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Description	一般論文

1D09 Optimal Trajectory of Agile Product Development Technology Stock Formation in Japan's Automotive Industry

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1. Introduction

Facing stagnation of domestic sales and substantial decrease in international competitiveness due to the bursting of the bubble economy in 1991, Japan's automotive industry has been used to increase agile product development (APD) technology implementation. APD aimed at rapidly introducing a steady succession of incremental product improvements which are really planned "***variations on a theme***" based on common parts and modular architecture (Anderson, 1998).

This change urges further increase in technology stock whereas such a requirement insists to effectively utilize technology from the global marketplace leading to increasing dependency on assimilated spillover technology. Thus, optimal trajectory of APD technology stock formation through identification of optimal dependency between indigenous R&D investment and assimilated spillover technology has become crucial to Japan's automotive industry for its survival strategy.

Since the Pontryagin (1962) pioneer work on the optimal control theory, application of this theory to broad fields have been attempted. Consecutively, Grossman and Helpman (1991) introduced endogenous growth theory, then, Tarasyev (1999), Tarasyev and Watanabe (2001^a, 2001^b) developed theoretical analysis and empirical demonstration of the optimal R&D investment trajectory control, followed by Watanabe *et al.* (2001), Tarasyev *et al.* (2002), Reshmin *et al.* (2002) and Izmodenova-Matrossova *et al.* (2003). Stimulated by these works, new insight has been developed to treat R&D investment in Japan's automotive industry in a context of dynamic optimality.

However, these works remain local optimality which represent an optimization within a firm's investment strategy or resources allocation within a sole nation. Stimulated by increasing concern on global optimization in a globalizing economy, this paper attempts to identify optimal trajectory of APD technology stock formation through optimal balance between indigenous R&D investment, technology stock and production.

2. Analytical Framework

As Grossman and Helpman (1991) stated, in determining optimal trajectory of APD technology stock as a function of time, the level of optimality is understood as a point which maximize the utility function J represented by an integral with discount rate ρ as follows:

$$J = \int_{t_0}^{\infty} e^{-\rho(t-t_0)} \log D(t) dt \tag{1}$$

$D(t)$ represents a consumption index of output of the automotive industry at time t, and t_0 indicates the initial period. The logarithm of $D(t)$ measures instantaneous utility at a moment in time.

Adopting D as a specification that imposes constant and equal elasticity of substitution between every pair of products, $D(t)$ can be depicted as follows:

$$D = D(t) = \left[\int_{t_0}^{\infty} x^{\alpha}(j) dj \right]^{1/\alpha} \tag{2}$$

$$\alpha = 1 - 1/\varepsilon \tag{3}$$

therefore, $\varepsilon = 1/(1-\alpha) > 1$ (4)

Here α is the parameter of elasticity of different tastes for variety of product, $0 < \alpha < 1$, and ε is the elasticity of substitution between two innovative goods.

Given $x(j) = Y/n$, $Y = Y(t)$, $T = T(t)$, $u = u(t)$,

$$n = n(t) = b e^{\psi t} T^{\beta_1} u^{\beta_2} \tag{5}$$

where j: current index of invented products; $x(j)$: quantity of production of brand j; n: quantity of available invented products; b: constant; and ψ, β_1 and β_2: elasticity coefficients. Notify that D depends on level of production Y, gross technology stock T, and real R&D investment which is measured using change in indigenous technology stock u as a proxy.

Substituting equation (5) into (2) and applying the result for equation (1), the utility function can be developed as,

$$J = \int_{t_0}^{\infty} e^{-\rho(t-t_0)}\left(\ln Y + a_1 \cdot \ln T + a_2 \cdot \ln u\right)dt \qquad (6)$$

$$a_1 = A \cdot \beta_1, \quad a_2 = A \cdot \beta_2 \qquad (7)$$

$$A \equiv (1-\alpha)/\alpha = (1/\varepsilon) - 1 \qquad (8)$$

where a_1: elasticity coefficient of technology; and a_2: elasticity coefficient of R&D investment.

By control parameter

$$u = u(t) = dT_d/dt = \Delta T_d \qquad (9)$$

subject to differential equation

$$dY/dt = f \cdot Y - g \cdot u \qquad (10)$$

the spillover effect can be depicted in terms of technology stock as follows:

$$T(t) = \mu \cdot T_d(t) + \nu \cdot u(t) \qquad (11)^1$$

$$\mu = 1 + \frac{\xi_0^2}{(\xi_0 + \omega)^2}, \qquad \nu = \frac{\omega}{(\xi_0 + \omega)^2} \qquad (12)$$

where f and g: parameters of growth and decline; ξ_0: initial condition of change rate of indigenous technology, $\xi = \Delta T_d / T_d$; and $\omega = \Delta T_s / T_s$: change rate of technology spillover pool.

Structure of the utility function in equation (6) implies that the investors include auto manufacturers, government, special corporations, and other non-government institutions, are interested in the growth of R&D investment, accumulative technology stock and production. Due to the logarithmic functions in the utility, the following variables are restricted from conditions:

$$Y = Y(t) > 0; \quad T = T(t) > 0; \quad u = u(t) > 0 \qquad (13)$$

Linearization of logarithmic term for technology stock ($a_1.\ln T$) in integral utility J

$$a_1 \cdot \ln T \approx a_1 \cdot \ln \mu + a_1 \cdot \ln T_d + a_1 \cdot \lambda \cdot u / T_d \qquad (14)$$

Thereby, utility after linearization and omitting term ($a_1.\ln\ \mu$) which does not depend on control u

$$J = \int_{t_0}^{\infty} e^{-\rho(t-t_0)}\Big[\ln Y + a_1 \cdot \ln T_d + a_1 \cdot \lambda \cdot u/T_d + a_2 \cdot \ln u(t)\Big]dt \qquad (15)$$

3. Analysis and Research Findings

On the basis of the empirical data on techno-production structure of Japan's automotive industry over the period 1982-2000, composition of gross technology stock in Japan's automotive industry is analyzed and optimal trajectory of APD technology stock formation is identified there on.

By means of a regression analysis over the period 1982-2000, **Figure 1** demonstrats composition of technology stock in Japan's automotive industry in terms of both the indigenous and the assimilated spillover technology.

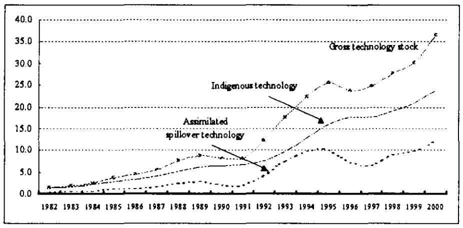

Figure 1. Trends in Composition of Technology Stock in Japan's Automotive Industry (*1982-2000*)

– trillion Yen at 1995 fixed prices.

Looking at Figure 1, we note that technology stock in Japan's automotive industry increased dramatically in the 1990s corresponding to the period after the bursting of the bubble economy. This increase aimed at increasing competitiveness through strengthening core competence amidst megacompetition

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[1] Gross technology stock is enumerated as a total sum of indigenous technology and assimilated spillover pool,

$$T_t = T_{d_t} + z \cdot T_{s_t} \cdot$$

Measuring indigenous technology stock

$$T_{d_t} = \alpha' + \beta t + \gamma \sum_{\tau=0}^{2} \theta^{\tau} r_{t-\tau} + \delta(1-\rho) T_{d_{t-1}} + \varepsilon_t$$

where α': constant; β and δ: coefficients of explanatory variable; t: time trend effect; γ: coefficient of lagged variable; θ: weight of geometric lagged variable, τ: time-lag to commercialization; r: R&D investment; ρ: obsolescence rate of technology; and ε: disturbance term,

and technology spillover pool

$$T_{s_t} = c \cdot e^{\kappa t} \sum_{t=0}^{2} \left(\tilde{r}_{t-t}\right)^{\eta\phi^t} \left(T_{\tilde{r}_{t-1}}\right)^{\zeta(1-\rho)} \mathrm{Im}_t^{\sigma}$$

where c: scale factor; κ, ζ and σ: coefficients of explanatory variable; t: time trend effect; $\tilde{r}$: net value of R&D funds received and paid outside; η: coefficient of lagged variable; ϕ: weight of lagged variables; t: time-lag to commercialization; $T_{\tilde{r}}$: technology stock generated from $\tilde{r}$; ρ: obsolescence rate of technology; and Im: technology import,

thereby, assimilation capacity

$$z = (1/1 + \omega/\xi) \cdot (T_d/T_s)$$

where ω : change rate of technology spillover pool; and x: change rate of indigenous technology stock. For detail mathematical development, see Ane (2003) and Watanabe et al. (2001).

while facing stagnation in domestic economy. Furthermore, we note that such dramatic increase in gross technology stock in the 1990s can be attributed chiefly to the assimilated spillover technology. This is the result of the industry effort in strengthening technological tie-ups with the US and European counterparts (Nihon Keizai Shinbun, 2003[a], 2003[b]).

Afterwards, simulating equations (2) and (5) using SPSS 10.0J utilizes similar empirical data in the same period and prior findings on the technology stock of Japan's automotive industry, the following elasticity coefficients are identified:

a. Elasticity coefficient of different tastes for variety of product (α)

$$\ln D(t) = \underset{(2.38)}{10.11} \ln(\underset{(2.37)}{0.09} \ln x(j)) \qquad (16)$$

$$adj.R^2 = 0.515 \qquad DW = 1.38$$

$$A = (1-\alpha)/\alpha = 10.11,\ \alpha = 0.09 \qquad (17)$$

b. Elasticity coefficient of technology (β_1) and R&D investment (β_2)

$$\ln n = \underset{(4.66)}{0.003t} - \underset{(-3.31)}{8.176D} + \underset{(4.66)}{0.050D.\ln T} + \underset{(9.68)}{0.599 \ln u} \qquad (18)$$

$$adj.R^2 = 0.782 \qquad DW = 1.22$$

where D: dummy variable, 1982-1986 = 1 and other years = 0.

The statistical results in equations (16) and (18) demonstrate that all identified coefficients are statistically significant. **Figure 2** depicts trend in consumption index for automotive product over the period 1982-2000.

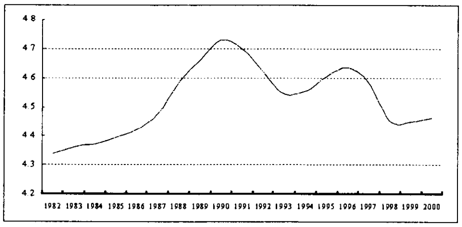

Figure 2. Trend in Consumption Index for Automotive Product (*1982-2000*).

Applying the estimated coefficients into equations (7) and (15), parameters of the utility function J that incorporate both the assimilated spillover technology and without it, T and T_d, can be identified as follows:

	α	β_1	β_2	α_1	α_2	r^0
T	0.09	0.04	0.60	0.40	6.07	1.11
T_d	0.09	0.05	0.60	0.51	6.07	1.16

where r^0 represents optimal R&D intensity. [2]

This result demonstrates that optimal R&D intensity (r^0) based on gross technology stock T (1.11) is lower than that on indigenous technology stock T_d solely (1.16). This demonstrates that assimilated spillover technology contributes to relax the burden of indigenous R&D investment by decreasing the optimal level of R&D intensity.

Figure 3 depicts the trend in the utility J expected by contributing factors of production, APD technology stock and R&D investment in Japan's automotive industry.

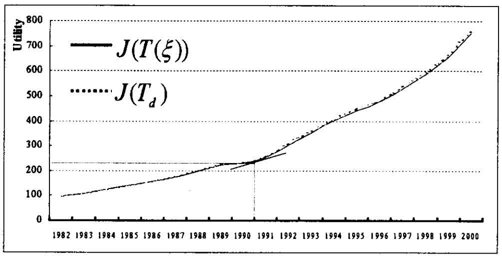

Figure 3. Trends in Utility (*1982-2000*).

Looking at Figure 3, trends in the utility of APD technology stock which utilize linear approximated gross technology stock $J(T(\xi))$ well represents $J(T_d)$. The utility increases significantly in the period of the 1990s after the bursting of the bubble economy which demonstrates an inflection point in 1991 and slope 21.48 trillion Yen at 1995 fixed prices.

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[2] Optimal level of R&D intensity can be computed by the following equation,

$$r^0 = a_2/(c \cdot g - a_1 \cdot \lambda \cdot x^*)$$

$g = -0.012$, t-value = 4.40 $\quad adj.R^2 = 0.845 \quad DW = 1.66$,

$\lambda = -0.003$, t-value = 8.69 $\quad adj.R^2 = 0.999 \quad DW = 2.08$

where $c = (1+a_1+a_2)/\rho$, g: parameter of decline; λ: eigenvalues of the Jacobi matrix, and $x^* = Y/T_d$: productivity of technology. For detail mathematical development, see Ane (2003).

4. Conclusion and Implication

Dramatic change in the 1990s has urged Japan's automotive industry to increasing expectation to agile product development (APD) technology implementation. This change urges further increase in technology stock whereas such a requirement insists to effectively utilize spillover technology from the global marketplace.

On the basis of the empirical data on techno-production structure of Japan's automotive industry over the period 1982-2000, composition of gross technology stock in Japan's automotive industry is analyzed and optimal trajectory of APD technology stock formation is identified. Our findings provide evidences on the following circumstance:

a. APD technology stock formation in terms of both indigenous and assimilated spillover technology increased dramatically in the 1990s corresponding to the period after the bursting of the bubble economy.
b. This dramatic increase can be attributed chiefly to the assimilated spillover technology as result of the industry effort in strengthening technological tie-ups with the US and European counterparts.
c. Optimal level of R&D intensity based on gross technology stock is lower than that on indigenous technology stock.
d. Assimilated spillover technology contributes to relax the burden of indigenous R&D investment by decreasing the optimal level of R&D intensity.

Identifying optimal dependency between indigenous R&D and assimilated spillover technology is crucial to Japan's automotive industry for its survival strategy, which in turn, leading to greater concern on the assimilation capacity of the industry.

Thereby, Japan Automobile Manufacturers Association (JAMA) as a major player suppose to develop a platform of industrial R&D and technology policy with respect to the increasing significance of global optimality of R&D investment to enable Japan's automotive industry effectively utilize technology gathered from multiple sources from global marketplace for their competitive strategy.

References

[1] Anderson, D.M., 1998. Agile Product Development for Mass Customization. McGraw-Hill, New York.

[2] Ane, B.K., 2003. Optimal Trajectory of Agile Product Development Technology through Effective Utilization of Spillover Technology - Survival Strategy of Japan's Automotive Industry. Dissertation, Tokyo Institute of Technology, Department of Industrial Engineering and Management, Tokyo.

[3] Grossman, G.M., Helpman, E., 1991. Innovation and Growth in the Global Economy. MIT Press, Cambridge.

[4] Izmodenova-Matrossova, K., Tarasyev, A.M., Watanabe, C., 2003. Optimization of R&D Investment under Technology Spillovers: a Model and a Case Study of Sony Corporation. IIASA Interim Paper.

[5] Nihon Keizai Shinbun, 2003^a (January 17). Kibo ikashi kouritsu kisou. Tokyo.

[6] Nihon Keizai Shinbun, 2003^b (January 18). Tokui bunya ni katsuro saguru. Tokyo.

[7] Pontryagin, L.S., Boltyanskii, V.G., Gamkrelidze, R.V., Mishchenko, E.F., 1962. The Mathematical Theory of Optimal Processes. Wiley/Interscience, New York.

[8] Reshmin, S.A., Tarasyev, A.M., Watanabe, C., 2002. Optimal Trajectories of the Innovation Process and their Matching with Econometric Data. Journal of Optimization Theory and Applications 112 (3), 639-655.

[9] Tarasyev, A.M., 1999. Control Synthesis in Grid Schemes for Hamilton-Jacobi Equations. Annals of Operations Research 88, 337-359.

[10] Tarasyev, A.M., Watanabe, C., 2001^a. Dynamic Optimality Principles and Sensitivity Analysis in Models of Economic Growth. Nonlinear Analysis 47, 2309-2320.

[11] Tarasyev, A.M., Watanabe, C., 2001^b. Optimal Dynamics of Innovation in Models of Economic Growth. Journal of Optimization Theory and Applications 108 (1), 175-203.

[12] Tarasyev, A.M., Watanabe, C., Zhu, B., 2002. Optimal Feedbacks in Techno-economic Dynamics. International Journal of Technology Management 23 (7-8), 691-717.

[13] Watanabe, C., Reshmin, S.A., Tarasyev, A.M., 2001. A Dynamic Model of R&D Investment. Journal of Applied Mathematics Mechanics 65 (3), 395-410.

[14] Watanabe, C., Zhu, B., Griffy-Brown, C., Asgari, B., 2001. Global Technology Spillover and its Impact on Industry's R&D Strategies. Technovation 21 (5), 281-291.