Pergamon

Technovation 21 (2001) 227–235

technovation

www.elsevier.com/locate/technovation

Unintentional technology spillover between two sectors: kinetic approach

Kwang In Hur, Chihiro Watanabe *

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

Received 17 January 2000; accepted 21 April 2000

Abstract

Here we focus on the attempt to measure spillovers using a kinetic concept. The first purpose of this paper is to review the important factors that increase the assimilation capacity. These factors allow us to suppose that each sector is separated by a different level of position in order to calculate spillover effects. The second purpose is, therefore, to estimate the spillover effects in terms of a kinetic approach.

In this paper, we simulated the model using techno-economic data sets (Japanese manufacturing sectors) and were able to obtain some interesting findings and implications: (1) R&D spillover is a positive and significant externality and (2) the institutional effect is a crucial factor to accelerate the assimilation capacity. However, it should be emphasized that this approach does not consider multi-dimensional interactions among sectors.

With such estimates, it would be possible to compute not only the absorption and assimilation capacities, but also the technology stock including technology spillover beyond its own industry's borders. We believe that the kinetic approach proposed in this paper could suggest a practical estimating method in terms of calculating absorption and assimilation capacities using the concept of speed, instead of using a regression-based approach.

Keywords: Technology spillover; Assimilation capacity; Kinetic approach; Technology stock; Institutional effect; Two sectors

1. Introduction

Externalities are a source of increasing returns and productivity growth. Technology spillovers exist and the R&D of nearby firms produce positive effects, so that firms could get large benefits from spillovers (Griliches, 1998; Anon., 1998). This presence of R&D spillovers results because the firm generating the spillover cannot completely appropriate the returns associated with its R&D capital (Shah, 1995). Thus, the lack of appropriability has positive effects on R&D dissemination. This indicates that knowing the actual magnitude of such effects is very important. In this field, the major research question is a measurement question. How much of the R&D in an area or industry is spillable?

Major approaches to this measurement can be classified into two types: the case studies approach and the regression approach. Case studies examine in detail all of the costs and benefits, direct and indirect, related to a particular R&D project in a particular sector. However, case studies are not representative, in that they have concentrated on the calculation of social rates of returns or spillovers only for successful inventions or fields (Griliches, 1998). The regression approach consists of estimating either a production function (primal approach) or a cost function (dual approach) (Mohnen, 1996). Regression-based studies contain some problems. How is output measured and do the available measures actually capture the contribution of R&D? How is R&D capital to be constructed, deflated and depreciated (Griliches, 1998)?

From this point of view, the methods of measuring technology spillover effects are still insufficient. Thus, we limit ourselves here primarily to a discussion of the work on measuring R&D spillovers using a kinetic concept, although there have been many attempts to estimate externalities. Mansfield et al. (1977) calculated social and private returns and found that the median social

---

* 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).

PII: S0166-4972(00)00037-7

return was double the private return (56%, in contrast to 25%). Bernstein and Nadiri (1991) also reached similar conclusions. A selective list of work on estimating spillovers is summarized in Table 1.[1]

This paper is structured as follows. Section 2 explains the analytical framework based on a kinetic concept, Section 3 analyzes the dynamism of technology spillover and the absorption and assimilation capacities, Section 4 demonstrates the empirical analysis, and Section 5 briefly summarizes concluding remarks.

2. Analytical framework

Usually, because of difficulties in measuring the assimilation capacity of a certain sector in a direct manner, the concept of speed is analyzed as a proxy. We may think that if the speed is higher, the capacity can be considered to be larger. We hypothesize that the volume by spillover depends on the absorption and assimilation capacities and the level of a sector's own technology stock, i.e., research expenditures. Namely, the volume of technology flows is mainly related to the assimilation capacity and technology distance[2] (see Jaffe, 1986). These assumptions lead to a simple formulation in which there is an interaction between the volume of technology stock of the two sectors and the capacity of the receiver. The general concept is illustrated in Fig. 1. In our simplified system, there exist two kinds of capacity in relation to spillover:

1. *absorption capacity* — the capacity of the receiver to absorb technology from the other sector; and
2. *assimilation capacity* — the capacity of the receiver to assimilate and then utilize the technology absorbed from the other sector.

Table 1
Selected estimates of returns to R&D and R&D spillovers[a]

Industry	Rates of return to R&D	
Case studies		
Mansfield et al. (1977)	25	56
I–O weighted	Within	From outside
Terleckyj (1974)		
Total	28	48
Private	29	78
Sveikauskas (1981)	10 to 23	50
Goto and Suzuki (1989)	26	80
R&D weighted (patent flows)		
Griliches and Lichtenberg (1984)	46 to 69	11 to 62
Mohnen and Lepine (1988)	56	28
Proximity (technological distance)		
Jaffe (1986)		30% of within
Cost functions		
Bernstein and Nadiri (1988, 1989)		20% of within
Differs by industry	9 to 27	10 to 160
Bernstein and Nadiri (1991)	14 to 28	Median: 56% of within

[a] Adapted from Griliches (1998, Table 11.1, p. 264).

The amount of technology that came from A in terms of technology spillover can be calculated as follows.

1. The amount of technology that flows from A:

$$-\frac{dT_a}{dt}=k_1[T_a] \quad \longrightarrow \quad T_a=T_{a0}\,e^{k_1 t}, \tag{1}$$

   where $[T_a]=[T_{a0}]$ at time 0.
2. The amount of technology in the absorption and assimilation process. By solving the first ordinary differential equation, using an integrating factor, where $t=0$ and $X=0$, the following equation can be obtained:

$$\frac{dX}{dt}=k_1[T_a]-k_2[X] \quad \longrightarrow \quad [X]=T_{a0}\frac{k_1}{k_2-k_1}(e^{-k_1 t}-e^{-k_2 t}). \tag{2}$$

3. The amount of technology of Z that resulted from spillover:

$$\Delta T_s=[T_{a0}]-[T_a]-[X]=\frac{[T_{a0}]}{k_2-k_1}\{k_2(1-e^{-k_1 t})-k_1(1-e^{-k_2 t})\}=[T_{a0}]\left(1+\frac{k_2\,e^{-k_1 t}-k_1\,e^{-k_2 t}}{k_1-k_2}\right). \tag{3}$$

Here we can make a quick check as follows:

1. ΔT_s is 0 when time is 0; and
2. ΔT_s is T_{a0} when time approaches infinity. This means that if infinite time passed, the technology stock of Z will be the same as the technology stock of A at time 0.

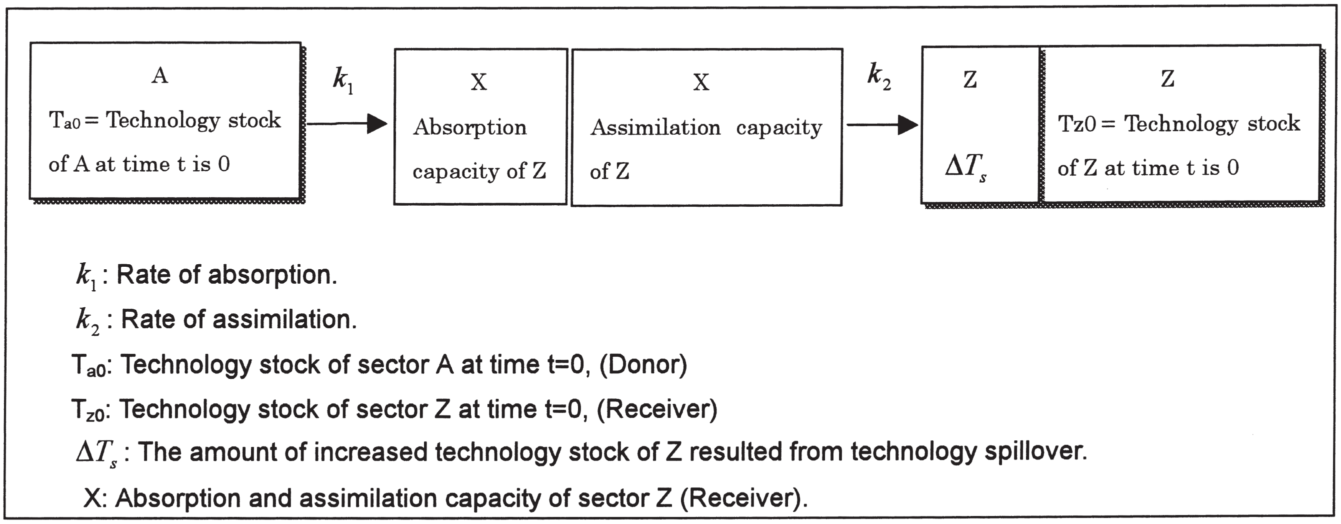
Based on Eq. (3), given absorption speed (k_1) and assimilation speed (k_2), the volume resulting from spillover can be computed. Since increasing technology stock by means of a sector's own investment would be the most significant way to upgrade its assimilation capacity, the relationship between technology stock and assimilation capacity is necessary to calculate the speeds.

To simplify our model and exhibit the essential technology stock (T)–assimilation capacity (AC) relationship,

---

[1] More details are shown by Mohnen (1996).

[2] $F_i=(R_{i1}/R_i, R_{i2}/R_i, \ldots, R_{in}/R_i)$, $F_j=(R_{j1}/R_j, R_{j2}/R_j, \ldots, R_{jn}/R_j)$, $P_{ij}=(F_i\cdot F_j)/(|F_i||F_j|)$. It ranges between 0 and 1. It is closer to unity the greater the degree of overlap of the two sectors' research interests. But, in this paper, $P_{ij}=D$ is only a conceptual idea that is not specified by mathematical formula. As the distance approaches 0, the closer are the research interests.



k_1: Rate of absorption.

k_2: Rate of assimilation.

T_{a0}: Technology stock of sector A at time t=0, (Donor)

T_{z0}: Technology stock of sector Z at time t=0, (Receiver)

ΔT_s: The amount of increased technology stock of Z resulted from technology spillover.

X: Absorption and assimilation capacity of sector Z (Receiver).

Fig. 1. Modeling of the technology spillover and assimilation mechanism.

let us first make assumptions. Assume that *AC* depends chiefly on *T* and institutional effects (such as specific culture, learning effect, regulation and deregulation, and so on) only, and, in the absence of *T*, there is no *AC*.

Mathematically we may express the dependence of *AC* on *T* as a functional relationship. Now let us describe this relational behavior by a differential equation. We hypothesize that, for changes in *T*, the growth rate of *AC* is usually proportional to technology stock, that is:

$$\frac{\Delta AC}{AC}=c\frac{\Delta T}{T} \quad (0\leq c\leq 1), \tag{4}$$

where the proportionality constant is c and the institutional effects are represented by α. By integrating:

$$AC=\alpha T^{c} \quad (0\leq c\leq 1). \tag{5}$$

As shown in Fig. 2, assimilation capacity would be expected to increase gradually in response to increased technology stock. However, although assimilation capacity may rise very rapidly at first, it would eventually level off due to the range limitation of c, despite the increase of technology stock.

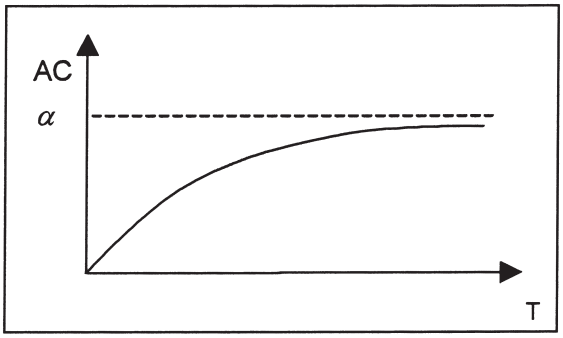


Fig. 2. The relationship between *AC* and *T*.

3. The dynamism of technology spillover and absorption and assimilation capacities

3.1. The impact and dynamism of technology spillover

In order to demonstrate the impact of technology spillover, the technology stock at time t (T_t), the rate of obsolescence of technology (ρ) and the time lag between R&D and commercialization (m) are introduced (Pakes and Schankerman, 1984). The following mathematical formulae were developed:[3]

$$T_t=R_{t-m}+(1-\rho)T_{t-1}, \tag{6}$$

$$\rho=A\rho_0\, e^{(T_1/T_0)^{\alpha}} \tag{7a}$$

and

$$m=\frac{\ln(R_0/T_0)-\ln(\rho+g)}{\ln(1+g)}+1, \tag{8a}$$

where g is the increasing rate of R_t in the initial period and R_{t-m} is the R&D expenditure in time $t-m$.

Regarding Eqs. (7)a and (8)a, Maclaurin approximation yields linear relationships as follows:

$$\rho=A+BT \tag{7b}$$

and

$$m=C-D\rho, \tag{8b}$$

where A, B, C and D are constant coefficients.

In line with previous approaches (Watanabe, 1996), these approximations coincide with empirical results in

---

[3] Regarding Eqs. (7)a and (8)a, see Watanabe (1996, 1999). In the case of Japanese manufacturing industry, ρ=0.0303 $\exp(T_t/T_0)^{0.15}$ and $m=-4.54\ln(g+\rho)-2.88$.

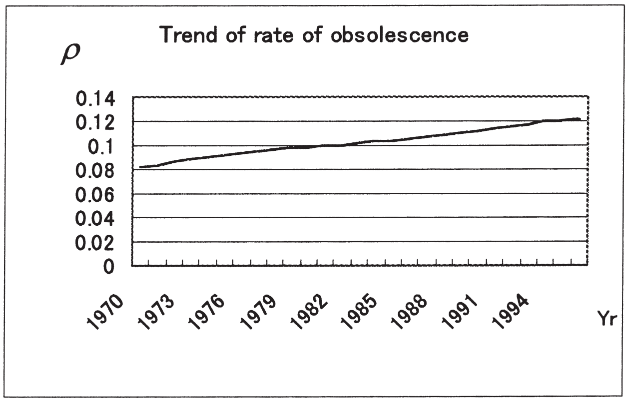


Fig. 3. The trend of rate of obsolescence (1970–96).

Japanese manufacturing sectors (Figs. 3 and 4 demonstrate the above relationships).

As demonstrated in Figs. 3 and 4, the rate of obsolescence[4] increases steadily as time passes and this leads to a decrease in the time lag that puts a brake on sustaining the level of technology. On the basis of the above formulae, we can suggest the role of technology spillover by utilizing mutual relationships between variables. As technology stock increases, the rate of obsolescence increases. Due to the relationship between lead time and rate of obsolescence, the increase of obsolescence shortens the lead time.

However, the increase of assimilation capacity through the increase of technology stock can sustain and support a desirable level of technology stock as a result of maximizing the spillover effect. In other words, an effort to upgrade spillover capacity plays an important role in sustaining technology stock under short lead time and risky R&D. These relationships are drawn in Fig. 5.

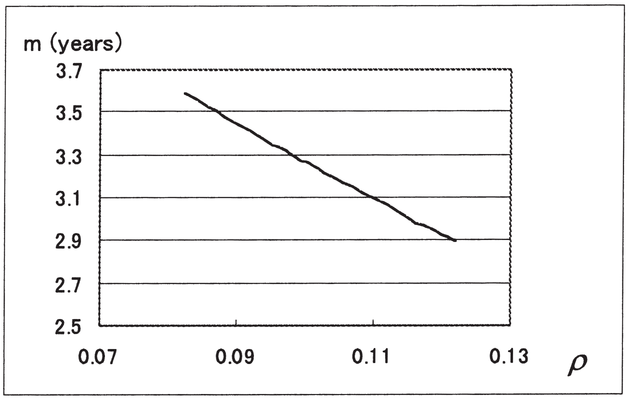


Fig. 4. Relationship between m and ρ (1970–96).

Increasing ρ and decreasing m are very general phenomena for every sector. Especially in the extreme case like the high-technology sector, these phenomena are really serious. However, despite risky R&D investment, we may explain that the spillover effect sustained the technology level of this high-technology sector by supporting the sector's own R&D investment and reducing the risk.

3.2. The estimation of absorption and assimilation capacities

In order to compute the volume by technology spillover, we have to calculate the speeds in relation to absorption and assimilation capacities. Instead of estimating absorption and assimilation capacities directly, we use absorption and assimilation speeds as a proxy of absorption and assimilation capacities. Assume that the overall speed depends chiefly on technology stock, technology distance and other factors like specific culture, learning effect, regulation, deregulation and so on. Thus, the overall rate (k_{overall}) can be described as follows:

$$k_{\text{overall}}=F(T, D, \alpha), \tag{9}$$

where D is the technology distance and α represents other factors.

Obviously, as the overall speed is larger if T and α are higher and D is lower, this relationship between k_{overall} and T can be represented in the following mathematical equation:

$$k_{\text{overall}}=\alpha\, \mathrm{e}^{-D/T}. \tag{10}$$

Fig. 6 illustrates this relationship.

As we mentioned earlier, the overall process can be divided into two parts. One is the absorption speed and the other is the assimilation speed. Decomposing the overall speed into two parts according to each step, we can get each speed as follows:

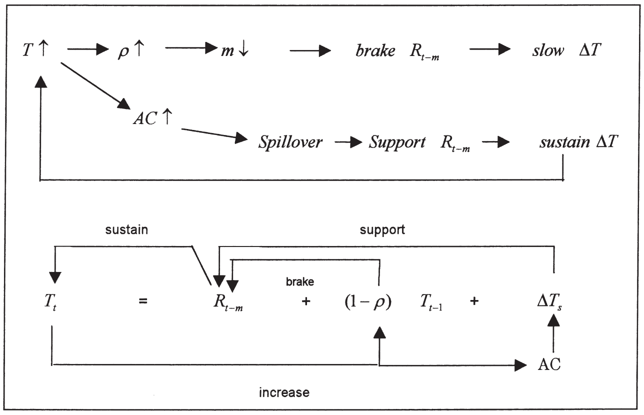


Fig. 5. The role of technology spillover in the accumulating process of technology stock.

---

[4] In order to identify the lead time and the rate of obsolescence of technology, we used data sets from a questionnaire to major firms undertaken in April 1990, supported by the Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry (MITI).

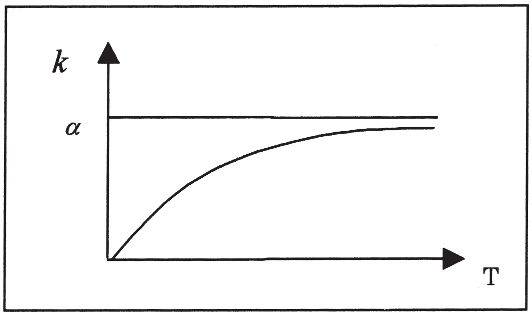


Fig. 6. The relationship between k and T.

1. rate of absorption (depends only on technology distance and α)

$$k_1=\alpha\, e^{-D} \tag{11}$$

2. rate of assimilation (depends only on technology stock of Z and α)

$$k_2=\alpha\, e^{-1/T} \tag{12}$$

In Eqs. (11) and (12), the variable α includes institutional effects such as the learning effect, labor quality, regulation, deregulation and so on. In order to estimate α, considering the differential form of a Cobb–Douglus type production function,[5] we get the following equation:

$$\frac{\Delta Y}{Y}=\sum_{L,\,K,\,M,\,E}\frac{\partial Y X}{\partial X Y}\frac{\Delta X}{X}+\lambda+\frac{\partial Y T}{\partial T Y}\frac{\Delta T}{T}. \tag{13}$$

In Eq. (13), institutional effects (learning effects, specific culture, etc.) usually are explained by λ. Therefore, if we substitute λ for α in the rate equations (11) and (12) and rewrite formulae, then:

$$k_1=\lambda\, e^{-D} \tag{14}$$

and

$$k_2=\lambda\, e^{-1/T}. \tag{15}$$

The above equations suggest that, given λ, T and D, we can calculate the rates, k_1 and k_2. Consequently, we are able to measure technology spillover effects in a bilateral relationship at different absorption and assimilation speeds.

4. Empirical analysis

4.1. The method of empirical analysis

Assume that technology spillovers coming from sector A (at time $t-1$) can affect only sector Z by time t (for example, within a year). The technology stock of Z at time t can be expressed as follows:

$$T_{t,\,z}=R_{t-m,\,z}+(1-\rho)T_{t-1,\,z}+\Delta T_s \tag{16}$$

In other words, given $T_{t-1,\,z}$, $T_{t-1,\,a}$, D (technology distance) and α (institutional effect, learning effect, etc.), we are able to calculate the rates k_1 and k_2, and then finally ΔT_s can be estimated. If we hypothesize that a sector's own R&D efforts are totally transferred to its technology stock, the technology stock of Z at time t will be:

$$T_{t,\,z}=T_{\text{own investment}}+(1-\rho)T_{t-1,\,z}+\Delta T_s \tag{17}$$

By taking a step-by-step procedure and repeating this calculation during a certain period, we can calculate total amount of ΔT_s, so that it is possible to compare the contributions of the spillover effect and the research effect in a certain sector. Fig. 7 describes the details of this process.

Finally, at time n, If we calculate the technology stocks of Z, $T^{\text{pure}}_{z,\,n}=R_{n-m,\,z}+(1-\rho)T_{z,\,n-1}$ (without considering spillover) and $T_{z,\,n}=T_{z,\,n-1}+\Delta T_{ns}$ (including spillover), and subtract $T^{\text{pure}}_{z,\,n}$ from $T_{z,\,n}$, we can find the total magnitude of technology spillover that comes from the specific sector A during a certain period (i.e., $T_{z,\,n}-T^{\text{pure}}_{z,\,n}=\sum_{i=1}^{n-1}\Delta T_{s,\,i}+\Delta T_{s,\,n}$).

4.2. Simulation and results

With the aim of simulating the model, we chose three leading sectors from Japanese manufacturing industry. One is electric machinery (EM), the others are precision instruments (PI) and general machinery (GM). Comparing data sets, EM has a relatively higher technology stock than PI and GM. Therefore, we can consider EM as the donor and PI and GM as the receivers (host) in our closed system. Also, the technology stock of GM is higher than that of PI. On the other hand, we took a technology distance range from 0 to 1. As the distance of technology between two sectors approaches 0, the receiver has very similar technology interests to the donor. Regarding institutional effects, α, they start from 0.01 with an annual

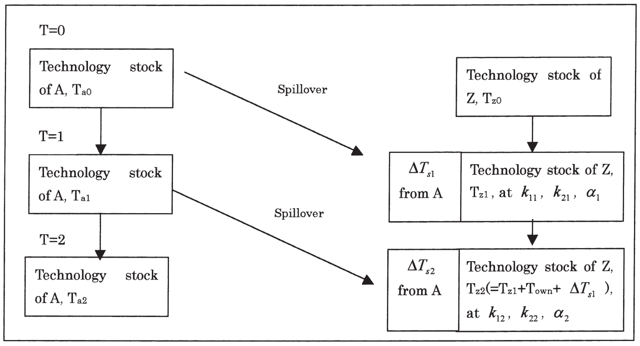
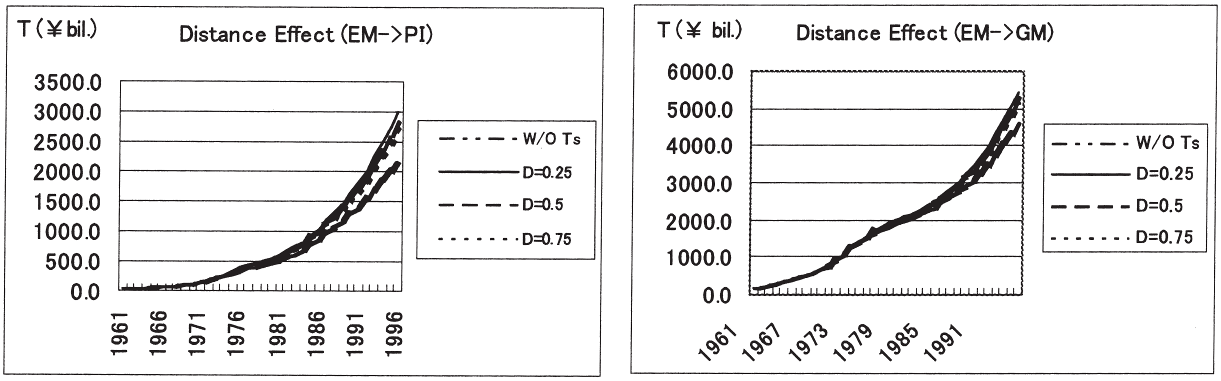


Fig. 7. The practical method of measuring technology spillover.

---

[5] Production function, $Y=F(L, K, M, E, T, t)=e^{\lambda t}L^{\alpha}K^{\beta}M^{\gamma}E^{\delta}T^{\xi}$, where Y=production; L=labor; K=capital; M=intermediate input; E=energy; T=technology; t=time trend; and α, β, γ, δ and ξ are the elasticities of respective production factors. Here, $\lambda=(\partial Y/\partial t)(1/Y)$.



$\Delta\alpha = 0.01$	W/O Ts	D=0.25	D=0.5	D=0.75
EM→ PI	2123.2	2989.2	2811.9	2668.5
EM→ GM	4552.7	5418.8	5241.5	5098.0

Fig. 8. Spillover effect under different technology distances when $\Delta\alpha$=0.01.

increment of 0.01 or 0.02 ($\Delta\alpha$=dα/dt, 0.01 or 0.02).[6] We tested the spillover effect under several different levels of technology distance (D=0.25, 0.5 and 0.75)[7] and institutional effects ($\Delta\alpha$=0.01 or 0.02) at each sector (spillover from EM to PI and GM). The simulation results are illustrated as follows.

Fig. 8 demonstrates that the differences of technology distance affect technology stock at each sector. Technology stock is 2123 billion yen (from EM to PI) and 4552 billion yen (from EM to GM) when we do not consider technology spillover. However, if we take spillover into consideration under a certain technology distance (for instance, D=0.25), technology stocks increase by nearly 40% and 19% in comparison to the stock without considering technology spillover at a fixed annual increment of institutional effects.

Looking at Figs. 9 and 10, we note that the annual increment of the institutional factor provides to a significant contribution to maximize the technology spillover effect. As the institutional factor of the receiver side doubles, assimilated spillover technology shows a significant contribution to technology stock of receiver sides. If we compare the institutional effect with the distance effect under the same technology distance, 0.25, spillover by the institutional effect is three times that of the distance effect at each sector. These simulation results indicate that upgrading assimilation capacity, especially in terms of the institutional factor, seems to be the best way to maximize the spillover effect.

Fig. 11 shows the distance effect in relation to technology stock and assimilation speed under different technology distances. We can note that differences of distance are not so significant as to accelerate the assimilation speed. However, as we mentioned earlier in Fig. 2, we are able to see that assimilation speed eventually levels off despite the increase of technology stock.

Contrary to Fig. 11, Fig. 12 indicates that an increment of the institutional factor gives a significant contribution to accelerate assimilation speed, rather than technology distance differences. At the same time, as shown in Fig. 12, increasing the institutional factor relieves the saturation of assimilation speed at high technology level, so that finally it increases the assimilation speed. Therefore, these results imply that upgrading the institutional factor is a crucial driving force to increase the assimilation speed and to maximize the spillover effect.

4.3. *Interpretations*

Based upon our simulation results, we can suggest several findings as follows:

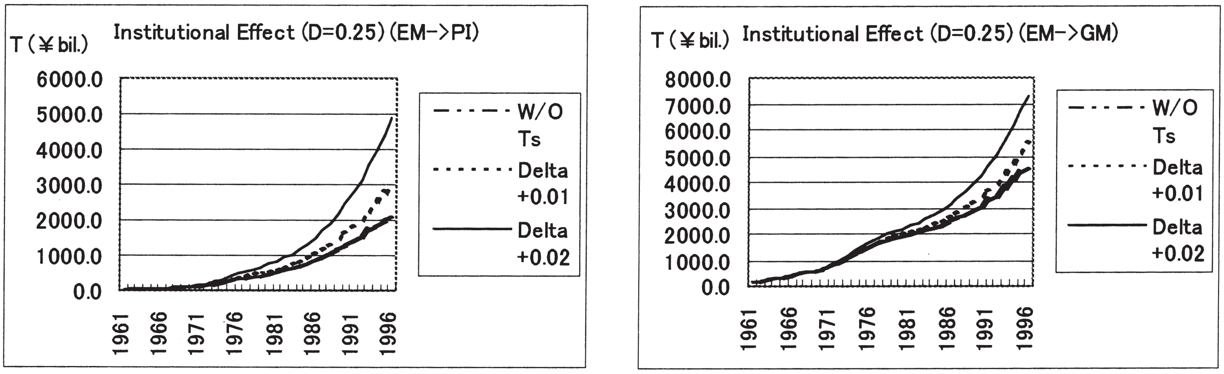
1. the spillover effect exists and its impact is significant (Table 2);
2. the spillover effect is large when technology stock is relatively small and technology distance is small (Fig. 13);[8]
3. technology distance is relatively not so significant but

---

[6] α was chosen arbitrarily. We tested several different levels of α, such as 0.001, 0.01 and 0.1 that are close to 0 at the starting point, when time is 0. Finally, we could get a reasonable result when we selected α=0.01 and it coincided with the range (two places of decimals) of absorption and assimilation speeds.

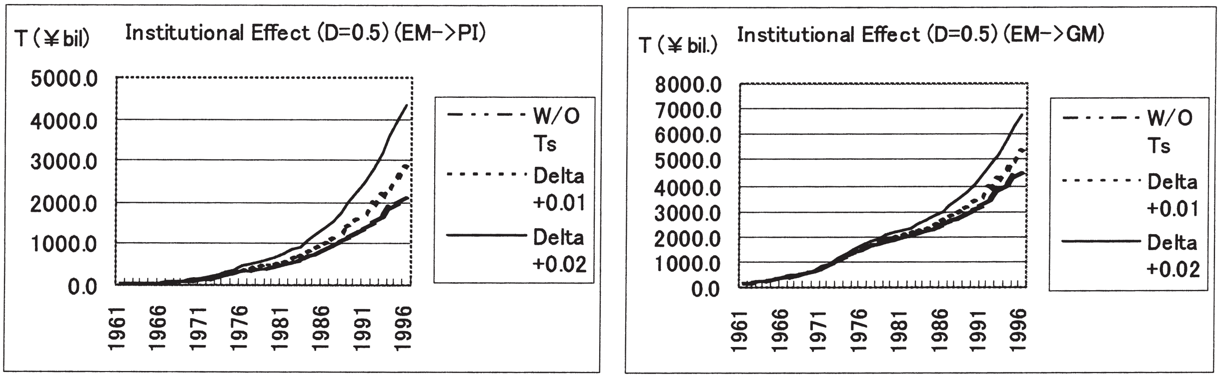
[7] We simulated the use of different technology positions. Technology distance was not designated especially.

[8] FD=food, PP=pulp and paper, CR=ceramics, PM=primary metal, MP=metal product, TM=transport machinery, GM=general machinery, PI=precision instruments.



D=0.25	W/O Ts	$\Delta\alpha = 0.01$	$\Delta\alpha = 0.02$
EM ➔ PI	2123.2	2989.2	4872.2
EM ➔ GM	4552.7	5418.8	7301.8

Fig. 9. Spillover effect under different institutional effects when *D* is 0.25.



D=0.5	W/O Ts	$\Delta\alpha = 0.01$	$\Delta\alpha = 0.02$
EM ➔ PI	2123.2	2811.9	4353.1
EM ➔ GM	4552.7	5241.5	6782.7

Fig. 10. Spillover effect under different institutional effects when *D* is 0.5.

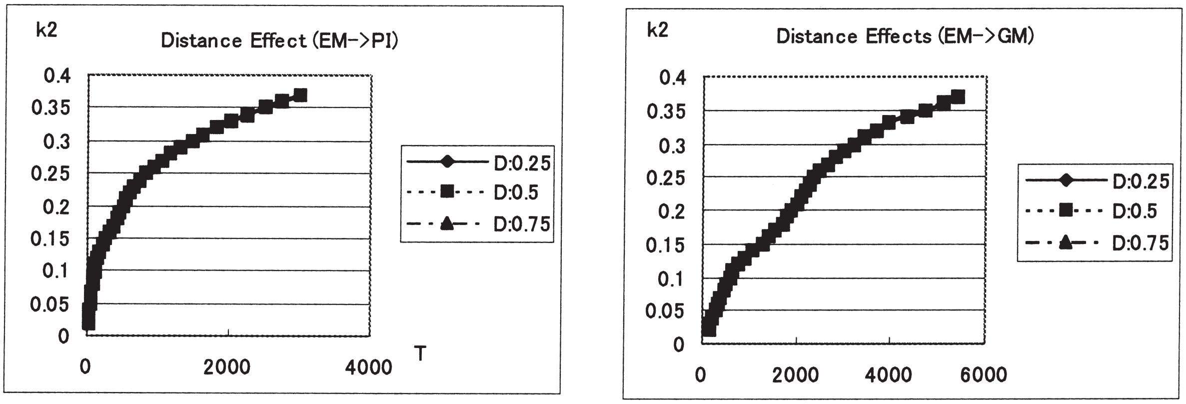


Fig. 11. Technology distance effect between *T* and k_2 when $\Delta\alpha$=0.01.

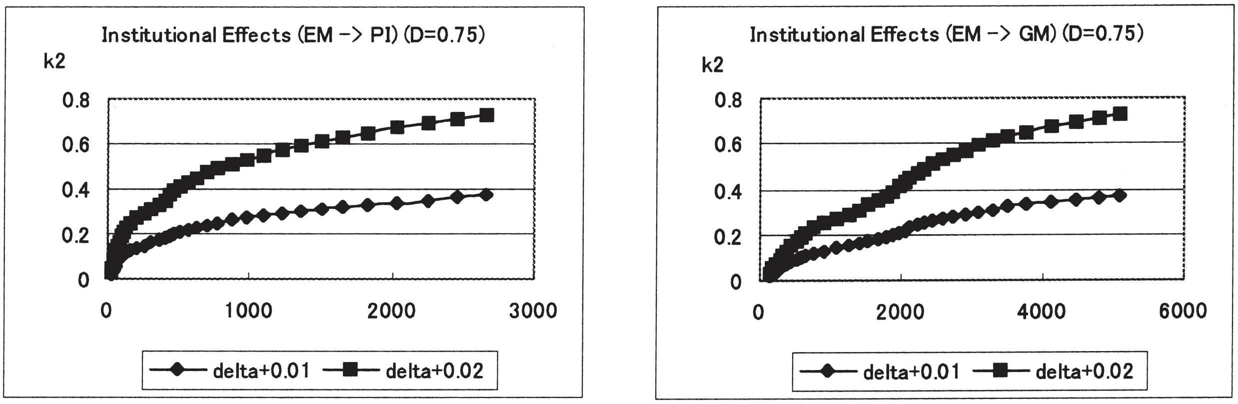
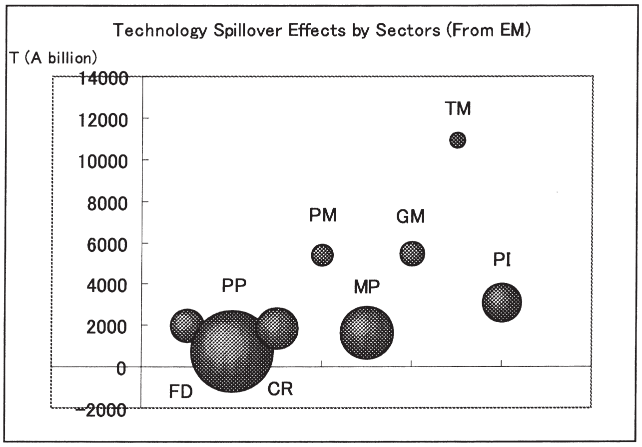


Fig. 12. Institutional effect between T and k_2 when D=0.75.

Table 2
Spillover effect

	D=0.25	D=0.5	D=0.75
EM→PI (%)	40.7	32	25.7
EM→GM (%)	19	15.1	11.9



From EM	FD	PP	CR	PM	MP	TM	GM	PI
D	0.9	0.8	0.6	0.5	0.4	0.3	0.2	0.1

Fig. 13. Spillover effects by sectors (D was chosen arbitrarily; the size of the circle indicates the magnitude of spillover effects).

the institutional effect is a very significant factor for technology spillovers (Table 3);
4. technology distance has only a small effect on assimilation speed (Fig. 11); and
5. the institutional factor (such as the learning effect, specific culture, labor quality, etc.) is significant to increase the assimilation speed (assimilation capacity) (Fig. 12).

Table 3
Spillover effect under different institutional effects and technology distances

	D=0.25		D=0.5	
	$\Delta\alpha$=0.01	$\Delta\alpha$=0.02	$\Delta\alpha$=0.01	$\Delta\alpha$=0.02
EM→PI (%)	40.7	129	32	105
EM→GM (%)	19	60	15.1	49

5. Concluding remarks

Although the concept of technology distance and assimilation capacity has attracted the attention of many researchers, it is still very hard to define and estimate in detail at this stage. In this paper, the institutional factor was considered as only one variable. However, the institutional factor contains many factors such as labor quality, learning effect, infrastructure, etc. From this prospect, the institutional factor should be subdivided into different factors to find the most crucial one and be measured more precisely. Also, this model considered only technology spillover effects from just two, certain designated sectors. But, actually, technology spillovers come from various sectors and have simultaneous effects. From this point of view, it is necessary to develop multidimensional models explaining the interactions among sectors. Finally, technology spillover occurs via several routes. Possible channels are patents, input purchases, products and R&D personnel mobilization, and so on. Each channel might have different characteristics and specific processes. Considering the importance and the increasing impact of technology spillover on the economy, this indicates that clarifying the relevant processes of each channel in the occurrence spillover is worthy of exploration.

Appendix A. Data construction and sources

A.1. Measurement of technology stock

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

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

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

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

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

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

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

A.2. Sources of data

S1 — R&D expenditure: The Management and Coordination Agency (MCA);
S2 — the rate of obsolescence and time lag between R&D and commercialization: questionnaire to major firms (undertaken in April 1990, supported by AIST of MITI); and
S3 — others: Watanabe (1999).

References

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

Bernstein, J.I., Nadiri, M.I., 1988. Interindustry R&D spillovers, rates of return, and production in high-tech industries. The American Economic Review 78 (2), 429–434.

Bernstein, J.I., Nadiri, M.I., 1989. Research and development and intra-industry spillovers: An empirical application of dynamic duality. Review of Economic Studies 56, 249–269.

Bernstein, J.I., Nadiri, M.I., 1991. Product demand, cost of production, spillovers, and the social rate of return to R&D. NBER WP 3625.

Goto, A., Suzuki, K., 1989. R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries. Review of Economics and Statistics 71 (4), 555–564.

Griliches, Z., Lichtenberg, F., 1984. Interindustry technology flows and productivity growth: A reexamination. Review of Economics and Statistics 66 (2), 324–329.

Griliches, Z., 1998. In: R&D and Productivity: The Econometric Evidence. The University of Chicago Press, Chicago, IL, pp. 251–268. Scandinavian Journal of Economics 94(reprint).

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.

Mansfield, E., Rapoport, J., Romeo, A., Wagner, S., Beardsley, G., 1977. Social and private rates of return from industrial innovations. Quarterly Journal of Economics 77, 221–240.

Mohnen, P., Lepine, N., 1988. Payments for technology as a factor of production, University of Montreal, Department of Economics, Paper No. 8818.

Mohnen, P., 1996. R&D externalities and productivity growth. In: STI Review No. 17. OECD, Paris, pp. 39–59.

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. University of Chicago Press, Chicago, IL, 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/World Bank, New York, pp. 240–243(also pp. 247-249).

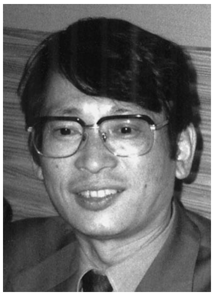
Sveikauskas, L., 1981. Technological inputs and multifactor productivity growth. Review of Economics and Statistics 63 (2), 275–282.

Terleckyj, N., 1974. Effects of R&D on the Productivity Growth of Industries: An Exploratory Study. National Planning Association, Washington, DC.

Watanabe, C., 1996. Measurement of the dynamic change in rate of obsolescence of technology and time lag from R&D to commercialization. In: Annual Conference of the Japan Society for Science Policy and Research Management, Osaka., pp. 240–245.

Watanabe, C., 1999. Systems option for sustainable development — effect and limit of the Ministry of International Trade and Industry's efforts to substitute technology for energy. Research Policy 28 (7), 719–749.

Kwang In Hur graduated from the 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 a graduate student at the Department of Industrial Engineering and Management, Tokyo Institute of Technology.



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 the International Institute for Applied Systems Analysis (IIASA).