

2B25 Dynamic Process of Technology Spillover; A Transfer Function Approach

許 光仁, ○渡辺千帆 (東工大社会理工学)

Abstract

This paper analyzes and demonstrates the spillover phenomenon related to technology stock in terms of mathematical model. It uses a transfer function approach focusing on dynamic relationship demonstrating how technology stock responds with respect to the change of various input variables such as their own R&D efforts, spillover from other sectors and the characteristics of this process. In terms of this analysis, it is possible to find useful relationships for calculating the appropriability and specific capacity relating technology flows among parameters. By utilizing the fact that time constant is equivalent to lead time, mathematical formulae with respect to appropriability could be obtained. In addition, by means of sensitivity concept of technology stock, it is possible to compute specific capacity in a broad manner. Based on this model, governing parameters such as appropriability and specific capacity including assimilation capacity are estimated and simulated in terms of the techno-economic data set of the Japanese manufacturing industry. Furthermore, the characteristic of technology stock that slows itself down is clarified using a mathematical formula.

1. Introduction

Accumulating technology stock has many characteristics. Technology will be stored by several kinds of technology flows that occur simultaneously and depend on the various environments. This indicates that this process is dynamic and worthy of exploration. This paper describes the relevant process of a certain sector on technology flows from various sources. First, input and output technology flows are distinguished and then relevant parameters are introduced. In terms of such parameters, each flow is restricted or controlled. Among these parameters, input spillover effect and own R&D is governed by specific capacity including assimilation capacity, and output spillover flow is limited by appropriability. Restoring appropriability and increasing capacity are considered as a useful factor to maintain desired level of technology stock, and, in particular, appropriability may affect the magnitude of spillover effect.

By utilizing these parameters and technology flows, this analysis attempted to analyze the dynamic process of technology flows and a dynamic relationship between parameters. Because technology flows play a fundamental role in accumulating technology stock in any sector, it is important to have as a systematic understanding of such process as possible.

Section 2 introduces analytical framework that describes the dynamic process of technology spillover and scheme of the analysis. Based on this analysis, section 3 estimates appropriability and specific capacity including own and assimilation capacities using techno-economic data sets of the Japanese manufacturing sector. Section 4 briefly summarizes findings and concluding remarks.

2. Analytical framework

2.1 Definitions of parameters

Let's define specific capacity as the amount of input technology that consists of own and spillover technology (T_{input})

required to raise technology stock (T) by unit in a certain sector:

$$C_{sp} = \left(\frac{\partial T}{\partial T_{input}} \right). \text{ Generally, when we estimate technology stock, the}$$

following formula is considered: $T_t = R_{t-m} + (1-\rho)T_{t-1} + \Delta T_t$ ¹.

According to this method, own R&D efforts and spillover effects are totally transferred to its technology stock. However, in general, we can realize that their relationships may have some efficiency. Therefore, only a portion of specific capacity with respect to the own R&D efforts and input spillover technology would be accumulated to the technology stock (Cohen and Levinthal, 1989).

Let's consider θ as a level of appropriability that led technology spillover to its own sector's borders and it ranges between 0 and 1. We can consider this appropriability as a potential spillover pool (Jaffe, 1986). Suppose that a fraction θ of the technology stock is shared by other sectors and a fraction, $(1-\theta)$ will not be shared. Let's assume that the increasing rate of θ will be proportional to the number [N] of firms in the sector (Spence, 1984)²: $v_\theta = k_a(1-\theta)[N]$. On the other hand, the diminishing rate of θ in turn is proportional to the fraction of technology shared: $v_\theta = k_b(\theta)$. Here k_a and k_b are rate coefficients relating to the level of appropriability. If it is assumed that there is an equilibrium at each point of time in sector, the increasing rate of θ and diminishing rate of θ are the same as following equation:

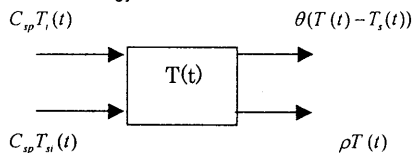
$$k_a(1-\theta)[N] = k_b\theta \quad (1) \quad \theta = \frac{K[N]}{1+K[N]} \text{ where } K = \frac{k_a}{k_b} \quad (2)$$

If the number of firms is large enough to diminish θ close to 1, then technology of firm or sector is a pure public good. Otherwise, if θ is 0, then appropriability is perfect.

2.2 Model construction

The modeling of technology flow process usually satisfies the conservation of quantity balance. Rate of quantity into process – Rate of quantity out of process = Rate of accumulation of quantity in process

Consider the technology stock illustrated as follows:



¹ R: Own R&D investment; ρ : rate of obsolescence; and ΔT_t : increase of spillover technology.

² Spence indicates that "As θ rises, the desirable number of firms will increase."

$Z_t = m_t + \theta \sum m_j$: tech stock, m : R&D investment. If $\theta=0$, no spillover, $\theta=1$, R&D shared completely.

A quantity balance on the contents of the technology stock gives us the relation between the input and output technology flows:

$$\frac{dT(t)}{dt} = C_{sp}T_i(t) + C_{sp}T_u(t) - \theta(T(t) - T_s(t)) - \rho T(t) \quad (3)$$

where $T(t)$: Technology stock at time t.

$T_i(t)$: Input technology flow by own R&D.

$T_u(t)$: Input technology flow by spillover.

$T_s(t)$: Technology stock of host (surrounding).

ρ : The rate of obsolescence.

θ : Appropriability of technology (shared portion)

C_{sp} : Specific capacity of a certain sector.

This equation is a first-order linear ordinary differential equation that provides the relationship between the input and output technology flows. In this equation there is only one unknown, $T(t)$. The input technology flows, $T_i(t)$, $T_u(t)$, is an input variable and thus is not considered as an unknown because it is up to us to specify how it will change. Equation (3) can be rearranged as follows:

$$\frac{1}{(\theta + \rho)} \frac{dT(t)}{dt} + T(t) = \frac{C_{sp}}{(\theta + \rho)} (T_i(t) + T_u(t)) + \frac{\theta}{(\theta + \rho)} T_s(t) \quad (4)$$

and let $\frac{1}{\theta + \rho} = \tau$, $\tau C_{sp} = K_1$, $\tau\theta = K_2$, so

$$\tau \frac{dT(t)}{dt} + T(t) = K_1(T_i(t) + T_u(t)) + K_2 T_s(t) \quad (5)$$

Since this is a linear differential equation, taking the Laplace transform of equation (5) gives,

$$\tau s T(s) + T(s) = K_1(T_i(s) + T_u(s)) + K_2 T_s(s) \quad (6)$$

where $T(0)=0$.

Rearranging this equation yields,

$$T(s) = \frac{K_1}{\tau s + 1} (T_i(s) + T_u(s)) + \frac{K_2}{\tau s + 1} T_s(s) \quad (7)$$

Every positive change of input variables can increase the technology stock. This is because that all the equations have positive signs concerning the technology stock and K_i are all positive. Here we can make a quick check. The equation indicates that if the input technology flows increase, the technology stock increases. It shows that if host (= surrounding) technology stock increases, the technology stock of donor also increases. Since if the technology stock of host increases, the rate of technology spillover from the technology stock to the host will decrease. At the same time, as technology stock of host increases, own technology stock becomes depending on own investment rather than spillover from its borders by the consequence of technology gap reduced.

In order to understand the quantitative behavior of the

technology stock, let us assume that the input technology flows (own investment and input technology spillover) to the technology stock increases by unit step function. The use of inverse Laplace transform gives following equations with respect to the unit increase of $T_i(t) + T_u(t)$ and $T_s(t)$, respectively.³

$$T(t) = \tau C_{sp} (1 - e^{-t/\tau}) \quad (8) \quad T(t) = \tau\theta (1 - e^{-t/\tau}) \quad (9)$$

2.3 The economic point of view of parameters

Rewriting the $K_1 = \frac{\Delta tech - stock}{\Delta input}$ = the magnitude of

technology stock to the change of input variables. In other words, K_1 is the sensitivity that specifies the amount of change of technology stock per unit change of input variables ($T_i(t)$, $T_u(t)$). K_1 increases as τ or C_{sp} increases. Because τ is at the mercy of θ , ρ , the smaller θ and ρ , the larger the sensitivity. Another expression of the equation (8) is

$$T(t) = \frac{1}{\theta + \rho} C_{sp} (1 - e^{-(\theta + \rho)t})$$

This means in case θ approaches 0 and/or ρ moves to 0, the technology stock would respond more sensitively to the change of input flows. It does not surprise for us, and this behavior is also applicable to K_2 . The problem is to measure the magnitude of specific capacity (C_{sp}) and appropriability (θ). However, this analysis will not directly deal with these capacity and appropriability related to their factors.

Next, let's call τ as time constant. The time constant is related to the speed of response of the technology stock. If the value of τ is large, then the speed of technology stock responds to a change of input variables is slow. The faster the speed, the smaller the value of τ . Based on this characteristics, τ has the same meaning as lead time (m) between R&D and commercialization. Therefore, following formulation can be derived:

$$\frac{1}{\theta + \rho} = \tau = m \quad \text{or} \quad \theta = \frac{1}{m} - \rho \quad (10)$$

As introduced in earlier study (Watanabe, 1996 and Pakes and Schankerman, 1984), the rate of obsolescence and lead time are given as following mathematical formulae:

$$\rho = A\rho_0 e^{g/T_0}, \quad m = \frac{\ln R_0 / T_0 - \ln(\rho + g)}{\ln(1 + g)} + 1$$

where g is Increasing rate of R_i in the initial period, R is the R&D expenditure.

³ Actually, equations (8) and (9) have to be analyzed simultaneously. However, the objective of this paper is focused on response with respect to the change of input variables only by own investment and input technology spillover. Due to this reason, analyzing the equation (9), response with respect to the change technology stock of host, is beyond the scope of this paper.

Maclaurin approximation yields,

$$\rho = a + bT \quad m = c - d\rho \quad (11)$$

where a,b,c and d : constant coefficients.

In line with previous approach (Hur & Watanabe, 2000), these approximations coincide with empirical results in the Japanese manufacturing sectors. Similarly, equation (10) gives us the same linear relationship as equation (11). Taking Maclaurin approximation, at fixed θ , then

$$\tau = \frac{1}{\theta} - \frac{1}{\theta^2} \rho = c' - d' \rho \cong m \quad (12)$$

Comparing equation (11) and (12), their mathematical structure is very similar to each other. Thus, the link between m and τ can be proved in terms of mathematical expression.

By applying lead time and time constant relationship ($\tau \cong m$) to equation (8), following equation can be obtained:

$$T(t) = mC_{sp}(1 - e^{-t/m}) \quad (13)$$

According to this equation, it explains that technology stock slows itself down due to the short lead time, so that it leads to stagnation of technology stock. However, due to the complementary role of technology spillover, technology stock can increase in spite of slow itself down characteristic under the condition that its capacity is enough to assimilate and maximize the spillover effects. Fig 1 describes the mechanism.

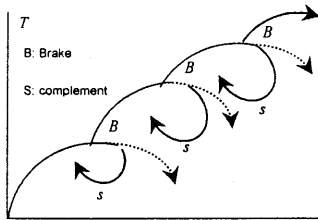


Fig. 1. Slow Itself Down Mechanism of Technology Stock

3. The Estimation of Appropriability and Specific Capacity

3.1 The estimate of appropriability using techno-economic data

Using equation (10), $\theta = \frac{1}{m} - \rho$, given m and ρ that it is possible to compute the appropriability of technology. To estimate θ , dynamic ρ and m were calculated using technology stock (i.e., $T_i = R_{i-m} + (1-\rho)T_{i-1}$) from the Japanese manufacturing sectors (1970 – 1996).

Finally, only after getting ρ and m, θ could be estimated and it was shown in Fig. 2. Fig 2 indicates that appropriability level of technology (θ = shared fraction) goes on increasing steadily from 1970 to 1996. In case of Japanese manufacturing industry, portion of shared technology is around 0.2, (1970: 0.1965, 1996: 0.2267). On the one hand, thinking about high-tech sector in which the spillovers are higher, it might be expected that its θ (=shared fraction) would increase rapidly

compared to the other industries.

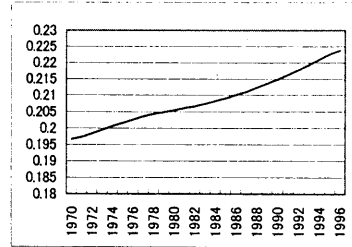


Fig. 2. Trends in Appropriability in Japan's MFG (1970 – 1996)

First two columns in table 1 show lead time and rate of obsolescence of each Japanese manufacturing sectors⁴. Almost all the lead times are located around 3.3 except CH, OIL sector. On the other hand, rate of obsolescence is the lowest value in PM and the highest one in P&P, CR of all sectors. On the basis of these data sets, average θ was computed by sectors. The result is illustrated in Table 1⁵.

Table 1 m, ρ and Estimated θ by Sectors (average value)

	m(Yr)	ρ (%)	θ
MFG Tot	3.3	9.8	0.205
P&P, CR	3.4	16.1	0.133
CH, OIL	4.2	9.0	0.148
PM	3.2	6.0	0.253
GM, EM, TM, PI	3.3	10.3	0.200
FD, MP	3.1	10.6	0.217

Comparing θ , sector PM has the highest value and the lowest rate of obsolescence of all the other sectors in the Japanese manufacturing sectors. We can infer that PM sector contains a lot of technology stock that is shared by other sectors (25.3% of technology stock). This implies that inside the PM sector, there may be large source of technology spillover and it can be considered as the most potential donor in the Japanese manufacturing sectors. However, estimated θ in Table 1 is not representative to draw implications, because it only shows the average values of Japan's MFG sector during the 1970s and 1980s.

Although shared portion of technology stock in memory sector is somewhat slightly larger than that of the Japanese manufacturing sectors, it should be emphasized that in the Japanese manufacturing sectors θ is not so significantly different from other sectors. In order to see and compare the trends in θ in detail, it will be more useful to compare other sectors like service sector, information & communication sector and computer sector and so on that has large rate of obsolescence and short lead time.

3.2 The estimate of specific capacity

As defined in section 2.1, specific capacity is equivalent

⁴ m and ρ are average values during 1970s and 80s. From Questionnaire to Major Firms (undertaken in April 1990, supported by AIST of MITI).

⁵ P&P, CR: pulp & paper, ceramics; CH, OIL: chemical, oil; PM: primary metal; GM, EM, TM, PI: general, electric, transportation machinery, precision instrument; and FD, MP: food, metal product.

to efficiency that specifies the amount of input own effort and spillover effect that increase technology stock by unit. Here if we think of meaning of sensitivity, it is the amount of change of the technology stock per unit change in the input variables. On the basis of the above definition, the relationship between sensitivity and specific capacity can be linked each other. That is to say, they have inverse relationship to each other. Mathematically, it can be expressed as follows:

$$\frac{1}{K_1} = C_{sp}, \quad \text{where } K_1 = \frac{C_{sp}}{\theta + \rho}$$

Thus, $C_{sp}^2 = \theta + \rho$, $C_{sp} = \sqrt{\theta + \rho}$ (14)

In order to understand the trend in specific capacity including spillover capacity, specific capacity is estimated and then was able to get following result using dynamic data set of ρ and θ . Fig. 3 shows the trend of specific capacity in the Japanese manufacturing sector and Fig. 4 indicates trends in growth rate of specific capacity and technology stock shared.

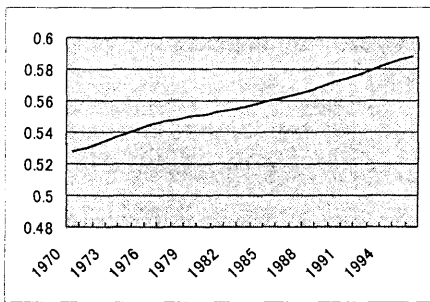


Fig. 3. Trends in Specific Capacity in Japan's MFG.

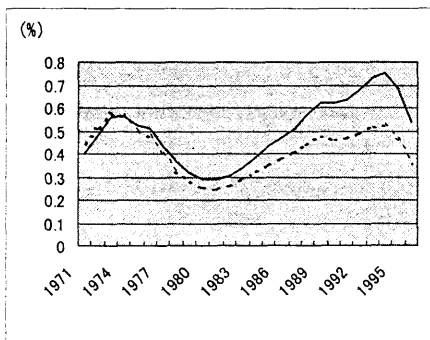


Fig. 4. The Growth Rate of Specific Capacity and Technology Shared in Japan's MFG (— θ , C_{sp})

Referring to the Fig. 4, growth rate of θ (a portion of shared technology stock) and specific capacity decreased from 1975 to 1982 and after 1995. The above trends suggest the

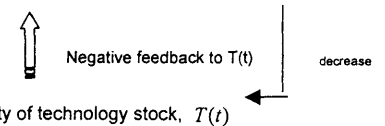
following interpretations: (i) although θ and C_{sp} increase steadily, there exist certain periods that spillover is not so active, and (ii) the gap between θ and C_{sp} increased more significantly from 1985. These imply that, although potential spillover pool increased in Japanese manufacturing sector, specific capacity was not sufficient to assimilate technology spillover.

4. Conclusion

4.1 Interpretations

(i) Upgrading specific capacity and restoring the appropriability play an important role to accumulate the technology stock efficiently.

$$T, (t) \uparrow, T_{st}(t) \Rightarrow C_{sp} \Rightarrow T(t) \uparrow \Rightarrow \rho \uparrow \Rightarrow m \downarrow \Rightarrow \tau \downarrow, \theta \uparrow$$



(ii) Due to self slow down trajectory of technology stock by means of short lead time, effective utilizing of technology spillover plays a complementary role to increase technology stock (Fig. 1).

(iii) In Japan's manufacturing sector, while potential spillover increased steadily, specific capacity was not sufficient to assimilate potential spillover pool (Fig. 4).

4.2 Concluding remarks

This paper has introduced several parameters as governing factors such as appropriability and specific capacity. Among these parameters, the increment of appropriability and the diminution of technology distance become spontaneous phenomena that we are not able to control. However, upgrading specific capacity including assimilation capacity never occurs automatically. It needs cost and efforts. This paper didn't treat the factors consisting of specific capacity and appropriability in a direct way. For the purpose of understanding this dynamic process of technology spillover more quantitatively, it is necessary to know and define the characteristics of specific capacity and appropriability in detail.

References

- Cohen, W.M. and Levinthal, D.A., 1989, Innovation and Learning: The Two Faces of R&D, *The Economic Journal* 99, 569-596.
- Griiches, Z., 1992, The Search for R&D Spillovers, *Scandinavian Journal of Economics* 94, 251-268.
- Hur K.I. and Watanabe C., 2000, Unintentional Technology Spillover between Two Sectors: Kinetic Approach, *Technovation*, in print.
- OECD, 1998, Analytical Report on Technology, Productivity and Job Creation - Best Policy Practices, Paris.
- Spence, M., 1984, Cost reduction, Competition, And Industry Performance, *Econometrica* 52, No. 1, 101 - 121.
- Watanabe, C., 1996, Measurement of the Dynamic Change in Rate of Obsolescence of Technology and Time Lag from R&D to Commercialization, *Proceedings of Annual Conference of the Japan Society for Science Policy and Research Management*, Osaka, 240-245.