1C15

R&D Interaction as an accelerator of creative innovation in systems of innovation

○Hur Jae Yong，渡辺千仭（東工大社会理工）

1. INTRODUCTION

As noted by C. Freeman and L. Soete (1997), strong links between scientists and entrepreneurs was one of factors influencing the British national systems of innovation more innovative than others during the eighteenth and nineteenth centuries. Innovators have exploited various benefits from these kinds of links, for example, between firms, government laboratories, universities, and so on until now. One of the ways we can examine these kinds of links might be the study on R&D outsourcing. The R&D outsourcing of firms implies that firms have maintained links with other research institutes so as to cooperate formally and informally. In this regard, this paper attempts to review the interaction between in-house and outsourced technology stocks using the rate of returns to technology stocks (marginal productivity), and measure the contribution of direct and indirect impact of the in-house and outsourced technology stocks to the growth of the total factor productivity (TFP) which is regarded as a main source of sustained economic growth. In addition, bearing in mind the systems of innovation context, we will review the structural differences between sectors of the Japanese manufacturing industry based on the R&D outsourcing patterns.

2. TECHNOLOGY STOCKS & TFP

2.1 ANAYTICAL APPROACH

Let the technology stocks are function of R&D expenditure, time lag from R&D to commercialization, and rate of obsolescence according to Watanabe *et al.*(2001), then in-house and outsourced technology stocks can be defined as following equations respectively.

$$dT_{i,t}/dt = R_{i,t-m_i} - \rho_i T_{i,t}$$
$$dT_{o,t}/dt = R_{o,t-m_o} - \rho_o T_{o,t}$$

where $T_{i,t}$: In-house technology stocks of *i*-th sector at time t

$R_{i,t-m_i}$: In-house R&D expenditure of *i*-th sector at time t-m_i

$T_{o,t}$: Outsourced technology stocks of *i*-th sector at time t

$R_{o,t-m_o}$: Outsourced R&D expenditure of *i*-th sector at time t-m_o

m_i, m_o : Time lag from R&D to commercialization

ρ_i, ρ_o : Rate of obsolescence of technology stocks.

Next, we will decompose the changes in TFP in order to measure the contribution of technical change due to in-house and outsourced technology stocks. First, we assume perfect market competition and then the only way of contributions of technical change to the production is cost down through process innovation.

According to Nadri and Schankerman (1981), Growth rat of the total factor productivity can be described as below:

$$T\dot{F}P = \dot{V} - \sum \frac{P_i V_i}{PV}\dot{X} \qquad (1)$$

where V: Production, P_i: factor price and X_i: Labor (L), capital (K).

From equation (1), production growth rate is obtained as follows:

$$\dot{V} = \sum \frac{\partial V}{\partial X_i}\frac{X_i}{V}\dot{X}_i + \frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V} + \frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V} \qquad (2)$$

From the first order conditions for the cost minimization

$$P = \frac{\partial C}{\partial V},\quad \frac{\partial V}{\partial X_i} = \frac{P_i}{P} = \frac{P_i}{\partial C/\partial V} \qquad (3)$$

By substituting equation (3) into equation (2), then we obtain following equation.

$$\dot{V} = \frac{P}{\partial C/\partial V}\sum \frac{P_i X_i}{PV}\dot{X}_i + \frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V} + \frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V} \qquad (4)$$

As a result, growth rate of the TFP is described as follows:

$$T\dot{F}P = \left(\frac{P}{\partial C/\partial V} - 1\right)\sum \frac{P_i X_i}{PV}\dot{X}_i + \frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V} + \frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}$$
$$= (k\eta^{-1} - 1)\sum \frac{P_i X_i}{PV}\dot{X}_i + \frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V} + \frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V} \qquad (5)$$

where $\eta(=\frac{\partial C}{\partial V}\frac{V}{C})$ and $k(=\frac{PV}{C}=\frac{P}{AC})$ are the cost elasticity and the ratio of output price to average cost.

From equation (1) and (5)

$$T\dot{F}P=(1-k^{-1}\eta)\dot{V}+k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right) \quad (6)$$

The second term of right hand side of the above equation is the direct impact of technical change due to in-house and outsourced technology stocks. In other words, the second term represents the amount of downward shift of average cost curve due to technical change.

The Change in output price is due to downward shift of the average cost curve and then movement along the average cost curve to the intersection with demand schedule. The latter is $\dot{V}(\eta-1)$ (see Watanabe et al., 2001), then the whole price change is as follows:

$$\dot{P}=-k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right)+(\eta-1)\dot{V} \quad (7)$$

The Changes in production due to price change is

$$\dot{V}=-e\dot{P} \quad (8)$$

where $e=\frac{\partial V}{\partial P}\frac{P}{V}$ is the price elasticity.

From equation (7) and (8), we obtain the increase in production due to technical change as follows:

$$\dot{V}=\psi k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right) \quad (9)$$

where $\psi=\frac{e}{1-e(1-\eta)}$.

The traditional factors (X_i) input will change due to two reasons. Increase in demand due to price down requires additional output and as a result additional traditional factors are required. Meanwhile, the cost down due to technical change saves traditional factors. The required increase in ith factor as a result of the former effect is as follows

$$\eta_i\dot{V}=\eta_i\psi k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right). \quad (10)$$

Note: Although Nadri and Schankerman (1981) decompose the TFP into direct and indirect impact of technical change, exogenous shift of demand, and change in factor price, in this paper we only focus our analysis on the direct and indirect impact of technical change.

The reserved amount of ith factor as a result of the latter effect is

$$-\eta_i k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right)+bias_i \quad (11)$$

From equation (10) and (11), the changes in ith factor is

$$\dot{X}_i=\eta_i(\psi-1)k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right)-bias_i \quad (12)$$

The change rate of the TFP ($\dot{F}_T$) due to indirect impact of technical change is determined by summing up changes in traditional factors.

$$\dot{F}_T=\eta^2(\psi-1)k^{-1}\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right) \quad (13)$$

Let $\dot{V}'=\dot{V}-\dot{F}_T$ and from equation (6) and (13)

$$\begin{aligned}T\dot{F}P&=(1-k^{-1}\eta)\dot{V}'\\&+(1-k^{-1}\eta)\eta^2(\psi-1)k^{-1}\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right)\\&+k^{-1}\eta\left(\frac{\partial V}{\partial T_i}\frac{dT_i/dt}{V}+\frac{\partial V}{\partial T_o}\frac{dT_o/dt}{V}\right)\end{aligned} \quad (14)$$

In equation (14) the second and third terms represent indirect and direct impact of technical change respectively. The first term is the contribution of other influences to the TFP growth. Figure 1 shows the mechanism of the TFP change briefly.

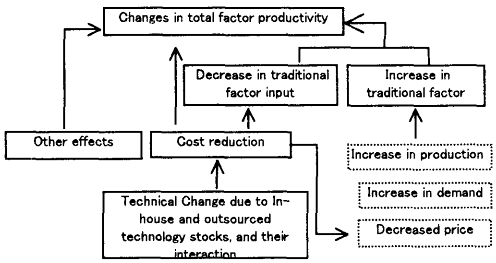

Figure 1. Interaction of technical change and TFP

Provided that the production function (V) is subject to the cost function (C), it can be expressed as follows:

$$V=f(L,K,T_i,T_o),\quad C=\sum p_iX_i \quad (15)$$

where X_i = L, K, T_i, T_o.

The production and cost are function of labor (L), capital (K), in-house technology stocks (T_i), outsourced technology stocks (T_o), and their prices. We use the lagrangian equation in order to maximize the profit and find the relation between in-house and outsourced technology stocks. The Lagrangian for this problem is

$$W = f(L,K,T_i,T_o) + \lambda(C - \sum p_i X_i) \quad (16)$$

The relation between the rate of returns to in-house and outsourced technology stocks is determined from the first-order conditions.

$$\frac{\partial V}{\partial T_i} = \frac{p_{T_i}}{p_{T_o}} \frac{\partial V}{\partial T_o} \quad (17)$$

2.2 INTERACTION BETWEEN IN-HOUSE AND OUTSOURCED TECHNOLOGY STOCKS

In-house and outsourced technology stocks will be accumulated through in-house and outsourced R&D as mentioned before. However, the amount of the two technology stocks will differ at the profit maximizing point because of the differences in the rate of returns and marginal cost schedules. The rate of returns to in-house technology stocks may equal that of outsourced technology stocks on the condition of the same price of the two. As shown the figure 2, a firm may first choose to invest in either in-house R&D or outsource R&D by comparing the ratio of rate of returns to in-house and outsourced technology stocks and their marginal costs. Assuming that the firm chooses in-house R&D, then it invest in in-house R&D and this causes the increase in in-house technology stocks. However, without outsourced technology stocks, the firm can't maximize production so that it reduces the in-house R&D spending to increase R&D outsourcing. As a result, in-house technology stocks decrease along the budget (cost) line while outsourced technology stocks increase. If the budget to invest in technology increases due to increased production and profit, the firm will compare the expected returns and repeat the above-mentioned process and reach the profit maximizing point. Figure 2 describes the interaction between in-house and outsourced technology stocks. As shown the below figure, if a firm can outsource R&D properly, then it can get additional revenue and achieve more efficient innovation than it relies only on own technology. However, one of the preconditions to achieve this kind of efficient innovation is the existence of links between firms and other actors in systems of innovation. In this context, we will review the R&D outsourcing patterns of the Japanese manufacturing industry in the last part.

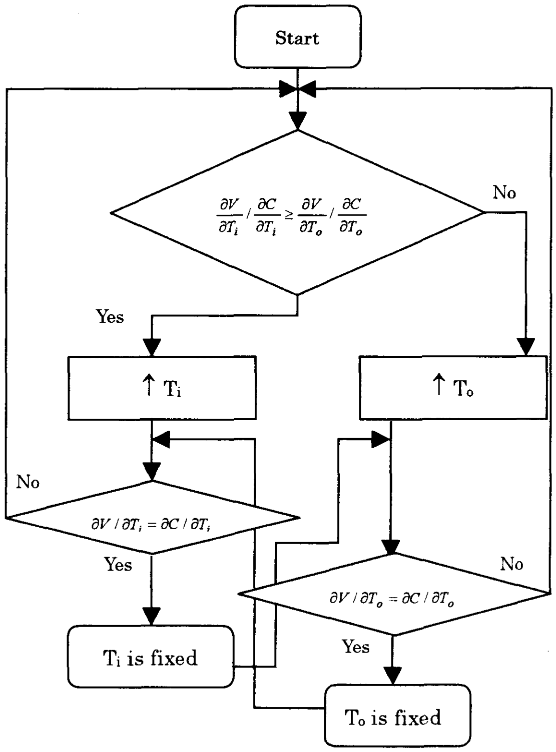

Figure 2. Mechanism of interaction between in-house and outsourced technology stocks

3. EMPERICAL ANAYSIS

3.1 CONTRIBUTION OF TECHNICAL CHANGE TO TFP GROWTH

Using equation (13) and (16), we can calculate the contribution of technical change to the TFP growth. Because there are no sufficient survey data on the outsourced R&D, we assume that the time lag from R&D to commercialization, rate of obsolescence and service price of outsourced technology stocks are the same as those of in-house technology stocks, and let k=1. We make use of the relevant data from 1970 to 1996 mainly from the Watanabe laboratory except the R&D outsourcing data. The R&D outsourcing related data are from the Statistics Bureau of Japan. The result of empirical analysis on the Japanese manufacturing industry is as shown the figure 4. However, the contribution of technical change is not so great. As will be discussed later, main reason of the low contribution of technical change is that we assume process innovation only. However, in the real world firms invest more in design and development that are sources of product innovation.

Table 1 Contribution of technical change to TFP growth

Year	Sector	TFP	Ti	To	Sector	TFP	Ti	To
70-73	MA	4.398	1.244	0.033	MP	8.606	-0.002	-0.004
74-78		2.032	0.805	0.015		-0.664	-0.002	-0.003
79-86		2.246	0.617	0.013		4.993	-0.003	-0.003
87-90		2.968	1.228	0.015		0.544	-0.002	-0.002
91-96		1.432	1.034	0.011		1.407	-0.001	-0.001
70-73	FD	3.255	0.011	0.011	GM	7.325	0.124	0.040
74-78		-2.240	0.007	0.005		7.457	0.084	0.018
79-86		-1.636	0.006	0.005		6.333	0.036	0.014
87-90		-4.173	0.013	0.007		3.087	0.060	0.016
91-96		-1.270	0.009	0.005		-0.124	0.092	0.014
70-73	PP	6.348	0.006	0.029	EM	15.449	0.884	0.090
74-78		5.067	0.003	0.008		8.892	0.527	0.036
79-86		-0.168	-0.000	0.005		13.013	0.534	0.039
87-90		3.796	0.001	0.004		11.963	1.334	0.041
91-96		-3.450	0.001	0.004		7.336	1.030	0.026
70-73	CH	12.704	0.906	0.094	TM	4.026	0.130	0.027
74-78		9.359	0.497	0.044		2.541	0.203	0.022
79-86		5.568	0.265	0.037		3.110	0.242	0.026
87-90		3.402	0.517	0.043		3.102	0.361	0.028
91-96		2.580	0.558	0.035		0.529	0.291	0.021
70-73	CR	3.195	0.134	0.189	PI	9.851	0.026	0.036
74-78		-0.878	0.044	0.041		6.831	0.035	0.024
79-86		2.390	0.042	0.047		5.844	0.068	0.034
87-90		1.234	0.132	0.062		4.756	0.156	0.050
91-96		0.792	0.111	0.050		-0.994	0.221	0.055
70-73	PM	3.852	0.111	0.035				
74-78		1.429	0.080	0.020				
79-86		-1.084	0.092	0.023				
87-90		1.769	0.143	0.026				
91-96		1.852	0.115	0.021				

(Unit: %)

3.2 CLUSTERING ANALYSIS

From no on, we will do cluster analysis to find the sectoral difference in outsourcing R&D to examine the correlation between outsourcing pattern and technical change. We make use of the data on R&D fund supplied to other institutes by sector. There are four actors in each sector except firms, which are central and local governments, special corporations, non-governments, and foreign institutes. R&D matrix is defined as the following equation using the share of R&D fund supplied to the four actors. $R_i = (r_1, r_2, r_3, r_4)$ where Ri: R&D matrix of i sector, r_1, r_2, r_3, r_4: Share of outsourced R&D performed by the four actors respectively. Secondly, similarity of two sectors are measured by the Pearson correlation coefficient between the two sectors using the above R&D matrix and then we obtain 13 by 13 similarity matrix as follows: $S = [S_{m,n}]$, for m,n = 1,2,…,13 where $S_{m,n}$: Pearson correlation coefficient between the mth and nth sector. Finally, using the average linkage method in the agglomerative hierarchical clustering (Johnson and Wichern, 1988) we obtain the following dendrogram.

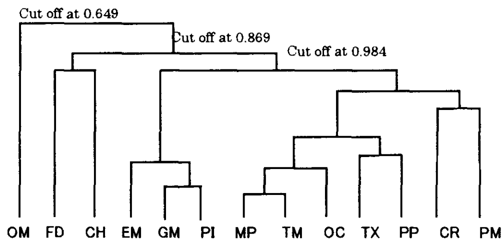

Figure 5. Dendrogram of the Japanese manufacturing sectors(1996)

As shown the above figure, the Japanese manufacturing sectors have uniform outsourcing patterns and their R&D cooperation partners are mainly from private sectors.

4. DISCUSSIONS

In this paper, we review the mechanism of interaction between in-house and outsourced technology stocks. If national systems of innovation are properly developed so as to make firms outsource their R&D, more efficient innovation is expected nation wide. However, according to the result of TFP decomposition, contribution of technical change to productivity is lower than expected. The main reason of this result may be from the perfect competition assumption. Therefore, it is required to develop a model of imperfect information in order to include the impact from product innovation in future. Although clustering of the Japanese manufacturing sectors is not successful due to high degree of similarity between sectors in outsourcing R&D. we confirm that most sectors prefer actors in private sector as their R&D partners.

SELECTED REFERENCES

C. Freeman and L. Soete, 1997, National Systems of Innovation, in The Economics of Industrial Innovation 3rd ed. (.Pinter, London and Washington) 295-315

C. Watanabe *et al.*, 2001, Institutional Elasticity as a Significant Driver of IT Functionality Development, Information Economics and Policy, under review.

M. Ishaq Nadri and Mark A. Schankerman, 1981, The Structure of Production, Technological Change, and the Rate of Growth of Total Factor Productivity in the U.S. Bell System, in Productivity Measurement in Regulated Industries (Academic Press Inc., New York) 219-247.

Yong-tae Park, 1999, A Taxonomy of National Systems of Innovation: R&D Structure of OECD economies, Science and Public Policy.