNA. One major feature of the 2008 SNA is that it provides guidelines on measuring the investment and stocks of intangible capital. Particularly, it includes research and development (R&D) expenses, which were mainly classified as intermediate consumption in the 1993 SNA, as investments that contribute to the knowledge stock. In July 2013, the U.S. Bureau of Economic Analysis (BEA) started capitalizing intellectual property investments, including R&D one. On the other hand, the European Union (EU) formulated the European System of Accounts 2010 (ESA 2010), which is consistent with the 2008 SNA, and all EU members began implementing the ESA 2010 in September 2014.

In Japan, the Department of National Accounts, Economic and Social Research Institute, Cabinet Office offers guidelines on how to prepare for the introduction of the 2008 SNA to the National Accounts of Japan in December 2016. Additionally, the Department of National Accounts published the "R&D Satellite Account" in 2011 (DNA, 2011), which presents guidelines for Japan's survey on R&D and for preliminary estimation methods to measure R&D investments and capital in the Japanese SNA (JSNA)[1]. Although guidelines for data collection and measurement methods are included in this publication, Shigeno (2012) argues that three major challenges need to be addressed before R&D investments can be capitalized in the Japanese SNA. The first challenge is the availability of basic statistics related to R&D investments for quarterly and revised estimates. To address this challenge, Tonogi et al. (2014) suggested the basic statistics and estimation methods of quarterly and revised estimates. The second challenge is measuring the price deflator of R&D assets. However, the statistical agency plans to use cost price indices as basic statistics for the deflator. The third challenge estimating the depreciation rate of R&D assets.

When estimating R&D capital stock using real R&D

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Published online at http://journal.sapub.org/ijfa

[1] Miyagawa and Hisa (2013) estimate the intangible assets based on Japan Industrial Productivity (JIP) database.

investment data and the perpetual inventory method, R&D capital depreciation rate is the most important factor for determining the level of R&D capital stock. The "R&D Satellite Account" (DNA, 2011) calculates R&D capital stock using three sets of R&D depreciation rates: 11%, 15%, and the obsolescence rates, which vary across economic activities and are based on the survey results published by the National Institute of Science and Technology Policy in 1999(NISTEP, 1999). The first two depreciation rates (11% and 15%) are obtained from two previous studies on the U.S. R&D satellite account, Carson et al. (1994) and Mead (2007). In the U.S.A., the BEA adopted Li's (2012a) forward-looking profit model to estimate industry-specific depreciation rates for business R&D capital. The required data are industry output and R&D investments.

Therefore, for measuring R&D capital stock in the JSNA, we use Japanese data on industry-specific R&D investments and outputs, and we apply Li's (2012a) model to estimate Japan's industry-specific R&D depreciation rates. The data cover 20 industries, and the estimates are consistent with the recent survey results reported by Miyagawa et al. (2014).

2. Model for Implementing Forward-Looking R&D Investment

In this section, we describe Li's (2012a) forward-looking profit model and our modification of the estimation of one model parameter.

The profit function of a representative firm for R&D investment in period *t* is as follows:

$$\max_{\mathrm{RD}_t} \pi_t = -RD_t + E_t \sum_{j=0}^{J-1} \left[\frac{(q_{t+j}) I(RD_t)(1-\delta)^j}{(1+r)^j} \right],$$

where π_t is the term profit of the firm, RD_t is the R&D cost, q_{t+j} are the future sales in period *j*, r is the discount rate, and δ is the R&D depreciation rate. $I(\cdot)$ is the increase in a firm's profit rate due to the R&D investment in period *t*. R&D capital depreciates because its contribution to a firm's profit declines over time, and the rate of decline is δ. A profit-maximizing firm will choose an R&D investment amount that maximizes the sum of the discounted present value of future profits minus R&D costs in period *t*.

The increase in profit rate due to R&D investment is formulated as follows:

$$I(RD_t) = I_\Omega \left(1 - \exp\left(\frac{-RD_t}{\theta} \right) \right),$$

where I_Ω is the upper limit of the R&D contribution to the profit rate increase, and θ is the R&D scale adjustment parameter. The function satisfies the following properties: $I'(RD_t) > 0$; $I''(RD_t) < 0$; $I(0) = 0$; and $I(\infty) = I_\Omega$. Li's formulation (2012a) of the $I(\cdot)$ function is inspired by a similar approach in Cohen and Klepper (1996).

The first-order condition of the profit function is $\partial \pi_t / \partial \mathrm{RD_T} = 0$, that is,

$$\frac{\theta}{I_\Omega \exp\left(-\frac{RD_t}{\theta}\right)} = E_t \left[\sum_{j=0}^{J-1} \frac{(q_{t+j})(1-\delta)^j}{(1+r)^j} \right].$$

Assuming a sufficiently large projection period, J, the distance function for the estimation of δ can be specified as:

$$\min_{\delta} \sum_{t=1}^{T} \left[\frac{\theta}{I_\Omega \exp\left(-\frac{RD_t}{\theta}\right)} - \sum_{j=0}^{J-1} \frac{E_t(q_{t+j})(1-\delta)^j}{(1+r)^j} \right]^2 .$$

Since the distance function is non-linear, we solve the minimization problem using numerical nonlinear minimization techniques.

To solve the distance function numerically, we determine the values of r and I_Ω. First, we determine the strategy to evaluate the discount rate, *r*, which is an opportunity cost of R&D investment. Since tangible capital investment is considered an alternative investment opportunity for R&D investment, we adopt the average rate of return on tangible capital as the discount rate.

Second, we determine how to evaluate the upper limit of the R&D contribution to the profit rate increase (I_Ω). Following Li (2012a), we use the average rate of return on tangible capital.

Third, we define the strategy for evaluating the R&D scale adjustment parameter (θ). Since the R&D scale adjustment parameters vary by industry and period, we use the estimated time trends of the R&D investments for each industry.

In Li (2012a), the first-order time trend of the R&D investment of industry i is:

$$\log(\theta_t^i) = \log(\theta_{2000}^i) + \alpha \cdot t.$$

However, we use the second-order time trend of the R&D investment of industry *i*, which is formulated as:

$$\log(RD_t^i) = \beta_0^i + \beta_1^i \cdot t + \beta_1^i \cdot t^2 + \epsilon_t$$

The fitted values of the second-order time trend regression are adopted as θ_t^i in our study, to fit the hump-shaped time-series of Japan's R&D investments:

$$\log\left(\theta_t^i\right) = \beta_0 + \beta_1 \bullet t + \beta_1 \bullet t^2.$$

If we have data for RD_t and q_{t+j}, we can estimate the R&D depreciation rate and θ2000 using the estimated values of *r* and I_Ω.

3. Data

To estimate industry-level R&D depreciation rates by the model described in the previous section, we construct a dataset of sales and R&D investments of Japanese industries from the Scientific Research and Development Survey (SRD), conducted by the Statistics Japan and the Japan Industrial Productivity (JIP) Database and compiled by the Research Institute of Economy, Trade and Industry, Japan. The dataset is compiled based on the industry classification presented in Table 1.

Table 1. Industry Level Classification of Sales and R&D Data

Classification of Sales and R&D Data

This Research	SRD	JIP
Agriculture, forestry, and fishing	Agriculture, forestry, and fishing	Rice and barley Other crop farming Breeding animals and sericulture Agriculture services Forestry Fishing
Mining	Mining	Mining
Counstruction	Counstruction	Counstruction Public works construction
Food products and beverages	Food products and beverages	Livestock products Sea foods Grain cleaning and milling Other foods Feedstuff and organic fertilizer Drink Tobacco
Textile	Textile	Textile
Pulp and paper product	Pulp and paper product	Pulp and paper Paper products
Printing	Printing	Printing, plate making and bookbinding
Medicines	Medicines	Medicines
Chemicals	Chemicals	Chemical fertilizer Basic organic chemicals Basic inorganic chemicals Organic chemicals Chemical fiber Chemical final product
Petroleum and coal	Petroleum and coal	Petroleum Coal
Rubber products	Rubber products	Rubber products
Ceramic products	Ceramic products	Glass products Cement and cement products Pottery Other ceramics, stone and clay products
Steel	Steel	Pig iron and crude steel Other steel products
Non-steel	Non-steel	Non-steel and refining
Metal Products	Metal Products	Processed non-steel Metal products for construction and architecture Other steel metal products
Machinery	Mashinery Precision machinery	General industrial machinery Special industrial machinery Other general machinery office and service appliance Precision machinery
Electrical machinery	Electrical machinery	Heavy electrical machinery Consumer electronic appliance
Communications, electronic and electrical instruments	information and communications equipment electrical components/devices	computer and its attachment communication equipment Electronic applied device, electric measure Semiconductor element, integrated circuit Electronic device Other erectronic equipment
Transportation equipment industry	Automobile Other transportation equipment industry	Automobile Automobile parts and accessories Other transportation equipment industry
Transportation, communication, public interest business	Transportation, communication, publi	electric utility Gas and heat supply Water and sewer services Industry water supply Waste disposal

The time-series data of "Output" from the JIP database are sales, and "Intramural Expenditure on R&D" from the SRD are used to represent R&D investments during the period CY1970–CY2010 (41 years). Although the "Intramural Expenditure on R&D" data in the SRD are expressed on a financial-year basis, we transform it into calendar-years (CY) using the linear interpolation method. As such, we use the GDP deflator to deflate sales and R&D investments and obtain real values. Tables 2 and 3 show the summary statistics for real sales and real R&D investments. Table 4 presents the summary of R&D intensities within the analyzed industries. As previously mentioned, the dataset contains 20 industries and covers a 41-year period. Subsequently, we calibrate the parameters and determine the estimation method of R&D depreciation.

Table 2. Summary of Industry Level Sales Data

Real Output

Variable	Obs	Mean	Std. Dev.	Min	Max
		Million Yen			
Agriculture, Forestry, and Fisheries	41	18,925,139	5,100,489	12,394,364	29,019,309
Mining and Quarrying of Stone and Gravel	41	2,306,218	968,872	1,047,658	4,119,899
Construction	41	75,756,450	10,790,812	59,573,658	97,807,049
Manufacture of Food	41	38,708,051	2,148,784	34,870,752	43,018,794
Manufacture of Textile Products	41	12,993,139	6,323,220	3,446,330	25,864,168
Manufacture of Pulp, Paper and Paper Products	41	9,431,824	1,237,453	7,142,576	12,948,975
Printing And Allied Industries	41	5,934,898	1,322,951	3,929,549	7,918,689
Manufacure of Medicines	41	5,732,705	1,060,568	3,842,071	7,352,334
Manufacture of Chemical and Allied Products	41	20,095,758	1,675,137	17,082,970	24,074,638
Manufacture of Petroleum and Coal Products	41	16,554,760	4,662,643	10,997,885	26,218,882
Manufacture of Rubber Products	41	3,174,112	263,317	2,479,192	3,722,994
Manufacture of Ceramic, Stone and Clay Products	41	9,502,434	1,589,279	5,937,423	11,952,414
Manufacture of Iron and Steel	41	29,474,553	9,349,415	15,686,852	47,610,915
Manufacture of Non-Ferrous Metals and Products	41	2,214,116	732,216	1,297,003	3,686,988
Manufacture of Fabricated Metal Products	41	19,794,128	2,724,338	14,827,322	25,068,750
Manufacture of General Machinery	41	30,533,508	4,525,914	22,259,344	40,842,381
Manufacture of Electrical Machinery	41	13,929,326	2,444,978	9,739,456	19,228,780
Manufacture of Electrical Equipment, Supplies and IC Equipment	41	26,898,409	9,884,889	10,151,689	40,848,789
Manufacture of Transportation Equipment	41	41,009,634	7,366,511	29,775,773	56,136,203
Transportation, IC, and Infrastructure	41	30,042,343	4,614,659	22,516,509	39,052,366

Data Source: RIETI "JIP Database". Sample Period: CY1970-2010.
Note: Real Output=Nominal Output/GDP Defrator.

Table 3. Summary of Industry Level R&D Investment Data

Real Intramental Expenditure on R&D (Cost)

Variable	Obs	Mean	Std. Dev.	Min	Max
		Million Yen			
Agriculture, Forestry, and Fisheries	41	5,756	1,985	2,440	10,026
Mining and Quarrying of Stone and Gravel	41	18,192	5,465	9,622	33,489
Construction	41	121,409	48,988	32,929	202,584
Manufacture of Food	41	164,643	79,858	48,905	314,222
Manufacture of Textile Products	41	62,018	28,495	25,954	140,021
Manufacture of Pulp, Paper and Paper Products	41	35,286	13,198	13,497	50,746
Printing And Allied Industries	41	22,438	13,799	4,539	48,092
Manufacure of Medicines	41	518,614	369,054	88,186	1,325,947
Manufacture of Chemical and Allied Products	41	648,557	226,361	280,238	891,911
Manufacture of Petroleum and Coal Products	41	48,829	17,825	14,143	80,370
Manufacture of Rubber Products	41	93,850	46,197	20,336	181,188
Manufacture of Ceramic, Stone and Clay Products	41	132,058	51,835	36,260	206,308
Manufacture of Iron and Steel	41	172,489	52,926	76,809	272,635
Manufacture of Non-Ferrous Metals and Products	41	102,708	45,933	35,443	176,559
Manufacture of Fabricated Metal Products	41	82,442	27,756	25,167	122,446
Manufacture of General Machinery	41	849,542	534,331	192,600	1,866,811
Manufacture of Electrical Machinery	41	697,816	315,415	216,142	1,089,221
Manufacture of Electrical Equipment, Supplies and IC Equipment	41	1,619,657	967,049	271,584	3,133,467
Manufacture of Transportation Equipment	41	1,160,355	658,984	200,085	2,485,681
Transportation, IC, and Infrastructure	41	249,311	129,462	71,913	511,213

Data Source: MIC "Survey of Scientific Research and Development". Sample Period: CY1970-2010.
Note: Real R&D=Nominal R&D/GDP Defrator.

Table 4. Summary of R&D Intensity

R&D Ratio

Variable	Obs	Mean	Std. Dev.	Min	Max
	R&D/Output (%)				
Agriculture, Forestry, and Fisheries	41	0.033	0.015	0.009	0.067
Mining and Quarrying of Stone and Gravel	41	0.948	0.448	0.294	1.749
Construction	41	0.158	0.051	0.050	0.225
Manufacture of Food	41	0.432	0.227	0.122	0.901
Manufacture of Textile Products	41	0.771	0.900	0.119	3.850
Manufacture of Pulp, Paper and Paper Products	41	0.393	0.181	0.123	0.656
Printing And Allied Industries	41	0.359	0.207	0.103	0.834
Manufacure of Medicines	41	8.279	4.764	1.991	19.050
Manufacture of Chemical and Allied Products	41	3.218	1.101	1.353	4.649
Manufacture of Petroleum and Coal Products	41	0.327	0.181	0.107	0.662
Manufacture of Rubber Products	41	3.007	1.613	0.646	6.785
Manufacture of Ceramic, Stone and Clay Products	41	1.463	0.645	0.325	2.573
Manufacture of Iron and Steel	41	0.663	0.292	0.170	1.163
Manufacture of Non-Ferrous Metals and Products	41	5.516	3.213	1.012	9.886
Manufacture of Fabricated Metal Products	41	0.426	0.147	0.106	0.616
Manufacture of General Machinery	41	2.707	1.648	0.657	6.911
Manufacture of Electrical Machinery	41	5.264	2.869	1.421	10.449
Manufacture of Electrical Equipment, Supplies and IC Equipment	41	5.465	2.190	1.805	10.585
Manufacture of Transportation Equipment	41	2.659	1.186	0.637	5.565
Transportation, IC, and Infrastructure	41	0.801	0.364	0.296	1.661

Note: R&D Ratio = Real Intramental Expenditure on R&D (Cost) / Real Output

4. Empirical Analysis

We estimate industry-specific R&D depreciation rates under two assumptions. First, we assume that the firms have perfect foresight in sales forecasting. Under this assumption, we can use R&D investment data for only 21 years (1970–1991) in our distance function data calculations because, in our estimation, the firm's prediction terms are considered to be for the subsequent 20 years. In the second setting, we assume that firms are supposed to forecast future sales with an autoregressive model. We generate 1,000 samples of the sales forecasts using stochastic simulations during the 1991–2030 period, and minimize the distance function using the 20-year sample period 1991–2010 to obtain the average and standard deviation of the R&D depreciation rates by industry. The second assumption is consistent with the method used by Li (2012a).

Before the estimation, we set θ_t^i (i.e., scale adjustment parameter). We use the second-order trend fitted value of R&D investment as θ_t^i, as described in the previous section. Figure 1 shows the trend and the actual industry R&D investment data.

First, we explain the estimation method for the perfect foresight assumption. When we calculate the distance function, we use the R&D investment data from 1970–1990 and the sales data from 1971–2010 as future sales expectations. That is, for calculating the first-order condition in 1970, we use the R&D investment data from 1970 and the sales data from 1971–1990, and for calculating the first-order condition in 1990, we use the R&D investment data from 1990 and the sales data from 1991–2010. After we set these data in the distance function, we estimate the depreciation rates so as to minimize the function. We use several calibrated parameters for I_Ω (i.e., upper limit of the contribution function) and r (i.e., discount rate of future sales) in the distance function. We also use several settings of I_Ω in our estimations because the upper limit of the contribution function is not available. It is possible that the average rate of return on all capitals in Japan ($I_\Omega = 0.06$) could be too low to serve as the upper limit of contribution for R&D investment. Therefore, we test the estimation with a higher upper limit of contribution, using the average rate of return on all capitals in the U.S.A. ($I_\Omega = 0.089$) and the average rate of tangible capital user cost in Japan ($I_\Omega = 0.098$). Furthermore, we test the estimation using actual time series for tangible capital user cost in Japan for the upper limit. We check the four cases for discount rates because the true discount rate is not identified. We report the estimated results in Table 5.

The estimates indicate that the R&D depreciation rates of R&D-intensive industries are lower than those of non-R&D-intensive industries. However, non-R&D-intensive industries have R&D depreciation rates above 0.5, which implies that service lives of the R&D assets in these industries are short. When both the discount rate and the upper bound of return rate are lower, the R&D depreciation rates are lower as well. Nonetheless, given the same discount rates, when the upper bound of the return rate is lower, the R&D depreciation rate is lower. With the standard setting of $I_\Omega = 0.06$ and $r = 0.06$, the R&D depreciation rates for R&D-intensive industries are in the range 0.19–0.61.

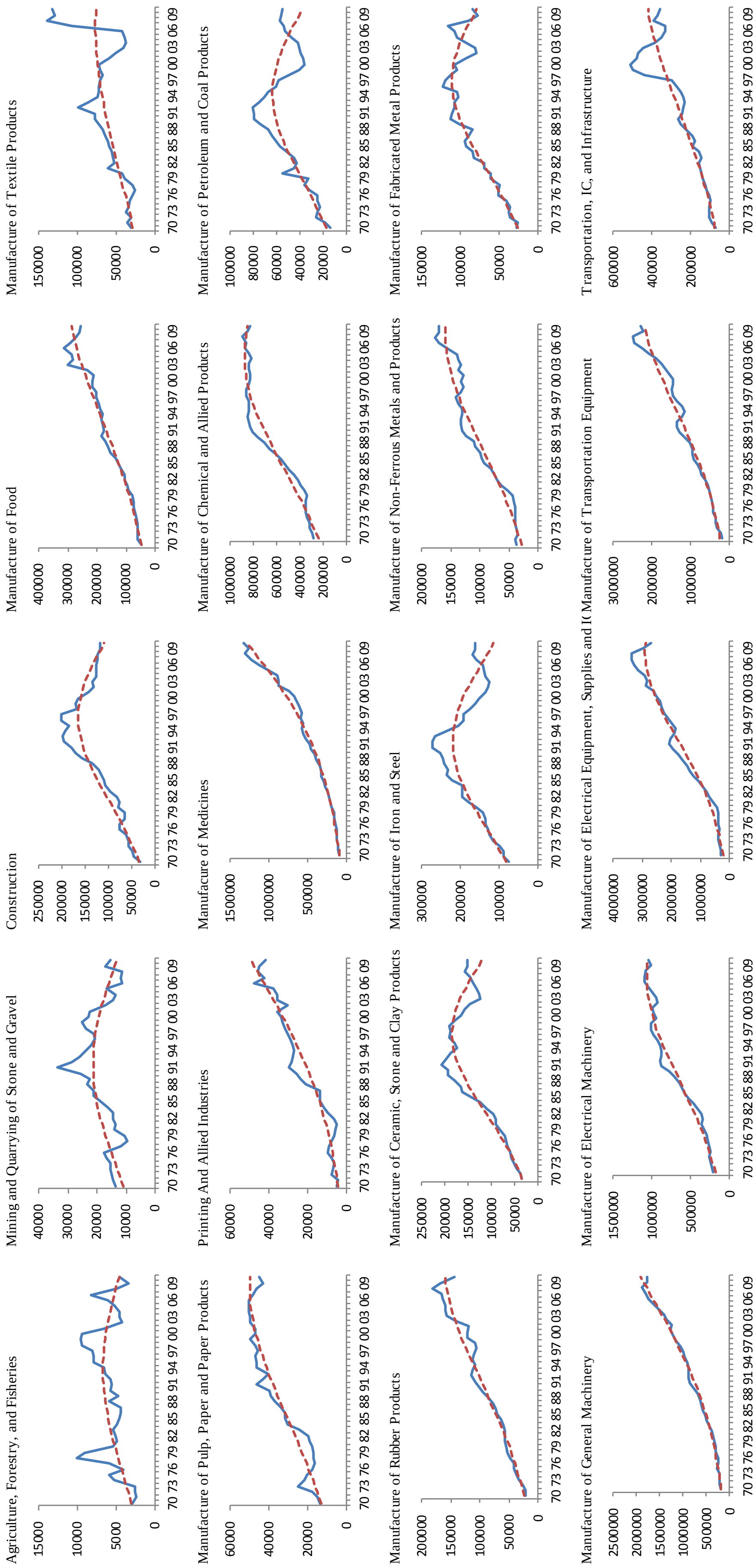

Figure 1. R&D Investment and Second-Order Time Trend

Table 5. Estimated Values of R&D Depreciation Rates (Perfect Foresight)

Estimated Value of R&D Depreciation Rate

	R&D Ratio	Depreciation Rate of R&D Capital Stock							
		Discount Rate	actual	0.089	0.060	0.098	actual	actual	actual
		Omega_I	actual	0.089	0.060	0.098	0.089	0.060	0.098
Agriculture, Forestry, and Fisheries	0.000		0.9896	0.9889	0.9840	0.990	0.989	0.983	0.990
Mining and Quarrying of Stone and Gravel	0.009		0.8209	0.8024	0.7373	0.816	0.799	0.726	0.815
Construction	0.002		0.9605	0.9576	0.9399	0.961	0.957	0.937	0.961
Manufacture of Food	0.004		0.9084	0.9024	0.8651	0.910	0.901	0.860	0.910
Manufacture of Textile Products	0.008		0.8876	0.8790	0.8343	0.888	0.878	0.828	0.888
Manufacture of Pulp, Paper and Paper Products	0.004		0.9082	0.9003	0.8623	0.908	0.899	0.857	0.908
Printing And Allied Industries	0.004		0.9267	0.9207	0.8896	0.927	0.920	0.885	0.927
Manufacure of Medicines	0.083		0.2517	0.2405	0.1892	0.254	0.239	0.166	0.259
Manufacture of Chemical and Allied Products	0.032		0.4778	0.4588	0.3736	0.480	0.455	0.353	0.481
Manufacture of Petroleum and Coal Products	0.003		0.9258	0.9207	0.8893	0.927	0.919	0.884	0.926
Manufacture of Rubber Products	0.030		0.5693	0.5544	0.4651	0.576	0.550	0.445	0.575
Manufacture of Ceramic, Stone and Clay Products	0.015		0.7069	0.6940	0.6114	0.712	0.689	0.595	0.711
Manufacture of Iron and Steel	0.007		0.7899	0.7787	0.7092	0.793	0.775	0.697	0.793
Manufacture of Non-Ferrous Metals and Products	0.055		0.3211	0.3048	0.2343	0.323	0.298	0.207	0.323
Manufacture of Fabricated Metal Products	0.004		0.8692	0.8621	0.8127	0.872	0.860	0.805	0.872
Manufacture of General Machinery	0.027		0.6105	0.5951	0.5074	0.616	0.592	0.491	0.617
Manufacture of Electrical Machinery	0.053		0.3252	0.3108	0.2450	0.328	0.308	0.222	0.332
Manufacture of Electrical Equipment, Supplies and IC Equipment	0.055		0.2692	0.2574	0.2073	0.271	0.256	0.185	0.276
Manufacture of Transportation Equipment	0.027		0.5319	0.5178	0.4313	0.539	0.515	0.412	0.541
Transportation, IC, and Infrastructure	0.008		0.7979	0.7858	0.7189	0.800	0.784	0.709	0.801

Sample: Output (1): 1971-2010, R&D: 1970-1990, Return Rate: 1970-2010

Note: (1) We assume the perfect foresight in the expectation in the period from 1991-2010.

(2) Discount rate, 0.060 , comes from the estimated internal rate of return by Dvision of National Accounts in CAO, Japan.

(3) Discount rate, 0.089 , comes from the capital return rate in Li (2010).

(4) Discount rate, 0.098 , comes from the average the estimation of net tangible capital return using constant depreciation rate, 0.0735.

(5) Discount rate, actural , comes from the estimation of net tangible capital return using constant depreciation rate, 0.0735.

Table 6. Estimated Values of R&D Depreciation Rates (Stochastic Simulation)

Estimated Value of R&D Depreciation Rate (Stochastic Simulation)

	R&D Ratio	Depreciation Rate of R&D Capital Stock						
		Discount Rate	0.089		0.060		0.098	
		Omega_I	0.089		0.060		0.098	
			average	std	average	std	average	std
Agriculture, Forestry, and Fisheries	0.000		0.9847	0.0003	0.9781	0.0004	0.9860	0.0002
Mining and Quarrying of Stone and Gravel	0.009		0.6590	0.0087	0.5699	0.0098	0.6792	0.0085
Construction	0.002		0.9349	0.0033	0.9080	0.0046	0.9400	0.0029
Manufacture of Food	0.004		0.8290	0.0024	0.7703	0.0029	0.8416	0.0023
Manufacture of Textile Products	0.008		0.7653	0.0110	0.6919	0.0134	0.7818	0.0107
Manufacture of Pulp, Paper and Paper Products	0.004		0.8402	0.0028	0.7845	0.0036	0.8523	0.0026
Printing And Allied Industries	0.004		0.8570	0.0085	0.8060	0.0109	0.8676	0.0075
Manufacure of Medicines	0.083		0.1616	0.0055	0.1165	0.0043	0.1740	0.0057
Manufacture of Chemical and Allied Products	0.032		0.3677	0.0092	0.2854	0.0080	0.3896	0.0093
Manufacture of Petroleum and Coal Products	0.003		0.8646	0.0067	0.8153	0.0084	0.8749	0.0062
Manufacture of Rubber Products	0.030		0.3798	0.0094	0.2967	0.0082	0.4015	0.0093
Manufacture of Ceramic, Stone and Clay Products	0.015		0.5713	0.0084	0.4785	0.0085	0.5938	0.0083
Manufacture of Iron and Steel	0.007		0.7350	0.0053	0.6566	0.0062	0.7522	0.0052
Manufacture of Non-Ferrous Metals and Products	0.055		0.1666	0.0046	0.1190	0.0036	0.1801	0.0045
Manufacture of Fabricated Metal Products	0.004		0.8296	0.0075	0.7709	0.0095	0.8421	0.0071
Manufacture of General Machinery	0.027		0.4100	0.0147	0.3242	0.0132	0.4315	0.0146
Manufacture of Electrical Machinery	0.053		0.2926	0.0193	0.2227	0.0160	0.3107	0.0203
Manufacture of Electrical Equipment, Supplies and IC Equipment	0.055		0.3355	0.0212	0.2670	0.0184	0.3559	0.0222
Manufacture of Transportation Equipment	0.027		0.4271	0.0090	0.3419	0.0081	0.4502	0.0092
Transportation, IC, and Infrastructure	0.008		0.7319	0.0067	0.6542	0.0074	0.7495	0.0063

Sample: Output (1): 1991-2010, R&D: 1991-1990, Return Rate: 1991-2010

Note: (1) We assume that AR(1) forecast in the expectation in the period from 1991-2030.

(2) Discount rate, 0.060 , comes from the estimated internal rate of return by Dvision of National Accounts in CAO, Japan.

(3) Discount rate, 0.089 , comes from the capital return rate in Li (2010).

(4) Discount rate, 0.098 , comes from the average the estimation of net tangible capital return using constant depreciation rate, 0.0735.

Table 7. Comparison of Estimated R&D Depreciation Rate and Inverse of Surveyed Duration

Compearing Estimated R&D Depreciation Rate and Inverse of Surveyed Duration

Industry	R&D Ratio	Perfect foresight	Stochastic simulation	Miyagawa et.al (2014)
Agriculture, Forestry, and Fisheries	0.000	0.9840	0.9781	
Mining and Quarrying of Stone and Gravel	0.009	0.7373	0.5699	
Construction	0.002	0.9399	0.9080	0.1685
Manufacture of Food	0.004	0.8651	0.7703	0.2289
Manufacture of Textile Products	0.008	0.8343	0.6919	0.1540
Manufacture of Pulp, Paper and Paper Products	0.004	0.8623	0.7845	0.1951
Printing And Allied Industries	0.004	0.8896	0.8060	0.1584
Manufacure of Medicines	0.083	0.1892	0.1165	0.1434
Manufacture of Chemical and Allied Products	0.032	0.3736	0.2854	0.1434
Manufacture of Petroleum and Coal Products	0.003	0.8893	0.8153	
Manufacture of Rubber Products	0.030	0.4651	0.2967	
Manufacture of Ceramic, Stone and Clay Products	0.015	0.6114	0.4785	0.1932
Manufacture of Iron and Steel	0.007	0.7092	0.6566	0.2857
Manufacture of Non-Ferrous Metals and Products	0.055	0.2343	0.1190	0.2065
Manufacture of Fabricated Metal Products	0.004	0.8127	0.7709	0.1921
Manufacture of General Machinery	0.027	0.5074	0.3242	0.1714
Manufacture of Electrical Machinery	0.053	0.2450	0.2227	0.2028
Manufacture of Electrical Equipment, Supplies and IC Equipment	0.055	0.2073	0.2670	0.2028
Manufacture of Transportation Equipment	0.027	0.4313	0.3419	0.1818
Transportation, IC, and Infrastructure	0.008	0.7189	0.6542	0.5333

Second, we explain the estimation method for the simulated sales assumption. When we calculate the distance function, we use R&D investment data for 1991–2010 and stochastically simulated sales data for 1991–2030 as future sales expectations. Firms forecast future sales using the time trend and autoregressive structure of cyclical terms of sales. As such, we estimate the time trend of sales data using the second-order polynomial from the full data of sales (CY1970–CY2010); subsequently, we estimate an AR(1) model from the de-trend sales data (CY1970–CY2010). We assume that firms know the time trend, the AR(1) parameter, and the innovation variance. We generate 1,000 simulated paths from CY1991 to CY2030 per industry, and we use these paths to calculate the distance function. After we set these data in the distance function, we estimate the depreciation rates so as to minimize the distance function. We also use several calibrated parameters for I_Ω (i.e., upper limit of the contribution function) and r (i.e., discount rate) in the distance function. The estimated results are reported in Table 6.

The estimated R&D depreciation rates based on the stochastic simulation method are generally lower than those in Table 5. The estimated R&D depreciation rates for R&D-intensive industries are in the 0.12–0.48 range in the standard setting of $I_\Omega = 0.06$ and $r = 0.06$. We infer that the differences are mainly because of the difference in the sample periods. Despite differences in the level of R&D depreciation rates for the perfect foresight method and that of the stochastic simulation method, their values are similar in both estimates.

Miyagawa et al. (2014) conduct an R&D survey on Japanese firms and report that scientific R&D service lives are between two and seven years. If the inverse of the duration is interpreted as depreciation rate, the implied R&D depreciation rates would be between 14% and 50%, approximately. Table 7 presents the industry level comparison of the estimated R&D depreciation rates based on the stochastic simulation method, and the implied ones based on the Miyagawa et al. (2014) survey. The relative industry rankings in terms of the corresponding R&D depreciation rates are similar for the two methods.

5. Conclusions

In this study, we adopt the forward-looking profit model of Li (2012a), and use Japanese data on industry R&D investments and outputs to estimate industry-specific R&D depreciation rates for 20 industries. Our estimates are consistent with the results of previous studies (Hachiya, 2005; NISTEP, 1999)[2] and the recent survey results reported by Miyagawa et al. (2014). As such, the estimated R&D depreciation rates for non-R&D-intensive industries are greater than 0.5. The relatively higher R&D depreciation rates for non-R&D-intensive industries may reflect the fact that firms in these industries cannot better appropriate the returns from their R&D investments compared to their

[2] Hachiya (2005) estimates the business R&D depreciation rate to be 20.2%, based on the survey in NISTEP (1985), by considering a scrap value. NISTEP (1999) reports that the average profit duration of business R&D is 8.7 years, based on a survey of 515 firms.

counterparts in R&D-intensive industries. The estimated R&D depreciation rates for R&D-intensive industries are in the 0.12–0.48 range; these rates are not very different from the U.S. R&D depreciation rates estimated based on Li's model (2012a). These results could indicate that Japanese and U.S. high-tech firms have similar technological competitiveness. Additionally, the abilities of these firms to appropriate the returns from their investments in R&D are similar across industries.

Moreover, since most previous econometric models cannot provide a good methodology for estimating R&D depreciation rates, the OECD Intellectual Property Product manual (OECD 2010) recommends the use of expert opinions or surveys to estimate R&D depreciation rates (Peleg, 2008). On one hand, the fidelity of past surveys has been seriously questioned. For example, a large-scale survey of 39,968 U.S. firms conducted in 2010 received an extremely low response rate (2.45%) (Li, 2012b), while a U.K. survey of 1,701 firms conducted in 2012 showed very high uncertainty (Ker, 2014). Expert opinions, on the other hand, can vary significantly, and no known method can reconcile these differences. Therefore, neither suggested methods can provide a true solution. Given these difficulties, the OECD (2010) further suggests that a single average service life of 10 years should be retained if no good solution can be found. This implies that both developed and emerging countries have the same R&D productivity growth, which contradicts common sense. Moreover, it is incorrect to assume that all countries and industries have the same technological progress pace. Therefore, in this paper, we applied Li's model (2012a) and uses data from Japan to estimate the R&D depreciation rates for 20 Japanese industries. The estimates we obtain are consistent with industry observations and results of past studies.

There are several tasks that need to be analyzed in future research. In this paper, we assume that R&D investments affect current and future sales. Generally, R&D investments are assumed to affect added value or profit because they are implemented in order to cut costs rather than increase sales. As such, further consideration of firm expectations may be required. We use actual data in the perfect foresight case as expected sales and simulated data in the stochastic simulation case. However, the R&D depreciation rate estimated with the forward-looking model might be far from actual expectations of Japanese firms. To validate the results, future research could use the survey of the expectations of firms. Furthermore, the functional form of sales contribution needs to be examined. The functional form of sales contribution in this research is a hypothetical one. As such, the relation between R&D investments and future sales or profit needs to be investigated using firm micro data (such as financial statements).

ACKNOWLEDGEMENTS

The authors would like to thank Tsutomu Miyagawa and the participants of the ESRI Seminar from February 18, 2015 for their helpful comments. This research is financially supported by the Grant-in-Aid for Research Activity Start-up (Research Project Number: 25885032).

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