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Empirical Analysis and Economic Implication for Optimal R&D Investment Control

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Abstract

Some new methodologies are developed to measure the core factors in the optimal R&D investment control model. By utilizing the developed approach, evaluation of R&D intensity in major Japanese manufacturing sectors is conducted by comparing optimal and actual levels identifying "pseudo innovation" in high-technology and its sources.

1. Introduction

R&D investment decision making has become a crucial issue in the era of mega-competition. In the first one of these dual papers, a model for identifying an optimal R&D investment is developed on the basis of the observation of structural change in Japan's techno-economic behavior. After the model is constructed and the analytic optimal solution is obtained, the key process of this research moves to the measurement of core factors in the model and to the empirical application of the model to actual industry.

In this paper, section 2 develops the measuring approaches for core factors in the optimal R&D investment control. Section 3 conducts the evaluation of R&D intensity in Japan's major manufacturing industries by comparing optimal and actual level. Section 4 briefly summarizes the conclusions.

2. Measurement of Core Factors of the Optimal R&D Investment Control Model

As developed in the first one of these dual papers, the optimal R&D intensity can be obtained by solving the optimal R&D control model:

$$\frac{r}{y}=\frac{1}{\varepsilon-1+(\beta_1+\beta_2)}\cdot\frac{\eta}{g}\approx\frac{\eta}{\varepsilon g} \qquad (1)[1]$$

Equation (1) suggests that the optimal R&D intensity depends on the elasticity of substitution ε, the discount rate η and the discounted marginal productivity of technology g, and its level increases as ε and g decrease and η increases.

[1] Empirical analysis on the invention of innovative goods in the Japanese manufacturing industry over the period 1975-1996 demonstrates $\beta_1+\beta_2\approx 1$.

2.1 Measurement of the Elasticity of Substitution

Under the condition of the equilibrium between demandand supply, the elasticity of substitution measured by demand-side factors (e.g. substitution between innovative goods) could be interpreted by the elasticity of substitution measured by supply-side factors (e.g. substitution among production factors) (see [1]). Given that production is represented by GDP (value added), the substitution elasticity should be between labor, capital and technology. By using a technology incorporation model to treat technology *(T)* embodied in labor *(L)* and capital *(K)*, the substitution elasticity could be treated as a bilateral substitution issue only between labor and capital $\varepsilon(K(T), L(T))$ (see [7]).

On the basis of technology incorporated production function, the elasticity of substitution between capital $K(T)$ and labor $L(T)$ can be formulated as follow:

$$\varepsilon=\frac{d\ln\frac{K(K',T)}{L(L',T)}}{d\ln\frac{P_l}{P_k}} \qquad (2)$$

$$=\left[\left(\frac{\partial\ln K(K',T)}{\partial\ln T}\right)\left(\frac{d\ln T}{d\ln\frac{P_l}{P_k}}\right)-\left(\frac{\partial\ln K(K',T)}{\partial\ln K'}\right)\left(\frac{d\ln K'}{d\ln P_k}\right)\right]$$

$$-\left[\left(\frac{\partial\ln L(L',T)}{\partial\ln T}\right)\left(\frac{d\ln T}{d\ln\frac{P_l}{P_k}}\right)+\left(\frac{\partial\ln L(L',T)}{\partial\ln L'}\right)\left(\frac{d\ln L'}{d\ln P_l}\right)\right]$$

where

L':	labor without technology incorporation;
K':	capital without technology incorporation;
P_l:	price of labor; and
P_k:	price of capital.

Following regression equations are used to measure the different terms in equation (2):

$$\ln(T/L) = a_{l0} + b_{l1}\ln T + b_{l2}\ln(P_l/P_{t0}) \qquad (3)$$

$$\ln(T/K) = a_{k0} + b_{k1}\ln T + b_{k2}\ln(P_k/P_{t0}) \qquad (4)$$

$$\ln(GLC/GTC) = b'_{l3} + b'_{l4}\ln T \qquad (5)$$

$$\ln(GCC/GTC) = b'_{k3} + b'_{k4}\ln T \qquad (6)$$

$$\ln(P_l(T)/P_k(T)) = h + i\ln T \qquad (7)$$

where

P_{t0}:	price of technology;
GLC:	gross labor cost;
GCC:	gross capital cost; and
GTC:	gross technology cost.

2.2 Measurement of the Discounted Marginal Productivity of Technology

In case using value-added (V) as production output, the discounted marginal productivity of technology *(g)* can be formulated as follows:

$$g \equiv p - q \tag{8}$$

$$p = \sum_{L,K} \frac{\partial V}{\partial X'} \cdot \frac{\partial X_T}{\partial T} \tag{9}$$

$$q = \frac{\partial V}{\partial T} \text{ (marginal productivity of technology)} \tag{10}$$

where X' are L' and K'; and X_T are L_T (labor for technology) and K_T (capital stock for technology).

In order to measure the discounted marginal productivity of technology, it is requested to simultaneously solve the following equations (11), (12) and (13) in advance (see [6]):

$$P_t = (1 - gs) \cdot [(Rls \cdot Dl + Rms \cdot Dm + Res \cdot De) + Rks \cdot Dk \cdot (\bar{r} + \rho)/(1 - ct)] \tag{11}$$

$$\frac{\partial V}{\partial T} = \frac{GTC \cdot (P'_t / P_t)}{GLC + GCC + GTC \cdot (P'_t / P_t)} \cdot \frac{V}{T} \tag{12}$$

$$e^{mr} = \int_0^{\infty} \frac{\partial V}{\partial T} e^{-(\bar{r}+\rho)} dt = \frac{\partial V}{\partial T} / (\bar{r} + \rho) \tag{13}$$

where

P_t: service price of technology;

P'_t: capital price of technology;

Rls, Rks, Rms and Res: shares of R&D expenditures for labor costs, tangible fixed assets, materials, and energy respectively;

Dl, Dk, Dm and De: wage index, investment goods deflator, wholesale price indices of materials and energy respectively;

gs: ratio of government financial support;

ct: ratio of corporate tax; and

$\bar{r}$: rate of internal return to R&D investment;

m: time-lag from R&D to commercialization; and

ρ rate of obsolescence of technology.

Assume that factor input directing to R&D *($X_T = L_T$, K_T, M_T, E_T)* which composes T and consists of labor, capital, materials and energy takes similar marginal productivity as production factors at the initial year. By introducing price indices D_V, D_X, D_T (here D_T is equal to P_t) and D_{XT} (initial year =1) corresponding to V, X, T and X_T, finally we can develop equation (9) into equation (14):

$$p \approx \sum_{L,K} \frac{D_X}{D_V} \cdot \frac{D_T}{D_{XT}} \cdot \frac{P_{y0}}{P_{V0}} \tag{14}$$

As shown in equation (10), term q is exactly the marginal productivity of technology. The discounted marginal productivity of technology (g) can be obtained from the balance of term p and q.

2.3 Measurement of the Composite Discount Rate

Normally the discount rate was treated as the average rate of bank loans. However, in recent years there is an argument to introduce weighted average capital cost for discount rate (e.g. [5]). Stimulated by this argument an attempt to introduce composite discount rate was conducted. Composite discount rate η can be measured by the following equation:

$$\eta = r_1 \cdot w_1 + r_2 \cdot w_2 / (1 - Tax) + r_3 \cdot w_3 \tag{15}$$

where

r_1 interest rate (average rate of bank loans);

r_2 real dividend yield (= $DIVD/(CAP+CAPRV)$);

r_3 risk free rate (government bond yield);

w_1 the share of interest-bearing liabilities to gross assets (= LI/GA);

w_2 the share of capital stock and capital reserve to gross assets (=$(CAP+CAPRV)/GA$);

w_3 the share of the other reserves to gross assets (=PS/GA);

Tax corporate tax rates;

DIVD dividend;

CAP capital stock;

CAPRV capital reserve;

LI interest-bearing liabilities;

SE shareholders' equity;

PS the other reserves (= $SE-CAP-CAPRV$); and

GA gross assets (= $LI + CAP + CAPRV + PS = LI+SE$).

Our analysis demonstrates that the composite discount rate introduced here seems to reflect the reactions of respective sector's behavior in the market.

3. Empirical Analysis and Evaluation of the Results

3.1 Results of Empirical Analyses

On the bases of the measurement of core factors (elasticity of substitution, discounted marginal productivity of technology, and composite discount rate), **Table 1** evaluates the optimal R&D intensity of Japan's manufacturing industry (manufacturing average (MA), food (FD), chemicals (CH) and electrical machinery (EM)) over the last two decades (1975-1996). The evaluation is conducted by dividing the period of the analysis into five periods: 1975-1978 (after the first energy crisis and before the second energy crisis); 1979-1982 (after the second energy crisis and before the fall of international oil prices); 1983-1986 (after the fall of international oil prices and before the bubble economy); 1987-1990 (during the period of the bubble economy); and 1991-1996 (after the bursting of the bubble economy). In addition to R&D intensity using the 1990 fixed prices, the nominal value (current prices) of optimal R&D intensity is also calculated.

Table 1 Optimal R&D Intensity in Major Japanese Manufacturing Sectors (1975-1996)

				1975-78	1979-82	1983-86	1987-90	1991-96
MA		η	(%)	8.45	8.55	7.21	6.11	4.70
		ε		1.01	1.01	1.01	0.71	0.42
		g		1.05	1.23	1.23	1.20	1.42
	1990	$(r/V)_{opt.}$	(%)	7.97	6.88	5.80	7.17	7.88
	prices	$(r/V)_{act.}$	(%)	*4.36*	*4.72*	*5.90*	*6.77*	*6.91*
	Current	$(r/V)_{opt.}$	(%)	6.15	6.05	5.34	6.87	8.20
	prices	$(r/V)_{act.(m)}$	(%)	*3.36*	*4.15*	*5.43*	*6.49*	*7.19*
FD		η	(%)	9.12	8.94	7.58	6.02	4.60
		ε		0.69	0.69	0.691	0.59	0.41
		g		2.41	2.55	2.31	1.90	2.13
	1990	$(r/V)_{opt.}$	(%)	5.48	5.07	4.75	5.33	5.32
	prices	$(r/V)_{act.}$	(%)	*0.75*	*0.84*	*1.09*	*1.67*	*1.64*
	Current	$(r/V)_{opt.}$	(%)	6.18	6.10	5.04	5.13	5.05
	prices	$(r/V)_{act.}$	(%)	*0.85*	*1.01*	*1.16*	*1.60*	*1.56*
CH		η	(%)	8.45	8.49	6.96	6.14	4.76
		ε		1.31	1.31	1.31	1.12	0.63
		g		0.34	0.51	0.63	0.67	0.87
	1990	$(r/V)_{opt.}$	(%)	18.97	12.71	8.43	8.18	8.68
	prices	$(r/V)_{act.}$	(%)	*18.28*	*15.78*	*15.14*	*15.26*	*14.14*
	Current	$(r/V)_{opt.}$	(%)	9.24	8.13	6.88	7.47	9.73
	prices	$(r/V)_{act.}$	(%)	*8.90*	*10.09*	*12.35*	*13.94*	*15.84*
EM		η	(%)	8.87	8.93	7.30	5.95	4.62
		ε		1.69	1.69	1.69	1.65	0.57
		g		0.18	0.27	0.30	0.42	0.81
	1990	$(r/V)_{opt.}$	(%)	29.16	19.57	14.40	8.59	10.01
	prices	$(r/V)_{act.}$	(%)	*33.93*	*23.70*	*20.59*	*17.35*	*12.95*
	Current	$(r/V)_{opt.}$	(%)	8.02	8.92	9.03	7.54	13.23
	prices	$(r/V)_{act.}$	(%)	*9.33*	*10.80*	*12.91*	*15.24*	*17.12*

a $(r/V)_{opt.}$: measured optimal R&D intensity; and $(r/V)_{act.}$: actual R&D intensity.

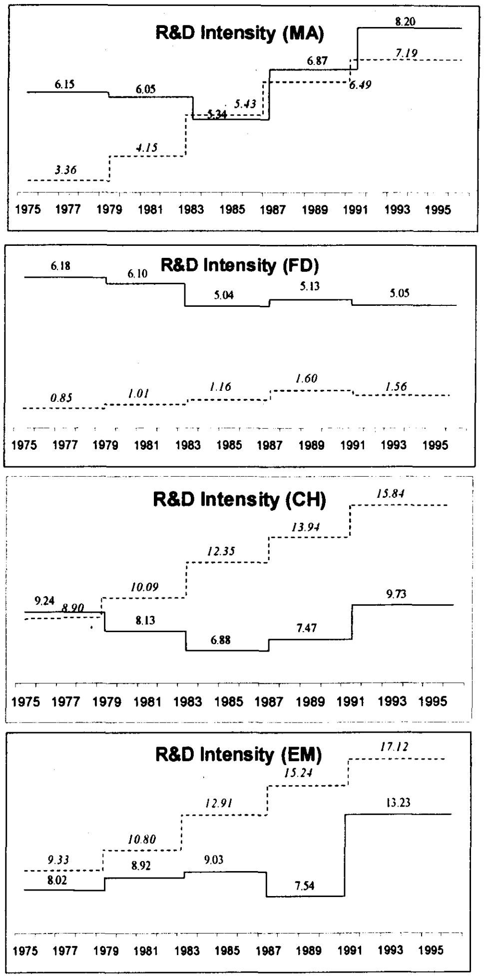
b Since the period between 1975-86 is relatively homogeneous in comparison to the other two periods examined, in order to use the elasticity of substitution of longer period as possible (see [2]) the elasticity of substitution for three periods is used for this evaluation analysis.

3.2 Comparative Analyses between Optimal and Actual R&D Intensity

Based on the calculation results summarized in Table 1, comparative analyses between optimal and actual R&D intensity for secors MA, FD, CH and EM in the Japanese manufacturing industry over the period 1975-1996 are illustrated in **Fig. 1**. By looking at the trends in R&D intensities of optimal and actual level, the quite defferent observations can be found between FD and other two sectors. While the similar observations can be found between CH and EM.

3.3 Allowance of R&D Intensity

It is generally pointed out that similar to the safety allowance of the machine, in order to secure sustainable development trajectory, certain allowance between actural R&D intensity and optimal R&D intensity level is necessary. **Fig. 2** illustrates the trends in the allowance of R&D intenisty (the ratio of actual and optimal R&D intensity). Looking at this figure, we note the following observations: (i) Allowance of R&D intensity has been



a ——: Optimal R&D intensity and ········: Actual R&D intensity

Fig. 1 Comparison of Optimal R&D Intensity and Actual R&D Intensity of Leading Sectors in the Japanese

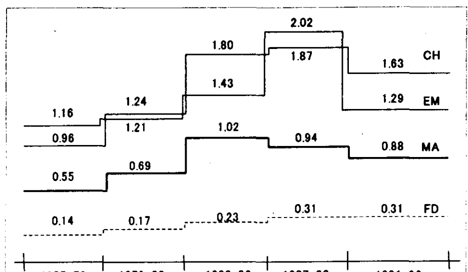


Fig. 2 Trends in the Ratio between Actual and Optimal R&D Intensity

increasing steadily until 1987 in all sectors examined; (ii) However, this ratio changed to the decreasing trend from 1987 in manufacturing average and chemicals. While the ratio of electrical machinery continued to increase until 1990, it changed to dramatic decrease from 1991; (iii) Contrary to the above trends, the ratio of food continued to increase and maintained the same level after 1987. Noteworth trends depicted in (ii) demonstrate the hypothetical view of the fear to vicious cycle between R&D and growth.

3.4 Interpretation of the results

In this empirical analysis, three leading manufacturing sectors, FD, CH and EM are examined. FD is one of the typical biological resources dependent industry, while EM is knowledge intensified industry. CH can be classified between FD and EM as it encompasses such nature as resources dependency and knowledge intensified. FD is generally classified in low-tech sector while encompassing some high-tech nature as depending on advanced bio-technology. Contrary to FD, CH and EM are generally classified in high-tech sector as they depend high level of R&D intensity. Pavitt (1989) [4] contrasted these three sectors as with scale-intensive characteristics (FD) and with science-based characteristics (CH and EM).

Fig. 1 suggests the following interesting observations with respect to clear contrast in three sectors examined:

(i) Optimal R&D intensity in EM and CH (typical high-tech sectors) are higher than FD.

(ii) Actual R&D intensity of EM and CH are much higher than the optimal level, while FD demonstrates the opposite. This is considered due to: (a) Among priority strategies for EM and CH firms to seek maximum profit including market strategies, process management/control, and strategic alliances, the decision for the investment option is one of the most crucial issue. (b) The results demonstrate that in order to achieve maximum return, R&D investment plays a more significant role than manufacturing investment for EM and CH in which speed of innovation is crucial. While manufacturing investment plays a significant role for FD in which mass volume production of variety of goods is crucial. Another reason for the lower level of R&D intensity in FD is because it mainly depends on other sectors R&D rather its own.

(iii) The high-level of R&D intensity in CH and EM is due to the typical nature of high-tech sectors under severe competition, encompassing not only really essential R&D intensity but also Pseudo R&D intensity ("Pseudo innovation," see [3]), similar to the safety allowance in a machine.

(iv) However, these allowances have dramatically decreased after the bursting of the bubble economy in 1991 leading to the vicious cycle between R&D and growth.

(v) Motivations for Pseudo innovation include: "Feint," "decoy" to rivals; Posture to be really high-tech firm demanding customers; "Cheaper propaganda;" "Cannot stop;" and "Innovation hungry" ......

These observations remind us a postulate of "pseudo innovation" postulated by Mensch [3]. He pointed a source of this pseudo innovations, particularly in high-tech sectors time discrepancy of customer's reaction to such characteristics of high-tech products as functionality of the product, safety for the user and durability of the product. Due to this discrepancy in high-tech products he pointed that

"It is important to note that in advanced stage of brand growth, important innovations are replaced with increase frequency by pseudo-innovation."

4. Concluding Remarks

(i) Methodologies for the measurement of core factors essential for the practical application of the optimal control model are developed.

(ii) The empirical analyses demonstrate the practical significance of this approach. Evaluations of the R&D intensity level in major sectors were conducted by comparing the optimal and actual level. "Pseudo innovation" in certain high-tech sectors and its sources are identified.

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