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Unintentional Technology Spillover between Two Sectors: Kinetic Approach

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Abstract

Here we focus only on the attempt to measure spillovers using a kinetic concept. Technology spillovers exist and the R&D of nearby firms produce positive effects, so that firms could get large benefits from spillovers. The first purpose of this paper is to review the important factors to increase the assimilation capacity. These factors allow us to suppose that each sector is separated by different level of position in order to calculate spillover effects. The second purpose is therefore to estimate the spillover effects in terms of kinetic approach. In this paper, we simulated the model using techno-economic data sets (Japanese manufacturing sector) and were able to obtain some interesting findings and implications: a) R&D spillover is a positive and significant externality and b) institutional effect is a crucial factor to accelerate 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 capacity but also the technology stock including technology spillover beyond its own industry's borders. We think, this kinetic approach that we proposed in this paper could suggest a practical estimating method in terms of calculating absorption and assimilation capacity using speed concept instead of using regression based approach.

1. Introduction

The externalities are a source of increasing returns and productivity growth. Spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates (Z. Griliches,1992 and OECD,1998). It does indicate that knowing the actual magnitude of such effects is a very important one. In this field, the major research question is a measurement question. How much of the R&D in an area or industry is spillable? The spillovers are ideas borrowed by a certain industry i from the research results of other industry j. The presence of spillovers resulted from that the firm generating the spillover cannot completely appropriate the returns associated with its R&D capital (A. Shah,1995).

There are basically two types of estimates to be found in the literature: the case studies approach and the regression approach. Case studies examine in detail all the costs and benefits, direct and indirect, related to a particular R&D project in a particular sector. However, case studies are not representative, that they have concentrated on the calculation of social rates of returns or spillovers only for successful inventions or fields (Z. Griliches, 1992). The regression approach consists in estimating either production function (primal approach) or cost function (dual approach) (Mohnen, 1996). Regression-based studies contain some problems. How output is measured and whether the available measures actually capture the contribution of R&D, and how R&D capital is to be constructed, deflated and depreciated (Z. Griliches, 1992). In this point of view, the methods of measuring technology spillover effects are still insufficient. Thus, here we limit primarily to a discussion of the work on only measuring R&D spillovers using kinetic concept though there are many attempts to estimate externalities. Mansfield(1977) calculated social and private returns and found that the median social return was twice as large as the private return (56% in contrast to 25%). Bernstein and Nadiri (1988) also reached similar conclusions. A selective list of estimating spillovers is summarized in table 1.

Table1. Selected Estimates of Returns to R&D and R&D Spillovers

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

- Adapted from Zvi Griliches (R&D and Productivity, The econometric evidence, table 11.1 p264).[1]

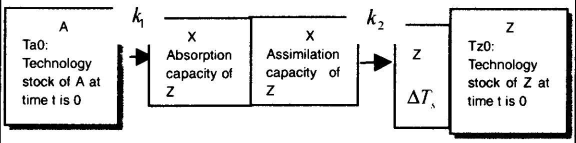
[1] More details are shown by Pierre Mohnen (R&D Externalities and productivity growth, table 1, 2 p43-48, STI Review No.17, OECD, 1996).

Section 2 explains the analytical framework based on kinetic concept. The relationship between technology stock and assimilation capacity is shown in section 3, and section 4 demonstrates the analysis of the impact of technology spillover. Section 5 is the estimate of assimilation capacity and section 6 provides the method of empirical analysis. Finally, in section 7 and 8, we simulated using techno-economic data sets and draw conclusions based on simulation results.

2. Analytical Framework

Usually, due to difficulties in measuring assimilation capacity of a certain sector, let's think about the speed concept. We may think that if the speed is higher, we can consider the capacity is larger. Moreover, the amount (speed as a proxy) borrowed unintentionally depends also on absorption and assimilation capacity and the level of own Technology stock, i.e, research expenditures. At the same time, the volume (speed) of technology flows is related to the assimilation capacity and technology distance (See Jaffe, 1986)[2]. These 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 receiver. The general concept is illustrated in Fig 1. Let's think about two capacities in relation to spillover.

1) Absorption capacity: The capacity of receiver to absorb technology from the other sector.
2) Assimilation capacity: The capacity of receiver to assimilate and then utilize technology absorbed from the other sector.



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

If we calculate the amount of technology that came from A in terms of technology spillover;

1) The amount of Technology that flows from A,

$$-\frac{dT_a}{dt} = k_1[T_a], \quad \rightarrow \quad T_a = T_{a0}e^{-k_1 t} \qquad (1)$$

where $[T_a] = [T_{a0}]$ at time 0,

2) The amount of technology in absorption and assimilation process.

If we solve 1st ordinary differential equation, using integrating factor, where t=0 and X=0, then the result is as follows,

$$\frac{dX}{dt} = k_1[T_a] - k_2[X] \rightarrow [X] = T_{a0}\frac{k_1}{k_2 - k_1}(e^{-k_1 t} - e^{-k_2 t}) \qquad (2)$$

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

$$\Delta T_s = [T_{a0}] - [T_a] - [X] = \frac{[T_{a0}]}{k_2 - k_1}\{k_2(1 - e^{-k_1 t}) - k_1(1 - e^{-k_2 t})\}$$

$$= [T_{a0}](1 + \frac{k_2 e^{-k_1 t} - k_1 e^{-k_2 t}}{k_1 - k_2}) \qquad (3)$$

Here we can make a quick check as follows,

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

3. The Relationship between Technology Stock and Assimilation Capacity

To simplify our model and exhibit the essential technology stock - assimilation capacity relationship, let us first make assumptions. Assume that assimilation capacity is a function of technology stock and institutional effects (such as specific culture, learning effect and so on) only and in the absence of technology stock, there are no assimilation capacity.

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 assimilation capacity is usually proportional to technology stock,

That is: $$\frac{\Delta AC}{AC} = c\frac{\Delta T}{T} \qquad (4)$$

Denote technology stock by T, assimilation capacity by AC, proportional constant by c and institutional effects by α.

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

By integrating:

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

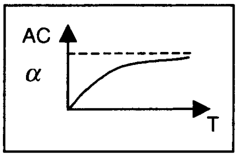

Fig. 2. The Relationship between AC and T

Due to the range limitation of c, assimilation capacity generally would be expected to increase in response to increased technology stock. However, although assimilation capacity may rise very rapidly at first, it would eventually level off under our assumption, despite the increase of technology stock.

4. The Impact and Dynamism of Technology Spillover

4.1 Mathematical relationship

1) $AC = \alpha T^c \quad (\alpha \ge 0, 0 \le c \le 1)$

2) $\rho = A\rho_0 e^{(T_t/T_0)^a}$, $\quad \rho = A + BT$,

3) $m = \dfrac{\ln {R_0}/{T_0} - \ln(\rho + g)}{\ln(1+g)} + 1$, $\quad m = C - D\rho$,

using Maclaurin approximation.[3]

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

Accumulation of technology stock.

AC: assimilation capacity.
ρ : the rate of obsolescence.
m : lead time (R&D to Commercialization).
R: R&D investment.
A,B,C,D: constant coefficients.
g : Increasing rate of R_t in the initial period.

4.2 Mutual relationship

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

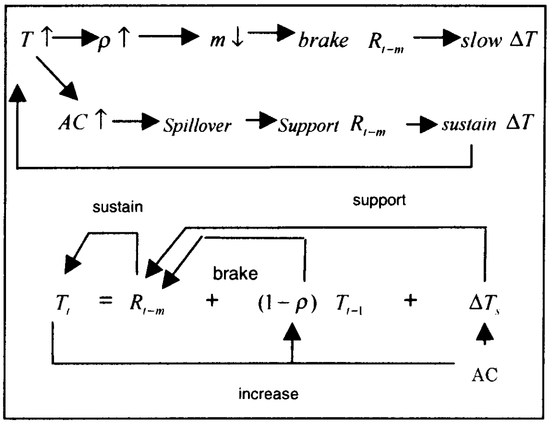

Fig. 3. The Role of Technology Spillover in the Accumulating Process of Technology Stock

5. The Estimate of Assimilation Capacity

Let's assume that assimilation capacity depends on technology stock and technology distance and other factors like specific culture, learning effect and so on. The overall rate (k) can be expressed as follows.

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

Where T: technology stock, D: technology distance, α : other factors.

Instead of estimating assimilation capacity directly, let's think of assimilation speed as a proxy of assimilation capacity. Overall assimilation speed is larger if T and α are higher and D is lower. This relationship can be expressed in the following form,

$$k_{overall} = \alpha e^{-D/T} \tag{6}$$

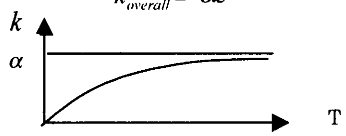

Fig 4. The Relationship between k and T

As explained above, overall assimilation process can be divided into two parts. One is absorption speed and the other is assimilation speed. Let's decompose the overall speed according to each step, then,

1) Rate of absorption (only depend on technology distance and α)

$$k_1 = \alpha e^{-D} \tag{7}$$

2) Rate of assimilation (only depend on technology

[3] Regarding equation b and c, see C. Watanabe[10].

stock of Z and α)

$$k_2 = \alpha e^{-1/T} \tag{8}$$

Variable, α includes institutional effects, such as learning effect and so on. In order to estimate α, let's consider differential form of Cobb-Douglus type production function[4].

$$\frac{\Delta Y}{Y} = \sum_{L,K,M,E} \frac{\partial Y}{\partial X}\frac{X}{Y}\frac{\Delta X}{X} + \lambda + \frac{\partial Y}{\partial T}\frac{T}{Y}\frac{\Delta T}{T} \tag{9}$$

In equation 9, institutional effects (learning effects, specific culture) usually are explained by λ. Therefore, if we substitute λ for α in the rate formula, then

$$k_1 = \lambda e^{-D} \qquad k_2 = \lambda e^{-1/T},$$

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 assimilation speeds.

6. The Method of Empirical Analysis

Let's assume that technology spillovers coming from sector A (at time t-1) can only affect sector Z by time t (for example, Within 1 year). Then, due to the spillover effect, the technology stock of Z at time t could be expressed like,

$$T_{t,z} = R_{t-m,z} + (1-\rho)T_{t-1,z} + \Delta T_s \tag{10}$$

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, then finally ΔT_s could be estimated. Applying this calculation, technology stock of Z at time t will be:

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

Repeating this calculation during a certain period, we can calculate total amount of ΔT_s, so that it is possible to compare contribution of spillover effect and own research effect in a certain sector. Figure 5 describes the details. Finally at time n, If we calculate the $T_{z,n}^{pure} = R_{n-m,z} + (1-\rho)T_{z,n-1}$ (without considering spillover) and $T_{z,n} = T_{z,n-1} + \Delta T_{ns}$ (including spillover) of Z, and subtract $T_{z,n}^{pure}$ from $T_{z,n}$, we can find a magnitude of technology spillover that comes from other specific sector A during a certain period (i.e. $T_{z,n}$ - $T_{z,n}^{pure}$ = $\sum_{i=1}^{n-1}\Delta T_{s,i} + \Delta T_{s,n}$).

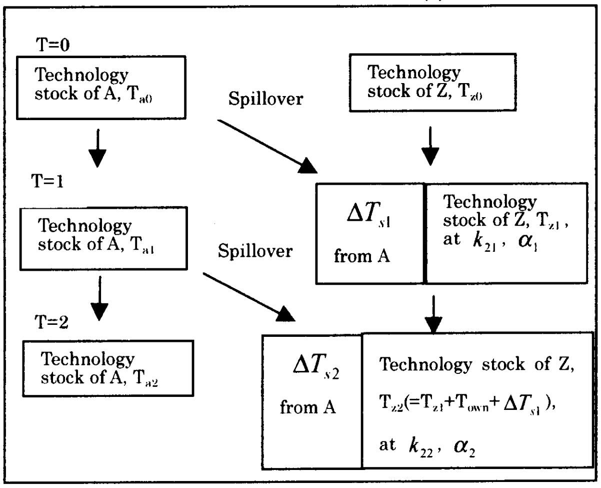

Fig. 5. The Practical Method of Measuring Technology Spillover

7. Simulation and Result

To simulate the model, we took three kinds of data sets from Japanese manufacturing sectors. One is electric machinery (EM) and the others are precision instrument (PI), general machinery (GM). Comparing data sets, EM has relatively higher technology stock than PI's and GM's. Therefore, we can consider EM as donor and PI and GM as receivers in our closed system. Also, technology stock of GM is higher than PI's. On the other hand, we took technology distance range from 0 to 1. As the distance of technology between two sectors approaches to 0, the receiver is very similar technology interests as the donor's. Regarding institutional effects, α, it starts from 0.01 with an annual increment of 0.01 or 0.02 ($\Delta\alpha$=dα/dt, 0.01 or 0.02)[5]. We tested the spillover effect under several different levels of technology distance (D=0.25, 0.5, 0.75)[6] and institutional effect ($\Delta\alpha = 0.01 or 0.02$) at each sectors (Spillover from EM to PI and GM). The simulation results are shown as follows.

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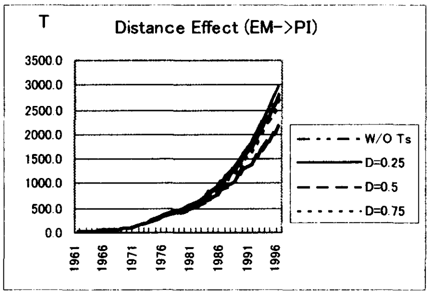
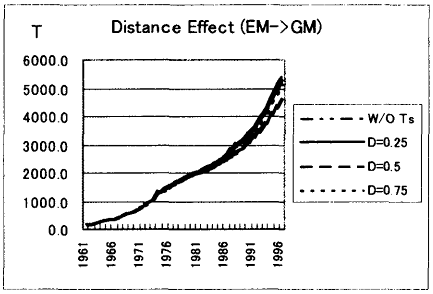
[4] Production Function, Y=F(L,K,M,E,T,t) $Y = e^{\lambda t} L^{\alpha} K^{\beta} M^{\gamma} E^{\delta} T^{\xi}$
L: labor, K: capital, M: intermediate material, E: energy, T: technology, t: time trend. Here, $\lambda = \frac{\partial Y}{\partial t}\frac{1}{Y}$

[5] α was chosen arbitrarily. We tested several different levels of α, such as 0.001,0.01,0.1 that are close to 0 at starting point, when time is 0. Finally, We could get reasonable result when we selected α, 0.01.

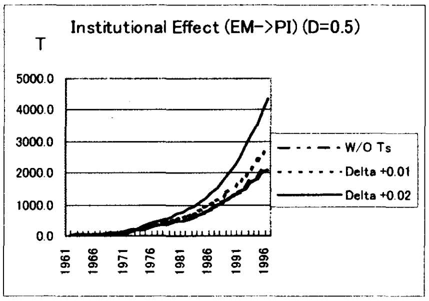
[6]. We simulated using different technology positions. Technology distance was not designated especially.

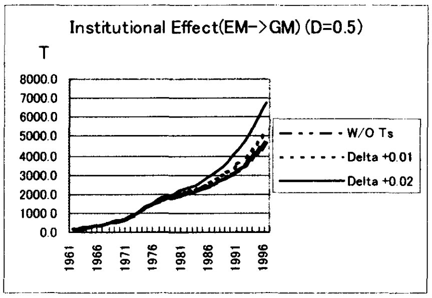




$\Delta\alpha = 0.01$	W/O Ts	D =0.25	D=0.5	D=0.75
EM -> PI	2123.2	2989.2	2811.9	2668.5
EM -> GM	4552.7	5418.8	5241.5	5098.0

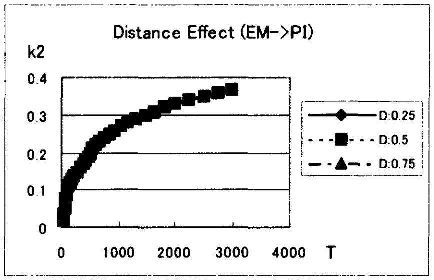
Fig 6. Spillover Effect under Different Technology Distances when $\Delta\alpha = 0.01$





$D = 0.5$	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 7. Spillover Effect under Different Institutional Effects



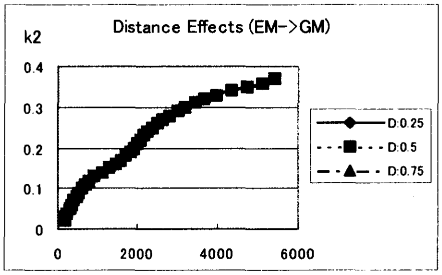
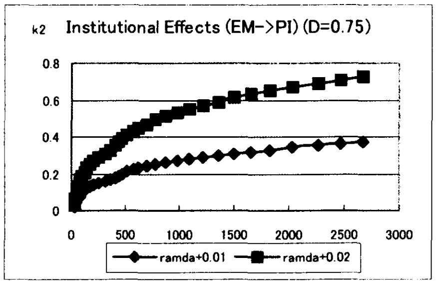


Fig 8. Technology Distance Effect between T and k2 when $\Delta\alpha = 0.01$



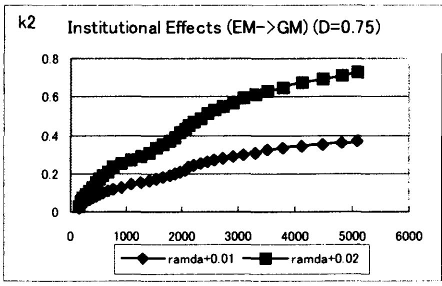


Fig 9. Institutional Effect between T and k2 when D=0.75

8. Concluding Remarks.

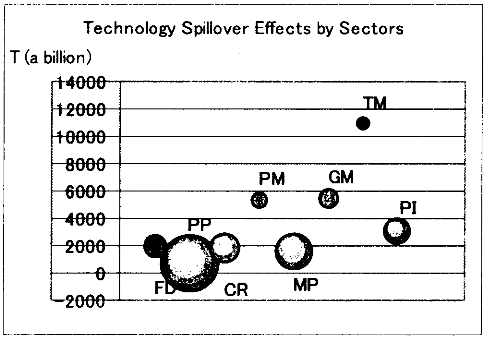
Based upon simulation results, we can suggest several findings as follows:

1) Spillover effect exists and its impact is significant (Table2).

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%

2) Spillover effect is large when technology stock is relatively small and technology distance is small. (Fig 10).



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 10. Spillover Effects by Sectors[7]

- D was chosen arbitrarily. Size indicates a magnitude of spillover effects.

3) Technology distance is relatively not so significant but the institutional effect is a very significant factor for technology spillovers (Table 3).

Table3. Spillover Effect under Different Institutional Effects and Technology Distance

	From / To	$\Delta\alpha=0.01$	$\Delta\alpha=0.02$		$\Delta\alpha=0.01$	$\Delta\alpha=0.02$
D=0.25	EM / PI	40.7%	129%	D=0.5	32%	105%
	EM / GM	19%	60%		15.1%	49%

4) Technology distance gives only a little effect on assimilation speed (Fig 8).

5) Institutional effect (such as learning effect, specific culture, labor quality etc.) is significant to increase the assimilation speed (assimilation capacity) (Fig 9).

Although the concept of technology distance and assimilation capacity has attracted many researchers' attention, but yet, it is very hard to define and estimate at this stage. Also this model considered only technology spillover effects from just a certain designated sector. But, actually, technology spillovers come from various sectors and affect simultaneously. Based on this point of view, it is necessary to develop multi-dimensional models explaining interactions among sectors.

[7] FD:food, PP:pulp&paper, CR:ceramics, PM:primary metal, MP:metal product, TM:transport machinery, GM:general machinery, PI:precision instrument.

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