Pergamon

Technovation 22 (2002) 437–444

technovation

www.elsevier.com/locate/technovation

Dynamic process of technology spillover; a transfer function approach

Kwang In Hur , Chihiro Watanabe [1],*

Department of Industrial Engineering and Management, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan

Received 18 September 2000; accepted 12 March 2001

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. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Technology spillover; Specific capacity; Transfer function; Technology stock; Appropriability

1. Introduction

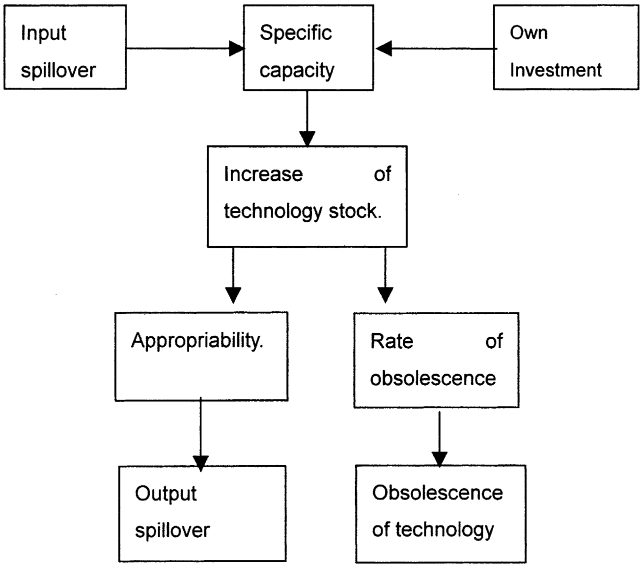

Fig. 1. Technology flow diagram and the parameters.

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. Fig. 1 summarizes 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.

---

* Corresponding author. Tel.: +81 3-5734-2248; fax: +81 3-5734-2252.

E-mail addresses: kihur@me.titech.ac.jp (K.I. Hur), chihiro-@me.titech.ac.jp (C. Watanabe).

[1] Senior advisor to the Director on Technology, International Institute for Applied Systems Analysis (IIASA)

PII: S0166-4972(01)00026-8

By utilizing the above 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 approach this process in a systematic way.

Section 2 introduces an 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 us 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:

$$C_{\mathrm{sp}}=\left(\frac{\partial T}{\partial T_{\mathrm{input}}}\right).$$

Generally, when we estimate technology stock, the following formula is considered: $T_{\mathrm{t}}=R_{\mathrm{t-m}}+(1-\rho)T_{\mathrm{t-1}}+\Delta T_{\mathrm{s}}$.[2] 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 in the technology stock (Cohen and Levinthal, 1989).

The nature of spillovers is unique to R&D. This special feature of R&D results from the imperfect appropriability of returns as a result of spillovers (Griliches, 1992). Technology spillovers exist and produce positive effects (OECD, 1998). Thus, lack of appropriability has positive effects on R&D dissemination (Shah, 1995). In other words, to recognize the portion of technology stock that is shared by other sectors may give us good informative facts. By calculating or estimating appropriability, it will be understood how much of technology is spillable from the donor side in technology spillovers.

Let us 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-θ) will not be shared. Let us assume that the increasing rate of θ will be proportional to the number [N] of firms in the sector (Spence, 1984):[3] $v_{\mathrm{a}}=k_{\mathrm{a}}(1-\theta)[\mathrm{N}]$ On the other hand, the diminishing rate of θ in turn is proportional to the fraction of technology shared: $v_{\mathrm{b}}=k_{\mathrm{b}}(\theta)$. 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 the equation:

$$k_{\mathrm{a}}(1-\theta)[N]=k_{\mathrm{b}}\theta \tag{1}$$

$$\frac{\theta}{1-\theta}=K[N] \text{ or } \theta=\frac{K[N]}{1+K[N]} \text{ where } K=k_{\mathrm{a}}/k_{\mathrm{b}} \tag{2}$$

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 in Fig. 2.

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

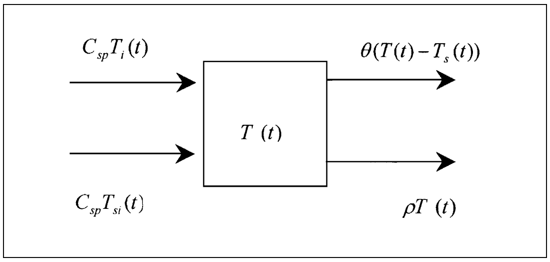

Fig. 2. Technology flows in a certain sector.

---

[2] R is own R&D investment; ρ is rate of obsolescence; and ΔT_{s} is increase of spillover technology.

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

$$z_{\mathrm{i}}=m_{\mathrm{i}}+\theta\sum_{j\neq i}m_{\mathrm{j}}.$$

where Z is tech stock; m is R&D investment. If θ=0, no spillover, θ=1, R&D shared completely.

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

where $T(t)$ is technology stock at time t; $T_i(t)$ is input technology flow by own R&D; $T_{si}(t)$ is input technology flow by spillover; $T_s(t)$ is technology stock of host (surrounding); ρ is the rate of obsolescence; θ is appropriability of technology (shared portion); and, C_{sp} is 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, $T_i(t)$, $T_{si}(t)$, is an input variable and thus is not considered as an unknown because it is up to us to specify how it will change. Eq. (3) can be rearranged as follows:

$$\frac{dT(t)}{dt}+(\theta+\rho)T(t)=C_{sp}T_i(t)+C_{sp}T_{si}(t)+\theta T_s(t), \tag{4}$$

$$\frac{1}{(\theta+\rho)}\,\frac{dT(t)}{dt}+T(t)=\frac{C_{sp}}{(\theta+\rho)}(T_i(t)+T_{si}(t))+\frac{\theta}{(\theta+\rho)}T_s(t)$$

and let

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

so

$$\tau\frac{dT(t)}{dt}+T(t)=K_1(T_i(t)+T_{si}(t))+K_2T_s(t) \tag{5}$$

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

$$\tau sT(s)+T(s)=K_1(T_i(s)+T_{si}(s))+K_2T_s(s) \tag{6}$$

where $T(0)=0$.

Rearranging this equation yields,

$$T(s)=\frac{K_1}{\tau s+1}(T_i(s)+T_{si}(s))+\frac{K_2}{\tau s+1}T_s(s) \tag{7}$$

Regarding input variables, their relationships with respect to the technology stock, $T(s)$, can be expressed individually as follows:

$$T(s)=\frac{K_1}{\tau s+1}(T_i(s)+T_{si}(s)) \text{ and } T(s)=\frac{K_2}{\tau s+1}T_s(s)$$

The above equations show the behavior of technology stock with respect to the change of technology flow of own R&D, of input spillover and technology stock of host, respectively.

Every positive change of input variables can increase the technology stock. This is because 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 dependent 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 response of the technology stock to this unit step function is given by

$$T(s)=\frac{K_1}{\tau s+1}\,\frac{1}{s} \text{ and } T(s)=\frac{K_2}{\tau s+1}\,\frac{1}{s}$$

$$\text{Unit step function } u(t)=\begin{cases}0(t<0)\\1(t\geq 0)\end{cases}$$

The use of inverse Laplace transform gives following the equations with respect to the unit increase of $T_i(t)+T_{si}(t)$ and $T_s(t)$, respectively.[4]

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

$$T(t)=\tau\theta(1-e^{-t/\tau}) \tag{9}$$

The response of Eq. (8) is shown graphically in Fig. 3.

2.3. The economic point of view of parameters

Rewriting the $K_1=\frac{\Delta\text{tech–stock}}{\Delta\text{input}}$ = the magnitude of technology stock to the change of input variables. In

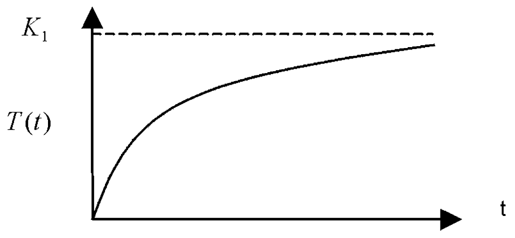

Fig. 3. Response of technology stock to a step change in $T_i(t)+T_{si}(t)$.

---

[4] Actually, Eqs. (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 Eq. (9), response with respect to the change technology stock of host, is beyond the scope of this paper.

other words, K_1 is the sensitivity that specifies the amount of change of technology stock per unit change of input variables $((T_i(t), T_{si}(t))$. 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 Eq. (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 is of no surprise that 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 capacity and appropriability related to their factors.

Next, let us 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. Fig. 4 shows the response of technology stock by different time constant.

Based on these characteristics, τ has the same meaning as lead time (m) between R&D and commercialization. Therefore, the following formulation can be derived:

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

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

$$\rho=A\rho_0e^{(T_t/T_0)^{\alpha}},\ m=\frac{\ln R_0/T_0-\ln(\rho+g)}{\ln(1+g)}+1$$

where g is the increasing rate of R_t in the initial period, R is the R&D expenditure. In the case of Japanese manufacturing industry, $\rho=0.0303e^{(T_t/T_0)^{0.15}}$, $m=-4.54\ln(g+\rho)-2.88$.

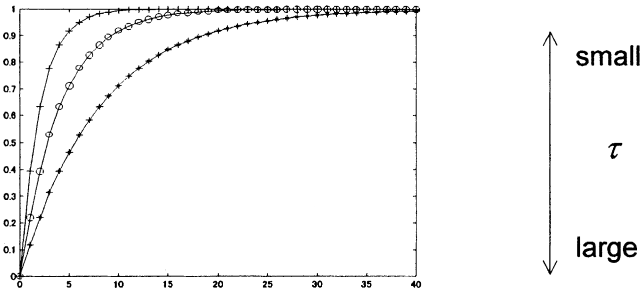

Fig. 4. Response of technology stock by different time constant.

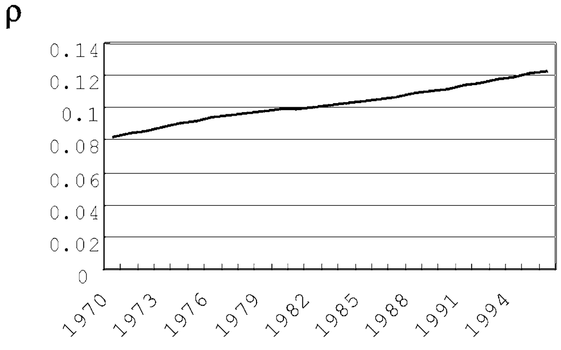

Fig. 5. Trends in rate of obsolescence in Japan's MFG (1970–1996).

Maclaurin approximation yields,

$$\rho=a+bT \text{ and } m=c-d\rho \tag{11}$$

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

In line with a previous approach (Hur and Watanabe, 2001), these approximations coincide with empirical results in the Japanese manufacturing sectors (Figs. 5 and 6 demonstrate the above relationships).

Similarly, Eq. (10) gives us the same linear relationship as Eq. (11). Taking Maclaurin approximation, at fixed θ, then

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

Comparing Eqs. (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.

As demonstrated in Figs. 5 and 6, the rate of obsolescence increases steadily as time goes by and it leads to a decrease of the time lag. On the basis of the above formulae, the role of technology spillover by utilizing mutual relationships between variables can be suggested (Fig. 7, Hur and Watanabe, 2001). As technology stock increases, the rate of obsolescence increases. Due to the relationship between lead time and rate of obsolescence, increment of obsolescence shortens lead time. Thus,

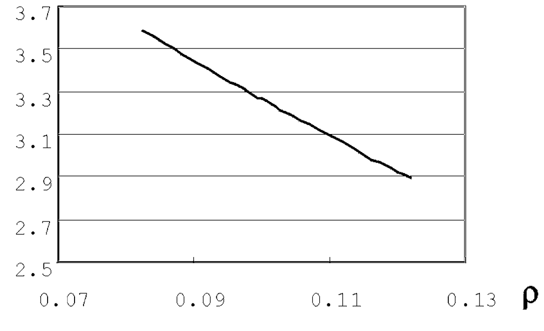

Fig. 6. Relationship between m and ρ in Japan's MFG (1970–1996).

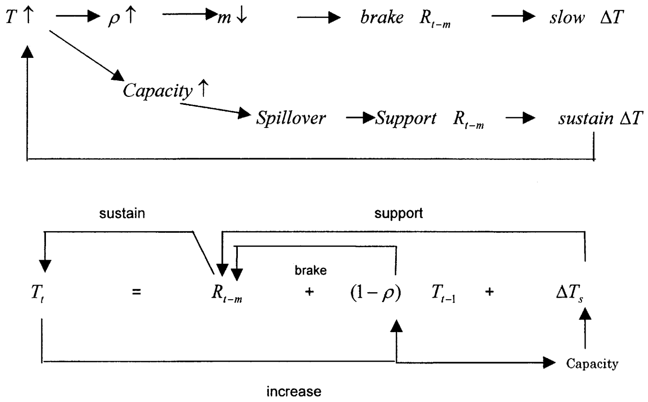

Fig. 7. The role of technology spillover in the accumulating process of technology stock.

short lead time puts the brake on sustaining level of technology stock.

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

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

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 slowing itself down characteristically under the condition that its capacity is enough to assimilate and maximize the spillover effects. Fig. 8 describes the mechanism.

3. The estimation of appropriability and specific capacity

3.1. The estimate of appropriability using techno-economic data

Using Eq. (10), $\theta=(1)/(m)-\rho$, given m and ρ that it is possible to compute the appropriability of technology.

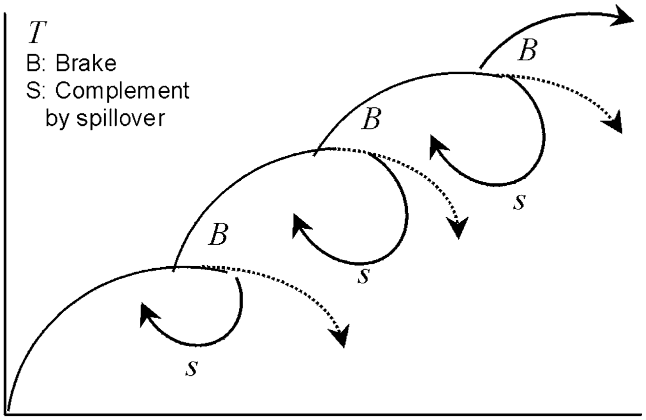

Fig. 8. Slow itself down mechanism of technology stock.

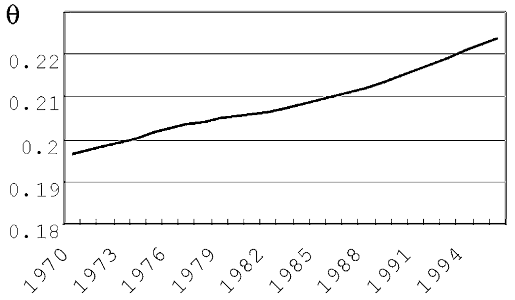

Fig. 9. Trends in appropriability in Japan's MFG (1970–1996).

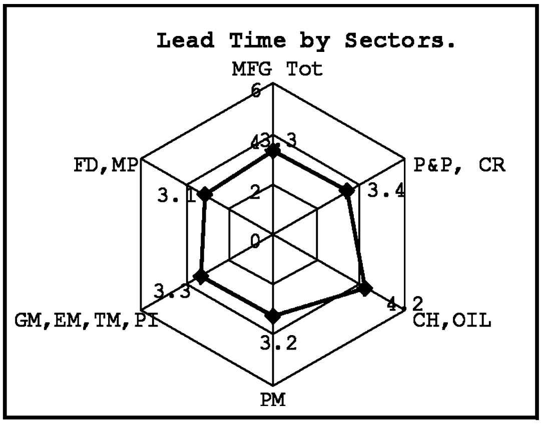

Fig. 10. Lead time by sectors.

To estimate θ, dynamic ρ and m were calculated using technology stock (i.e. $T_t=R_{t-m}+(1-\rho)T_{t-1}$) from the Japanese manufacturing sectors (1970–1996). Finally, only after getting ρ and m, θ could be estimated and it was shown in Fig. 9. Fig. 9 indicates that appropriability level of technology (θ= shared fraction) goes on increasing steadily from 1970 to 1996. In case of Japanese manufacturing industry, the 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.

Figs. 10 and 11 show lead time and rate of obsol-

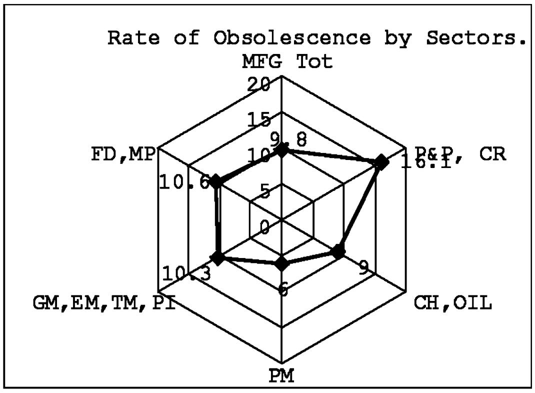

Fig. 11. Rate of obsolescence by sectors.

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

escence of each Japanese manufacturing sectors.[5]. 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 1[6] and Fig. 12.

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 sources 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.

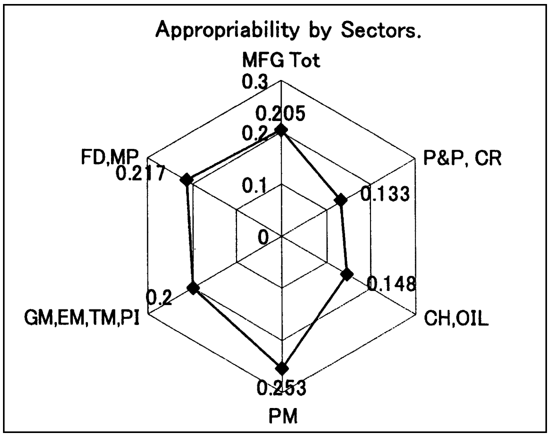

Fig. 12. Appropriability (shared portion) by sectors.

In order to review the situation of the Japanese manufacturing sectors, let us think of a semiconductor field, especially memory sector. 16M Dram was developed in early 1990 and the first sample shipment was made in the second half of 1991. 16M Dram was developed 2 years later when 4M Dram was developed (late 1987). Also, 64M Dram emerged in late 1992. Based on the above fact, we can think of lead time as around 2 or 2.5 years. After emergence of 16M Dram in 1990, its price decreased rapidly from the end of 1995. So, the rate of obsolescence in memory semiconductor field can be treated as 0.2 (life time is 5 years). Calculating θ of memory semiconductor field, θ has the value of 0.2 to 0.3. Broadly speaking, this value is not so different from that of the Japanese manufacturing sectors. The reason resulted from that fundamentally, memory industry is a kind of manufacturing sector. Its characteristic primarily depends on mass production.

Although the 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 and 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 to efficiency that specifies the amount of input own effort and spillover effect that increase technology stock by unit. Here if we think of the 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 to each other. That is to say, they have an inverse relationship to each other. Mathematically, it can be expressed as follows:

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

where ρ is the rate of obsolescence of technology stock; and θ is the appropriability.

Thus,

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

In order to understand the trend in specific capacity including spillover capacity, specific capacity is estimated and was then able to obtain the following result using the dynamic data set of ρ and θ. Fig. 13 shows the trend of specific capacity in the Japanese manufacturing sector and Fig. 14 indicates trends in growth rate of specific capacity and technology stock shared.

---

[5] m and ρ are average values during 1970s and 80s, from a questionnaire to major firms (undertaken in April 1990, supported by AIST of MITI).

[6] 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.

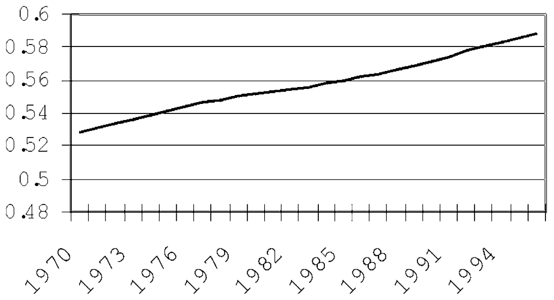

Fig. 13. Trends in specific capacity in Japan’s MFG.

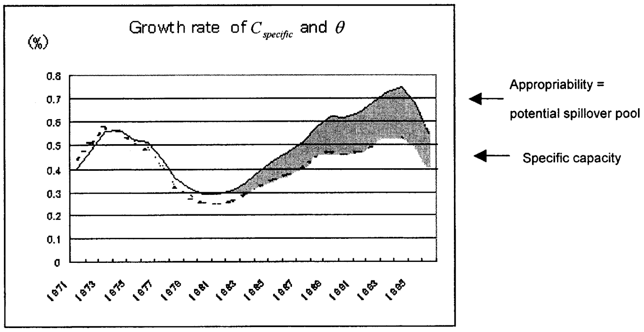

Fig. 14. The growth rate of specific capacity and technology shared in Japan’s MFG.

Referring to Fig. 14, 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. This implies that, although potential spillover pool increased in Japanese manufacturing sector, specific capacity was not sufficient to assimilate technology spillover.

4. Conclusion

4.1. Interpretation

1. Upgrading specific capacity and restoring the appropriability play an important role to accumulate the technology stock efficiently (Fig. 15).
2. 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. 8).
3. In Japan’s manufacturing sector, while potential spillover increased steadily, specific capacity was not sufficient to assimilate potential spillover pool (Fig. 14).

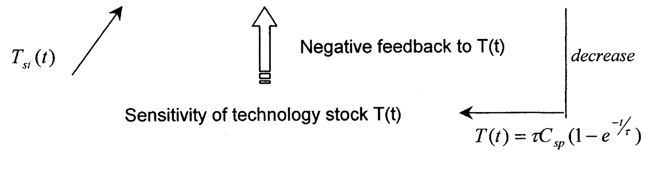

Fig. 15. Diagram in relation to the sensitivity of technology stock.

4.2. Concluding remarks

Applying transfer function concept, this study described the dynamic mechanism of spillover by mathematical models. Significance of model was demonstrated by means of empirical analysis focusing on Japan’s manufacturing sectors over the period 1970–1996. Furthermore, appropriability and specific capacity were identified and estimated. In addition, by proving the self slow down trajectory of technology stock in terms of mathematical expression, the complementary role of technology spillover was clarified.

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 effort. Considering new paradigm characterized by globalization, transboundary flow of technology, product and marketplace and information, technology spillover plays a critical role in sustainable strategic advantage. Under this situation, the continuous efforts on improving specific capacity would be most important to cope with an up and coming new paradigm.

In terms of this analysis, it was possible to find useful relationships for calculating the appropriability (= shared fraction) 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 order to understand how much spillable technology exists in a certain sector on the donor side, it will be very helpful to know the level of appropriability. Also, by means of sensitivity concept of technology stock, it was possible to estimate specific capacity in a broad manner. Transfer function analysis makes it possible to know the trends of appropriability on spillovers and of specific capacity in a certain sector. However, this paper did not 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.

Appendix A. Sources and data construction

S1 R&D expenditure: The Management and Coordination Agency (MCA), Report on the Survey of R&D (annual issues).

S2 The rate of obsolescence and time lag between R&D and commercialization: Questionnaire to Major Firms (undertaken in April 1990: supported by AIST (Agency of Industrial Science & Technology) of MITI).

S3 Others: Watanabe basic database

Given R&D expenditure in the period t (R_t), the increasing rate of R_t in the initial period (g), time lag of R&D to commercialization (m), and rate of obsolescence of technology (ρ), technology stock (T_t) is measured by the following equation:

$$T_t=R_{t-m}+(1-\rho)T_{t-1},\ T_0=R_{1-m}/\rho+g \tag{A1}$$

Given payment for technology imports, gross technology cost (GTC) is measured as follows:

$$GTC_t=R_t+T_{im} \tag{A2}$$

Considering GTC as total R&D expenditure in the period t, Eq. (A1) can be described as follow:

$$T_t=GTC_{t-m}+(1-\rho)T_{t-1},\ T_0=GTC_{1-m}/\rho+g \tag{A3}$$

where R is R&D expenditure at 1990 fixed prices; T_{im} is R&D expenditure for technology import at 1990 fixed prices.

References

Cohen, W.M., Levinthal, D.A., 1989. Innovation and learning: the two faces of R&D. The Economic Journal 99, 569–596.

Griliches, Z., 1992. The search for R&D Spillovers. Scandinavian Journal of Economics 94, 251–268.

Hur K.I., Watanabe C., 2001, Unintentional technology spillover between two sectors: kinetic approach. Technovation 21(4), 227–235.

Jaffe, A.B., 1986. Technological opportunity and spillovers of R&D: evidence from firm's patents, profits, and market value. The American Economic Review 76 (5), 984–1001.

OECD, 1998. Analytical Report on Technology, Productivity and Job Creation — Best Policy Practices. Paris.

Pakes, A., Schankerman, M., 1984. The rate of obsolescence of patents, research gestation lags and the private rate of return to research resources. In: Griliches, Z. (Ed.), R&D, Patents and Productivity. The University of Chicago Press, Chicago, pp. 73–88.

Shah, A., 1995. R&D capital, spillovers and industrial performance. In: Shah, A. (Ed.), Fiscal Incentives for Investment and Innovation. Oxford University Press for the World Bank, New York, pp. 240–243 and 247–249.

Spence, M., 1984. Cost reduction, competition, and industry performance. Econometrica 52 (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. In: Proceedings of Annual Conference of the Japan Society for Science Policy and Research Management, Osaka, 240–245.

Kwang In Hur graduated from Korea Advanced Institute of Science and Technology (KAIST) with a Bachelor's Degree in Chemical Engineering in 1996. He began his affiliation with a semiconductor company in Seoul, Korea and was in charge of overseas sales and marketing and JV (Joint Venture) coordinator. Currently, he is graduate student at the Department of Industrial Engineering and Management, Tokyo Institute of Technology while working at Samsung Electronics.

Chihiro Watanabe graduated from Tokyo University with a Bachelor's Degree in Engineering (Urban Planning) in 1968 and received his Ph.D. (Arts and Science) in 1992, also from Tokyo University. He began his affiliation with the Ministry of International Trade and Industry (MITI) in 1968. He is former Deputy Director-General of Technology Development at MITI. He is currently Professor at the Department of Industrial Engineering and Management, Tokyo Institute of Technology, and also Senior Advisor to the Director on Technology at International Institute for Applied Systems Analysis (IIASA).