Pergamon

Technovation 21 (2001) 281–291

technovation

www.elsevier.com/locate/technovation

Global technology spillover and its impact on industry's R&D strategies

Chihiro Watanabe *, Bing Zhu , Charla Griffy-Brown , Behrooz Asgari

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

Received 10 January 2000; received in revised form 20 May 2000; accepted 30 May 2000

Abstract

A dramatic increase in the transboundary flow of people, goods and information together with an increase in technology complementarity with capital stock and labor forces has accelerated the growth and spread of global technology spillovers.

Facing the R&D stagnation, effective utilization of technology from the global marketplace gathered from multiple sources has become an important competitive strategy leading to greater concern for assimilation capacity of spillover technology (the ability to utilize this spillover technology). In fact, how to effectively utilize this substitution potential has become one of the most crucial R&D strategies for industry.

Notwithstanding its strong assimilation capacity up until the 1980s, Japan's capacity has deteriorated in the 1990s and the remediation of this problem has become urgent.

This paper, uses both theoretical and empirical analyses of the mechanisms of (i) technology spillover contribution to production increase, and (ii) the role of assimilation, in addition to numerical analyses of the trends in assimilation capacity and the governing factors of this capacity. Furthermore, this investigation attempts to identify the sources and mechanism governing assimilation capacity, in order to extract suggestions for restructuring industry's R&D strategy.

Keywords: Global technology spillover; Assimilation capacity; R&D strategy

1. Introduction

Under a new paradigm characterized by a dramatic increase in the transboundary flow of people, goods and information together with an increase in technology complementarity with capital stock and labor forces has accelerated the growth and spread of global technology spillovers as illustrated in Fig. 1.

Facing the R&D stagnation (OECD, 1998), effective utilization of technology from the global marketplace gathered from multiple sources has become an important competitive strategy leading to greater concern for assimilation. In fact, how to effectively utilize this substitution potential and maximize multiplier effects with indigenous R&D has become one of the most crucial R&D strategies for industry.

Notwithstanding its strong assimilation capacity up until the 1980s (OECD, 1996), Japan's capacity has deteriorated in the 1990s (IIMD, 1998) and the remediation of this problem has become urgent.

While a number of studies have analyzed positive and negative impacts of technology spillovers (Bernstein and Nadiri 1988, 1989; Bernstein, 1998; Griliches, 1979; Jaffe, 1986), the majority are focusing on domestic spillovers (Bernstein and Nadiri 1988, 1989; Bernstein, 1998; Jaffe, 1986) and few have undertaken analyses of transboundary spillovers. Furthermore, the idea of assimilation capacity still remains conceptual (Grossman and Helpman, 1991; Kryazhimskii et al., 1995) and no substantial work has been undertaken to identify methodology for measuring or identifying the critical factors governing assimilation capacity in relation to technology spillover.

This paper uses both theoretical and empirical analyses to reveal several technology spillover mechanisms at work in Japan. These mechanisms include: (i) technology spillover contribution to production increase, and

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

E-mail address: chihiro@me.titech.ac.jp (C. Watanabe).

0166-4972/01/$ - see front matter
PII: S0166-4972(00)00048-1

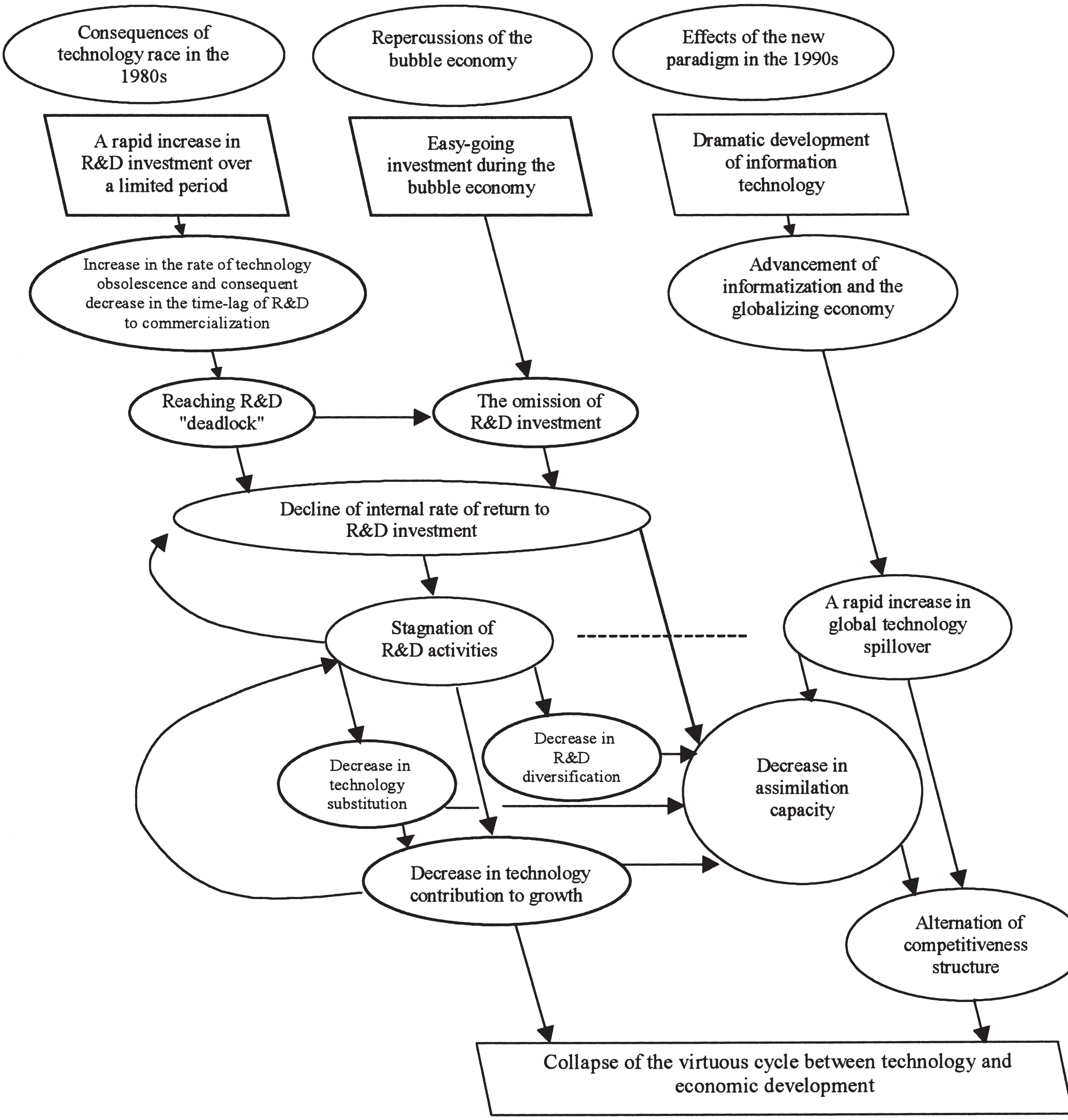


Fig. 1. Circumstances surrounding industry's R&D.

(ii) the role of assimilation. In addition this work applies numerical analyses of the trends in assimilation capacity and governing factors of this capacity. Finally, this investigation attempts to identify the sources and mechanism governing assimilation capacity, in order to extract suggestions for restructuring industry's R&D strategy.

Section 2 reviews the significance of technology spillover and its mechanism. Section 3 postulates a concept of assimilation capacity and measures the trends in assimilation capacity in Japan. An evaluation of the measured assimilation capacity is also included. Section 4 briefly summarizes implications for restructuring industry R&D strategy.

2. Technology spillover and its mechanism

2.1. The significance of technology spillover

In its report on 'Technology and Industrial Performance' in 1997 (OECD, 1997), the OECD pointed that industry's productivity can be attributed more to technologies embodied into capital and intermediate goods than to its indigenous technology. This suggests the strong significance of technology spillover.

Currently, economic globalization dramatically increases the transboundary flows. In addition, recent technology has a general tendency to increase complementarity with capital stock and labor forces. This is the embodiment in capital or intermediate goods or 'technology lock in' which has made the traditional intellectual property right (IPR) system inadequate for preventing new technology diffusing from the developer. These trends inevitably accelerate transboundary technology spillovers. The stagnation of R&D investment, common to almost all advanced countries in the 1990s (OECD, 1998), also drives the substitution of 'spillover' technology from the global market place for indigenous technology.

Japan's ability to assimilate imported technology from the USA and Europe was generally considered a critical component of its high-tech miracle in the 1980s (Dertouzos et al., 1989; NRC, 1991). However, while the comparative advantages of Japan's assimilation capacity [such as 'Just in time system' (JIT) and 'Total quality control' (TQC)] have become internationally universal assets (NRC, 1998), comparative disadvantages (such as rigidness and less-flexibility due to the life time employment and the seniority system) have revealed their negative aspects as Japan faces new trends (such as low, zero or minus economic growth, globalization, a service intensified industrial structure, and a rapidly aging society) (Watanabe and Wakabayashi, 1996). These structural trends characterized by (i) a dramatic increase in global technology spillovers, (ii) substitution of spillover technology for indigenous technology, and (iii) the deterioration of assimilation capacity have dramatically altered Japan's international competitiveness structure. Facing these circumstances, the restructuring of industry's R&D strategy is a crucial subject as illustrated in Fig. 2.

2.2. The mechanism of technology spillover

Technology spillovers emerge in line with the R&D products of the firms undertaking R&D activities ('Donor'). Usually their results flow to other firms ('Host'), which do not necessarily challenge R&D activities and they can benefit from the results at a low or non-existent price. This is one negative aspect of technology spillovers as they discourage the host from undertaking R&D.

However, the host may not be capable enough to efficiently enjoy the benefits of spillovers without sufficient assimilation capacity. However, if both sides have mutual interests and respective abilities which complement each other in a bilateral framework, they can maximize the mutual benefits of R&D activities in such a way as constructing a 'virtuous spin cycle.' In other words, the mutual cooperation generates greater capacity on the donor side and more utilization and assimilation capacity on the host side.

Fig. 3 illustrates this framework as a joint dynamic 'game' for donor and host spillover production. In this game, both sides can cooperate and benefit from R&D spillovers at a maximum level.

2.3. The mechanism of the contribution of technology spillover to production increase

The production function is generally seen in the following way:

$$V_i = F(L_i, K_i, TFP_i) \tag{1}$$

where V_i, L_i, K_i and TFP_i are GDP, labor, capital stock and total factor productivity of firm i, respectively.

TFP_i can be decomposed in the following way:

$$TFP_i = T(T_i, [T_i]_j, t) \tag{2}$$

where T_i: firm i's own technology knowledge stock (TS); $[T_i]_j$: stock of technology spillovers (TSO) generated by firm j and assimilated in firm i; and t: time trend which is a proxy of disembodied technological change represented by institutional change.

Firm i's technology knowledge stock in time t T_{it} can be measured in the following way:

$$T_{it} = R_{it-m} + (1-\rho)T_{it-1} \tag{3}$$

where $R_{i\,t-m}$: firm i's R&D expenditure in time $t-m$; m: time lag between R&D and commercialization; and ρ: rate of obsolescence of technology.

Substituting TFP_i in Eq. (2) for TFP_i in Eq. (1), following production function is obtained:

$$V_i = F(L_i, K_i, T_i, [T_i]_j, t) \tag{4}$$

GDP change and contribution of respective factors to this change can be described as follows:

$$\frac{\Delta V_i}{V_i} = \frac{\partial V_i}{\partial L_i}\cdot\frac{L_i}{V_i}\cdot\frac{\Delta L_i}{L_i} + \frac{\partial V_i}{\partial K_i}\cdot\frac{K_i}{V_i}\cdot\frac{\Delta K_i}{K_i} + \frac{\partial V_i}{\partial T_i}\cdot\frac{T_i}{V_i}\cdot\frac{\Delta T_i}{T_i} + \frac{\partial V_i}{\partial [T_i]_j}\cdot\frac{[T_i]_j}{V_i}\cdot\frac{\Delta [T_i]_j}{[T_i]_j} + \lambda_i \tag{5}$$

where $\lambda_i = \frac{\partial V_i}{\partial t}/V_i$: contribution of institutional change.

Eq. (5) suggests that change of stock of technology spillover (TSO) ($\Delta[T_i]_j$) can be approximated by $[R_i]_j$ (flow of TSO generated by firm j and assimilated in firm i) and, by introducing the technology distance concept (Jaffe, 1986), this can be described in the following way:

$$\Delta[T_i]_j = [R_i]_j = P_{ij}\cdot R_j \tag{6}$$

where

$$P_{ij} = \left[\sum_k \left(\frac{R_{ik}}{R_i}\right)\left(\frac{R_{jk}}{R_j}\right)\right] \Big/ \left[\sum_j \left(\frac{R_{ij}}{R_i}\right)^2 \cdot \sum_i \left(\frac{R_{ji}}{R_i}\right)^2\right]^{1/2}$$

is the technology distance between firm i and j; and R_j: firm j's R&D expenditure.

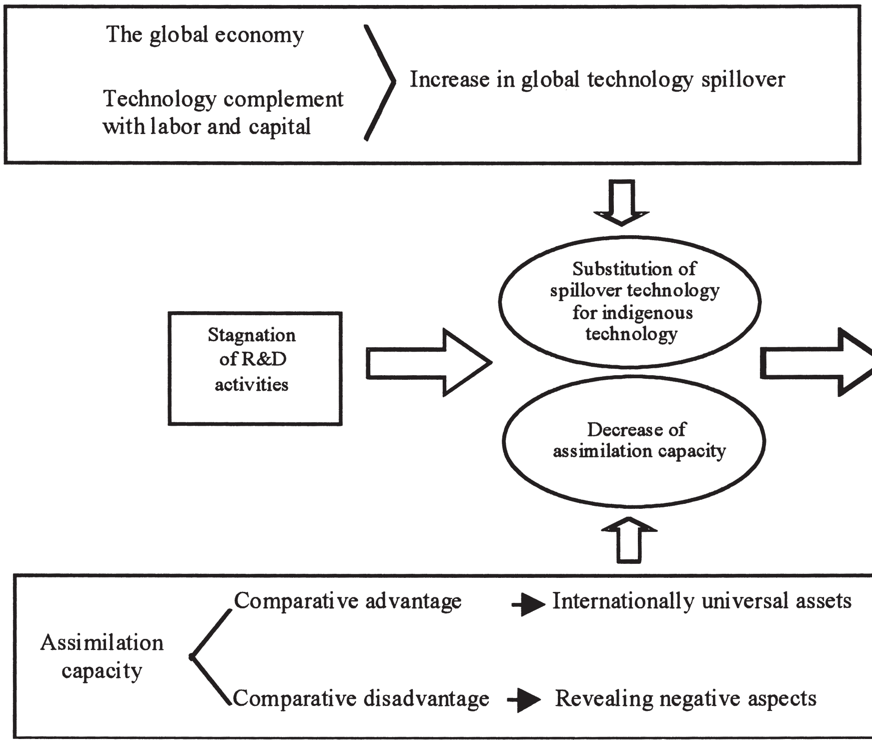


Fig. 2. Scheme of Japan's current international competitive structure with respect to technology development, spillovers and assimilation.

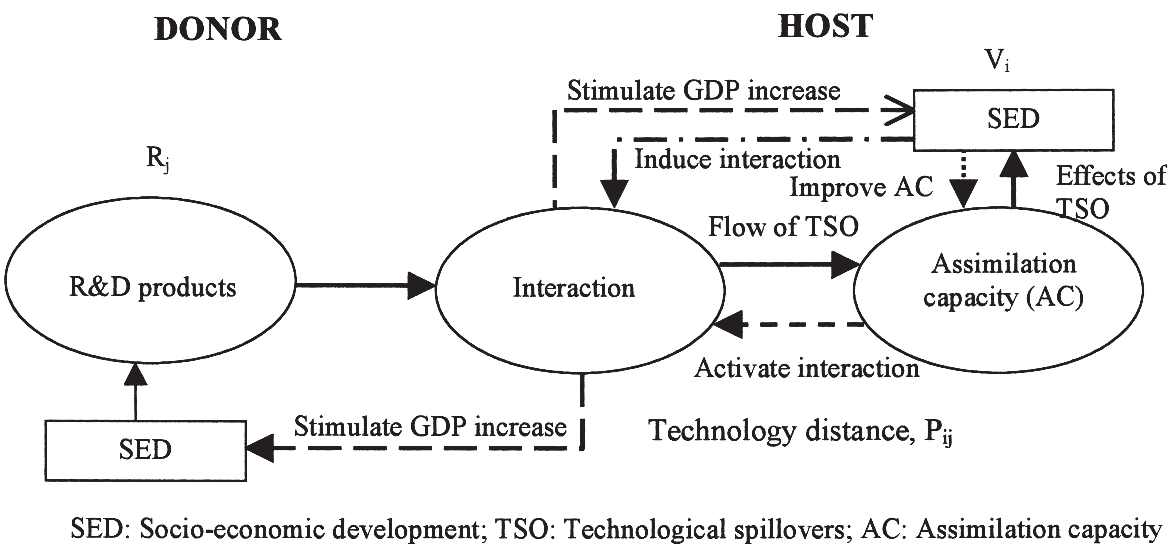


Fig. 3. Dynamism of technology spillover.

Therefore, the contribution of TSO to GDP change can be described in the following way:

$$\frac{\partial V_i}{\partial [T_i]_j}\cdot\frac{[T_i]_j}{V_i}\cdot\frac{\Delta[T_i]_j}{[T_i]_j}\approx\frac{\partial V_i}{\partial [T_i]_j}\cdot\frac{[R_i]_j}{V_i}=\frac{\partial V_i}{\partial [T_i]_j}\cdot P_{ij}\cdot\frac{R_j}{V_i} \quad (7)$$

Eq. (7) suggests that TSO's contribution to GDP change is governed by marginal productivity of TSO ($\partial V_i/\partial[T_i]_j$) and technology distance (P_{ij}). While the latter depicts interaction between host (i) and donor (j), the former depicts assimilation capacity in Fig. 3, respectively.

3. Assimilation capacity for technology spillover

3.1. The concept of assimilation capacity

In order to maximize the effects of TSO (technology spillovers) on SED (socio-economic development) the capacity to link TSO to production is crucial. Assimilation capacity creates this link (Bernstein, 1998). Existing approaches [e.g. Bernstein, 1998; Suzuki, 1993) treat received stock of TSO as heterogeneous than own TS (technology stock). However, given that the host makes every effort in maximizing TS's contribution to effective production processes, treating received stock of TSO as homogeneous to its own TS is an important strategy for a host to maximize the effects of the stock of TSO on SED. In addition, the stock of TSO has potentially greater comparative advantages (e.g. 'global character') over TS ('pure local') as established technology (Griffy-Brown and Watanabe, 1998). The assimilation capacity encompasses systems efficiency purporting comparative efficiency of the stock of TSO's contribution to production in comparison to similar efficiency of the firm's own TS. Therefore, the system of assimilation capacity consists of the following capacities as illustrated in Fig. 4 (Watanabe et al., 1998):

(i) distinguishing profitable TSO,
(ii) internalizing accepted TSO, and
(iii) embodying the internalized the stock of TSO to production process.

Among these capacities, the internalizing capacity which depends on absorptive capacities (ii), plays a crucial role in constructing the assimilation system by bridging (i) and (iii).

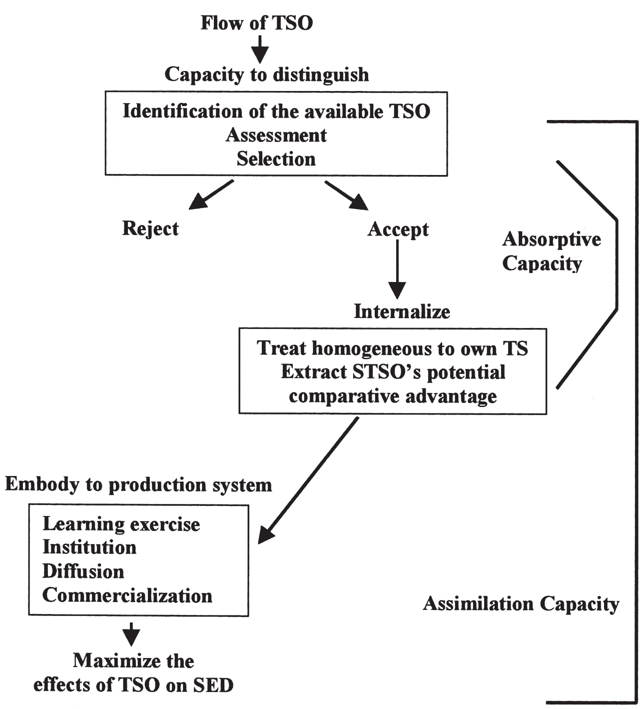


Fig. 4. The concept of assimilation capacity for spilling over technology.

3.2. Measurement and evaluation of assimilation capacity

In order to inspect the behavior of assimilation capacity, a comparative analysis of the assimilation process of spillover technology in Japan's electrical machinery industry[1] over the period 1975–1995 was conducted. The analysis is based on the following simple Cobb–Douglas type production function which encompasses labor (L), capital stock (K), materials (M), energy (E) and technology knowledge stock (T):

$$Y=AL^{\alpha}K^{\beta}M^{\gamma}E^{\eta}T^{\zeta} \quad (8)$$

Technology knowledge stock is treated in the following way:

$$T=T(T_i,Z\cdot T_s) \quad (9)$$

where T_i: own technology stock (TS); Z: assimilation capacity; and T_s: stock of technology spillovers (TSO).

The behavior of assimilation capacity is inspected by comparing the following variations:

(a) TSO is treated homogeneous to TS and its contribution to production is subject to assimilation capacity ($T=T_i+Z\cdot T_s$: assimilation capacity approach),
(b) TSO is treated homogeneous to TS and makes full contribution to production (Z=1, $T=T_i+T_s$),
(c) TSO is treated heterogeneous to TS ($T^{\zeta}=T_i^{\zeta i}\cdot T_s^{\zeta s}$), and
(d) TSO is treated as small impact as negligible ($T=T_i$).

Considering that assimilation capacity is influenced by labor quality (Kaldor and Mirrless, 1962), an attempt to identify the impact of labor quality was also conducted by treating labor (L) in the following way:

(A) Measuring only by quantity ([number of employed persons]*[working hours]), and
(B) Measuring by labor quality (by means of wage level: Rasche–Tatom approach (Rasche and Tatom, 1977).

Results of the analysis are summarized in Table 1.

Looking at the Table we note that the 'assimilation capacity approach' [models (a) and (e)] is extremely statistically significant in both cases ((A) and (B)) examined. In addition, comparing case (A) and (B) with respect to the treatment of the labor, case (B) (labor quality approach) is more statistically significant.

[1] Electrical machinery industry plays a leading role in Japan's manufacturing industry sharing 16.3% of GDP and 37.9% of R&D expenditure of manufacturing industry in 1997.

Table 1
Comparative analysis of assimilation process of spillover technology in Japan's electrical machinery industry (1975–1995)

	α	β	γ	η		ζ	adj.R^2	DW
	L	K	M	T	T_i	$Z.T_s$		
Labor measured by labor quantity ([number of employed persons] * [working hours])								
a. ($T=T_i+Z\cdot T_s$)	0.24 (2.96)	0.08 (1.68)	0.89 (25.42)	0.01 (0.32)	0.15 (3.05)	0.23 (4.15)	0.999	1.46
b. ($T=T_i+T_s$)	0.17 (1.54)	−0.01 (−0.14)	0.94 (21.51)	0.01 (0.15)	0.23 (3.95)		0.999	1.21
c. ($T^{\zeta}=T_i^{\zeta_i}\ T_s^{\zeta_s}$)	0.17 (2.41)	0.16 (3.09)	0.79 (17.84)	0.02 (0.55)	−0.32 (−2.66)	0.33 (4.96)	0.999	2.01
d. ($T=T_i$)	0.08 (0.66)	0.01 (0.10)	0.96 (21.16)	0.04 (0.61)	0.20 (2.91)		0.999	1.40
Labor measured by labor quality (by means of wage level: Rasche-Tatom approach)								
e. ($T=T_i+Z\cdot T_s$)	−0.29 (−2.30)	0.10 (1.97)	1.05 (18.19)	0.10 (3.64)	0.20 (2.68)	0.35 (3.79)	0.999	1.63
f. ($T=T_i+T_s$)	0.06 (0.55)	0.03 (0.40)	0.95 (14.07)	0.09 (2.41)	0.11 (1.17)		0.999	1.41
g. ($T^{\zeta}=T_i^{\zeta_i}T_s^{\zeta_s}$)	−0.08 (−0.90)	0.18 (3.05)	0.84 (15.74)	0.09 (3.26)	−0.39 (−2.88)	0.36 (4.12)	0.999	2.39
h. ($T=T_i$)	0.09 (0.79)	0.03 (0.46)	0.94 (13.70)	0.10 (2.46)	0.09 (0.96)		0.999	1.41

Thus, we can conclude that the assimilation capacity approach using labor quality [model (a)] reflects a very real behavior in term of assimilation capacity.

3.3. The numerical measurement of assimilation capacity

On the basis of the findings obtained by the empirical analysis of the assimilation capacity behavior, numerical measurement of assimilation capacity was also attempted.

Provided that

(i) the host makes every effort in maximizing the contribution of acquired spillover technology to production by embodying it into production processes, and that
(ii) the prices of proprietary technology and acquired spillover technology are decided competitively,

assimilation capacity (Z) can be calculated by the following equation by using the ratio of marginal productivities of respective technologies (ϕ) (see details of mathematical development in Appendix A).

$$\phi=\frac{T_i\Delta\frac{T_s}{T_i}}{\Delta T_s-\Delta T_i\cdot\frac{T_s}{T_i}-Z\cdot T_s\cdot\Delta\frac{T_s}{T_i}}=\frac{1}{1-Z\cdot\frac{T_s}{T_i}} \tag{10}$$

$$Z=\left(1-\frac{1}{\phi}\right)\cdot\frac{T_i}{T_s},\ 0<Z<T_i/T_s \tag{11}$$

On the basis of this mathematical development, following findings which explain the behavior of assimilation capacity are obtained as illustrated in Fig. 5:

(i) assimilation capacity plays a key role in constructing a virtuous cycle of technology spillover and leading future trajectory of host, and
(ii) assimilation capacity has a general trend of successive diminution.

By utilizing Eq. (11), trends in assimilation capacity of Japan's major manufacturing industry over the period 1981–1995 were measured as summarized in Table 2.

Fig. 6 illustrates trends in assimilation capacity in Japan's electrical machinery, chemicals and primary metals over the period 1981–1995. Looking at Fig. 6 we note that assimilation capacities in electrical machinery and primary metals increased before the bubble economy in 1987, but changed to a dramatic decrease starting from the period of the bubble economy. While assimilation capacity of chemicals continues to decline from 1983.

3.4. Analysis of the governing factors of assimilation capacity

On the basis of the above findings, particularly of the noteworthy trends in a dramatic decrease starting from the period of the bubble economy, the sources stimulating this decrease are analyzed.

As observed in Section 2, assimilation capacity is subject to labor quality. In addition, the recent informatization trend as well as the aging trend inevitably influence this capacity (Motohashi, 1997; OECD, 1997). Fig. 7 compares these trends.

Looking at Fig. 7 we note that the increasing trend of informatization stagnated and decreased after the bursting of the bubble economy starting from 1991 (Griffy-Brown and Watanabe, 1999), while the aging trend still continues (Asgari, 1998). Synchronizing these trends, the quality of labor also decreased after the bursting of the bubble economy.

In order to identify factors contributed to this decrease

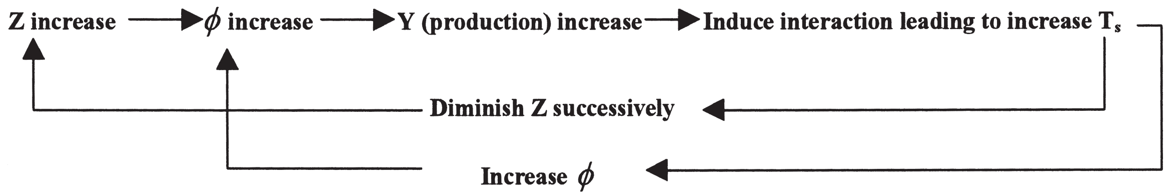


Fig. 5. Dynamism of assimilation capacity for spillover technology.

Table 2
Trends in assimilation capacity of Japan's major manufacturing industries (1981–1995)[a]

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1990-95 Average
EM	2.82	2.70	3.48	3.83	3.83	4.01	3.30	2.46	2.53	2.48	2.03	1.40	1.83	1.40	1.40	(1.68)
GM	0.46	0.41	0.42	0.44	0.49	0.52	0.46	0.27	0.25	0.26	0.25	0.20	0.15	0.10	0.10	(0.17)
TM	0.31	0.54	1.68	1.58	1.84	1.61	1.37	1.18	0.78	0.60	0.35	0.32	0.69	1.03	1.03	(0.70)
CH	2.95	3.07	3.11	2.56	2.25	2.52	2.42	2.30	2.24	2.12	1.74	1.07	0.68	0.35	0.35	(1.06)
PM	1.06	1.16	1.38	1.46	1.45	1.47	1.28	1.08	0.81	0.62	0.45	0.36	0.31	0.27	0.27	(0.38)
FD	0.18	0.25	0.28	0.19	0.17	0.17	0.17	0.16	0.14	0.12	10.09	0.09	0.11	0.09	0.09	(0.11)
CR	0.17	0.14	0.21	0.24	0.18	0.19	0.20	0.20	0.19	0.15	0.07	0.05	0.06	0.06	0.06	(0.08)
TX	0.10	0.13	0.12	0.11	0.09	0.08	0.07	0.07	0.05	0.03	0.03	0.01	0.01	0.02	0.01	(0.02)

[a] EM: Electrical machinery; GM: General machinery; TM: Transport machinery; CH: Chemicals; PM: Primary metals; FD: Food; CR: Ceramics; TX: Textiles.

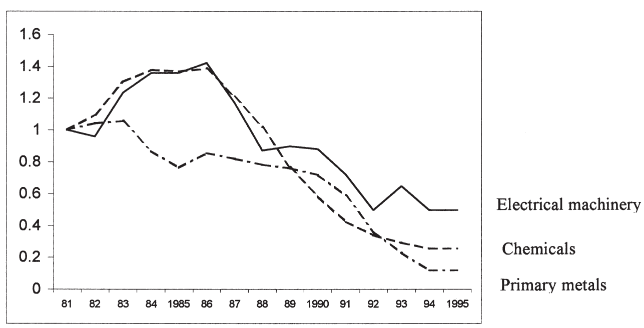


Fig. 6. Trends in assimilation capacity of Japan's major manufacturing industries (1981–1995)—Index: 1981=1.

in labor quality, Fig. 8 analyzes factors influencing labor quality in Japan's electrical machinery industry over the period 1979–1985 by dividing the time into four periods: 1979–1982 (after the second energy crisis and before the fall of international oil prices); 1983–1986 (after the fall of international oil prices and before the 'bubble economy'); 1987–1990 (during the period of the 'bubble economy'); and 1991–1995 (after the 'bubble economy').

Looking at Fig. 8 we note that the quality of labor (which is the decisive factor of assimilation capacity as demonstrated in the preceding parts of this section) is significantly influenced by trends in informatization and aging. In the case of the electrical machinery industry, informatization contributes to improve labor quality, while the aging trend deteriorates labor quality. The labor quality of electrical machinery industry changed to a decrease after the bubble economy, and this is primarily due to the stagnation of informatization and the aging trend.

On the basis of the above findings we postulated the following assimilation capacity function (Z) incorporating informatization (Inf) and the aging (Age) trend as governing factors and also successive diminution factor (λ) as observed in Eq. (11):

$$Z=Ae^{\lambda t}\mathrm{Inf}^{\alpha}\mathrm{Age}^{\beta} \quad (12)$$

Using Eq. (12) the governing factors of assimilation capacity in Japan's major manufacturing industries over the period 1975–1995 were analyzed. Results of the analysis are summarized in Table 3.

Looking at Table 3 we note the following trends:

(i) all sectors demonstrate a successive diminution trend (TM is statistically not significant),
(ii) all sectors can be attributed to informatization for their assimilation capacity improvement (PM, CR and TX are statistically not significant), and
(iii) assimilation capacities of EM and CR are deteriorated by the aging trend while CH, PM and appreciate along with their assimilation capacity improvement.[2]

[2] Among Japan's manufacturing industries average age of employer EM displayed the highest increasing rate (from 31.9 in 1975 to 37.1 in 1995), CR stood the highest level (39.4 in 1975 and 43.1 in 1995) while increasing rate of CH, PM and FD is relatively low (from 34.6, 36.4 and 37.3 in 1995 to 39.8, 41.4 and 41.2, respectively).

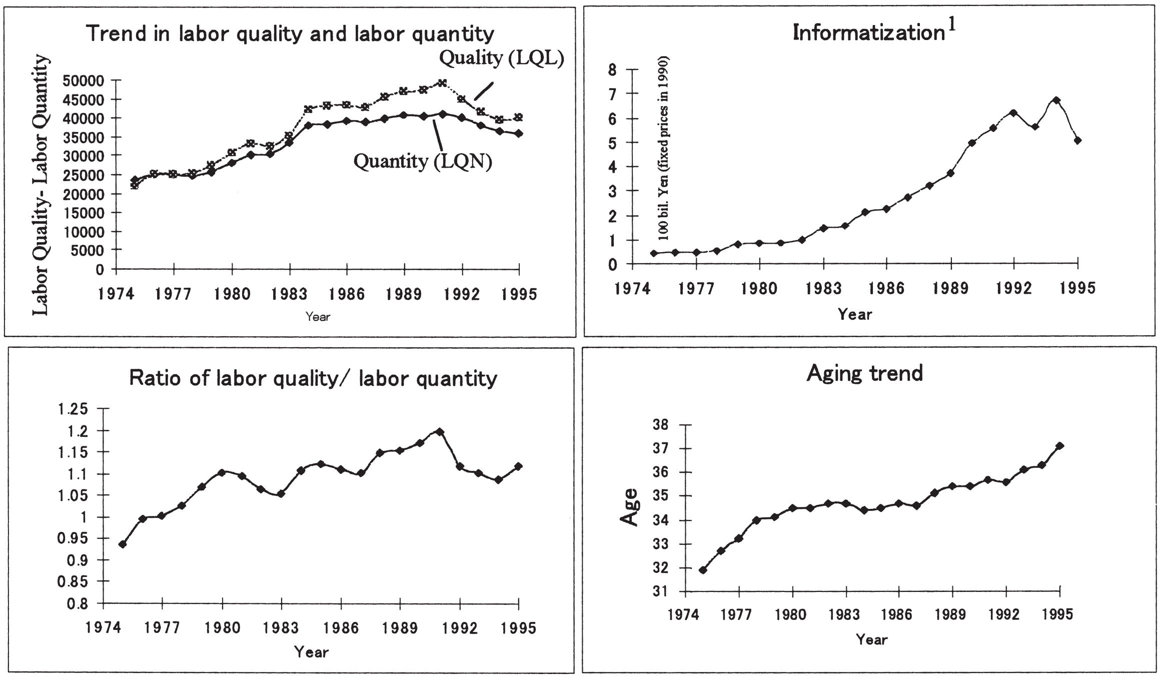


Fig. 7. Trends in labor quality, labor quantity, informatization and aging in Japan's major electrical machinery industries (1975–1995). Sources: Labor quantity (LQN): [number of employed persons]*[working hours]. Labor quality (LQL): by means of wage level: Rasche–Tatom approach. Informatization: Information index (Inf)[1] [Provided that firm's information investment reflects the most efficient combination of information encompassing various hardwares, softwares and networks which aims at maximizing the benefit of the investment, trends in informatization is measured by using the following information index composed of expenditures for information capital and expenditures for information operation and maintenance: Information index=$\left(\frac{\text{Information expenditure for capital}}{\text{Capital deflator}}+\frac{\text{Information expenditure for operation and maintenance}}{\text{Labor deflector}}\right)\times$Number of firms. Numerator indicates unit expenditure per firm.

Sources: Information expenditure: MITI (1971–1995); Capital deflator: Bank of Japan (1971–1995); Labor deflator: Ministry of Labor (1971–1995);Number of firms: RDMCA (1971–1995).]. Aging trend: Average age of employed persons (Age): Ministry of Labor (1975–1995).

Labor quality ratio — Information Index — Average age of employee

$$\ln(LQL/LQN) = 3.65 + \underset{(3.75)}{0.06 \ln Inf} - \underset{(-2.00)}{0.98\,Age} \quad \text{adj.}R^2\ 0.626 \quad DW\ 1.48$$

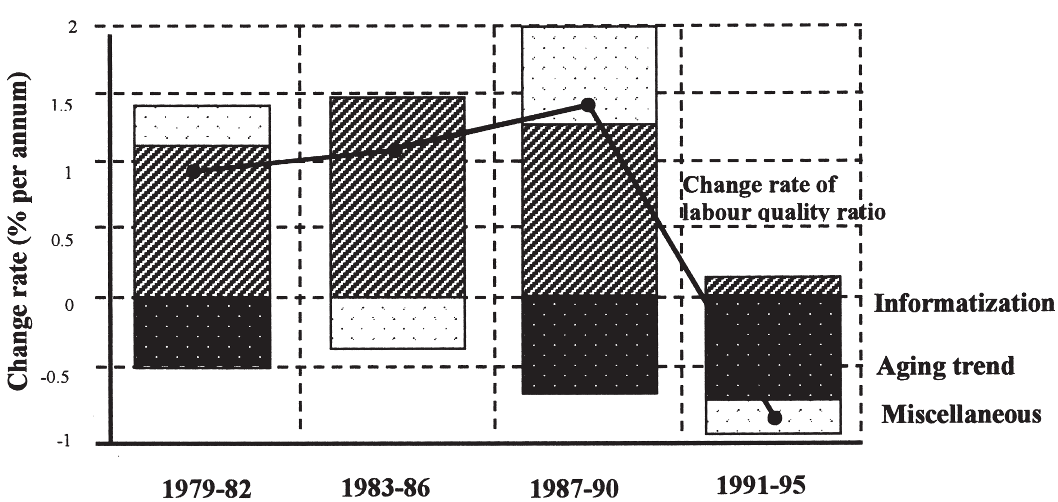


Fig. 8. Trends in labor quality and factors influencing labor quality in Japan's electrical machinery industry (1979–1985).

Table 3
Factors governing assimilation capacity of spillover technology in Japan's major manufacturing industries (1975–1995)[a]

Industry	Successive diminution factor	Informatization	Aging trend	adj. R^2	DW
EM	−0.11 (−2.31)	0.50 (2.05)	−10.23 (−3.25)	0.941	1.83
GM	−0.17 (−4.20)	0.67 (2.48)	−3.27 (−0.67)	0.947	1.53
TM	−0.08 (−0.92)	0.66 (2.34)	−12.41 (−1.00)	0.798	1.48
CH	−0.31 (−4.78)	0.93 (1.91)	10.67 (3.08)	0.912	1.43
PM	−0.24 (−7.94)	0.04 (0.11)	23.78 (6.63)	0.919	1.43
FD	−0.22 (−4.22)	0.38 (1.66)	21.54 (2.88)	0.820	1.14
CR	−0.04 (−1.19)	0.09 (0.53)	−15.71 (−2.30)	0.905	1.94
TX	−0.18 (−9.26)	0.09 (0.62)	−0.66 (−0.30)	0.990	1.35

[a] Figures in parenthesis indicate *t*-value.

The difference in the influence of the aging trend to assimilation capacity among sectors is considered due to differences in the advantage of learning exercises of aged employee and the disadvantage of their inability to absorb the rapid advancement of informatization (Motohashi, 1997).

These observations are not necessarily only the case in Japan but also a general trend common to all nations in the world (Motohashi, 1997; OECD, 1996). Not only rapid advancement of informatization but also the aging trend has become a common critical global problem as demonstrated in Table 4. Furthermore, the successive diminution trend of assimilation capacity has been generally observed. All data indicates that assimilation capacity is becoming an internationally universal asset.

4. Concluding remarks

Newly emerging structural trends characterized by (i) a dramatic increase in global technology spillovers, (ii) substitution of spillover technology for indigenous technology, and (iii) the deterioration of assimilation capacity have significantly altered the structure of international competitiveness.

Facing these circumstances, the restructuring of industry's R&D strategy has become a crucial subject, and this strategy should, together with sophisticated, thoughtful, scientifically designed, rational R&D investment, aim at pursuing effective assimilation of spillover technology.

In this context, the development of methodology for measuring technology assimilation capacity and utilizing the developed methodology to evaluate assimilation capacity for spillover technology is extremely crucial.

In response to these requirements, a numerical measurement of assimilation capacity was attempted and factors governing assimilation capacity in Japan's major manufacturing industries were identified.

These analyses suggest that:

(i) Assimilation capacity plays a key role in constructing a virtuous cycle of technology spillover and leading the future trajectory of 'technology hosts' (which acquire spillover technology in the market place),
(ii) The quality of labor is a decisive factor in assimilation capacity, and this quality is governed by informatization, the aging trend and the institutional system,

Table 4
Aging trends in major countries

Country	Year when population older than 65 reaching the indicated share 7%	14%	Year from 7 to 14%
Japan	1970	1994	24 yr
USA	1942	2012	70
UK	1929	1976	47
Germany	1932	1972	40
France	1864	1992	128
South Korea	2000–2005	2020–2025	20
Thailand	2005–2010	2025–2030	20
China	2000–2005	2025–2030	25
India	2015–2020	2040–2050	30
Indonesia	2020	2040–2050	25–30

Source: UN (1996)

(iii) Therefore, the systematic advancement of informatization and carefully designed R&D investment corresponding to changing institutional systems under the new paradigm characterized by zero or minus economic growth, globalization, a service intensified industrial structure, and a rapidly aging society are crucial subjects for industry's techno-managerial strategy.

In light of these emerging strategies, the development of a practical method for a mathematical econometric analysis of R&D investment, and measuring technology assimilation capacity is essential. Further work should include an analysis of the optimal R&D investment including (i) optimal timing of R&D investment, (ii) the optimal level of R&D intensity and (iii) the evaluation of assimilation capacity for spillover technology.

Appendix A. Measurement of assimilation capacity

A.1. Model synthesis

Technology contribution to production change can be expressed as follows:

$$\frac{\partial Y}{\partial T}\cdot\frac{T}{Y}\cdot\frac{\Delta T}{T}=\frac{\partial Y}{\partial T_i}\cdot\frac{T_i}{Y}\cdot\frac{\Delta T_i}{T_i}+\frac{\partial Y}{\partial(Z\cdot T_s)}\cdot\frac{Z\cdot T_s}{Y}\ \frac{\Delta(Z\cdot T_s)}{Z\cdot T_s}=\frac{\partial Y}{\partial T}\cdot\frac{T}{Y}\cdot\left(\frac{\partial T_i}{T_i}+Z\cdot\Delta\frac{T_s}{T_i}\right)$$

$$\because \ln T\approx\ln T_i\left(1+Z\frac{T_s}{T_i}\right)=\ln T_i+Z\frac{T_s}{T_i}).$$

Given that the prices are determined in a competitive way,

$$\frac{\partial Y}{\partial T}=\frac{P_t}{P_y},\ \frac{\partial Y}{\partial T_i}=\frac{P_{ti}}{P_y},\ \frac{\partial Y}{\partial(Z\cdot T_s)}=\frac{P_{ts}}{P_y}\ (Z \text{ is independent from } P_{ts})$$

where P_t, P_{ti} and P_{ts} are prices of T, T_i and T_s respectively.

Define the marginal productivity ratio[3] as follows:

$$\phi=\frac{P_{ts}}{P_{ti}}=\frac{\partial Y/\partial(Z\cdot T_s)}{\partial Y/\partial T_i},$$

$$\phi>1,\ \frac{d^2\phi}{dt^2}<0 \text{ (diminishing return)}$$

[3] This ratio is the ratio of marginal productivity of technology between spillovers and own, and equivalent to the ratio of return to R&D investment.

$$P_t=\frac{T_i\cdot P_{ti}+Z\cdot T_s\cdot P_{ts}}{T}=\frac{P_{ti}(T_i+Z\cdot\phi\cdot T_s)}{T_i+Z\cdot T_s}$$

$$\frac{\partial Y}{\partial T_i}\cdot\frac{T_i}{Y}\cdot\frac{\Delta T_i}{T_i}+\phi\frac{\partial Y}{\partial T_i}\cdot\frac{Z\cdot T_s}{Y}\cdot\frac{\Delta(Z\cdot T_s)}{Z\cdot T_s}$$

$$=\frac{P_{ti}(T_i+Z\cdot\phi\cdot T_s)}{(T_1+Z\cdot T_s)\cdot P_y}\cdot\frac{T_i+Z\cdot T_s}{Y}\cdot\left(\frac{\Delta T_i}{T_i}+Z\cdot\Delta\frac{T_s}{T_i}\right)\Delta T_i+\phi\Delta(Z\cdot T_s)$$

$$=(T_i+Z\cdot\phi\cdot T_s)^*\left(\frac{\Delta T_i}{T_i}+Z\cdot\Delta\frac{T_s}{T_i}\right)$$

$$\phi=\frac{T_i\Delta\frac{T_s}{T_i}}{\Delta T_s-\Delta T_i\cdot\frac{T_s}{T_i}-Z\cdot T_s\cdot\Delta\frac{T_s}{T_i}}=\frac{1}{1-Z\frac{T_s}{T_i}},\ Z=\left(1-\frac{1}{\phi}\right)*\frac{T_i}{T_s}\ 0<Z<T_i/T_s$$

A.2. Data construction

See Watanabe and Baba (1998) and Watanabe (1999).

References

Asgari, B., 1998. Impacts of technology spillovers on socio-economic development and the role of information technology. Master thesis submitted to Tokyo Institute of Technology.

Bank of Japan, 1971–1995. Annual Report on Prices of Commodity Index (annual issues).

Bernstein, J.I., 1998. The structure of Canadian inter-industry R&D spillovers, and the rates of return to R&D. The Journal of Industrial Economics 37 (3), 3125–3328.

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 (2), 249–269.

Dertouzos, M.L. et al., 1989. Made in America. MIT Press, Cambridge, MA.

Griffy-Brown, C., Watanabe, C., 1998. A systems approach to technology transfer in the energy sector. Paper presented at the United Nations International Workshop on Technology Transfer in the Energy Sector, Amsterdam.

Griffy-Brown, C., Watanabe, C., 1999. Technology spillovers and informatization in Japan. International Journal of Technology Management 17 (4), 362–386.

Griliches, Z., 1979. Issues in assessing the contribution of R&D to productivity growth. Bell Journal of Economics 10 (Spring), 92–116.

Grossman, G.M., Helpman, E., 1991. Innovation and Growth in the Global Economy. MIT Press, Cambridge, MA.

International Institute for Management Development, 1998. The World Competitiveness Yearbook of 1998. International Institute for Management Development, Zurich.

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.

Kaldor, N., Mirrless, A., 1962. A new model of economic growth. Review of Economic Studies 29 (79), 174–192.

Kryazhimskii, A., Hutschenreiter, G., Kaniovski, Y.M., 1995. Endogenous growth, absorptive capacities and international R&D spillovers. IIASA WP-95-92.

Ministry of Labor, 1971-1995. Monthly Labor Survey (annual issues).

Ministry of Labor, 1975-1995. Wage Census (annual issues).

MITI, 1971–1995. Current State of the Japanese Information Processing (annual issues).

Motohashi, K., 1997. ICT diffusion and its economic impact in OECD countries. STI Review 20, 13–45.

National Research Council, 1991. R&D Consortia and US–Japan Collaboration. National Academy Press, Washington.

National Research Council, 1998. Science and Technology Policy for the Future of US Economy. National Academy Press, Washington.

OECD, 1997. Technology and Industrial Performance. OECD, PAris.

OECD, 1996. R&D externalities and productivity growth, in OECD. STI Review 17, 39–66.

OECD, 1998. Technology Productivity and Job Creationy. OECD, Paris.

Rasche, R.H., Tatom, J.A., 1977. Energy resources and potential GNP, review. Federal Reserve Bank of St. Louis, June, pp. 10–24.

Report on the Survey of Research and Development, Management and Coordination Agency, 1971–1995 (annual issues).

Suzuki, K., 1993. R&D spillovers and technology transfer among and within vertical Keiretsu group. International Journal of Industrial Organization 11, 573–591.

United Nations, 1996. World Population Prospects: The 1996 Revision. United Nations, Washington.

Watanabe, C., 1999. Systems option for sustainable development. Research Policy 28 (7), 719–749.

Watanabe, C., Baba, K., 1998. An empirical analysis on the structural relationship between R&D, its diversification and technology spillovers. Abstract of Annual Conference of the Japan Society for Science Policy and Research Management, Tokyo, pp. 150–155.

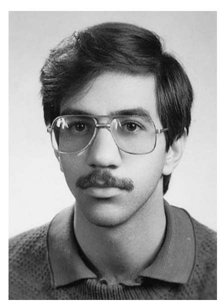
Watanabe, C., Wakabayashi, K., 1996. The perspective of techno-metabolism and its insight into national strategies: the case of Japan 1955–1993. Research Evaluation 6 (2), 69–76.

Watanabe, C., Zhu, B., Asgari, B., 1998. Analysis on global technology spillover and its impact to technology management. Abstract of Annual Conference of the Japan Society for Science Policy and Research Management, Tokyo, pp. 369–374.

Chihiro Watanabe graduated from Tokyo University with a bachelor's degree in Engineering (urban planning) in 1968 and received his PhD (arts and sciences) in 1992, also from Tokyo University. He began his affiliation with the Ministry of International Trade and Industry (MITI) in 1968. He is a 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).

Bing Zhu graduated from Tsinghua University, Beijing, China with a bachelor's degree in Engineering (chemical engineering) in 1990 and received his Master's degree (engineering) in 1995, also from Tsinghua University. He was formally a Lecturer at the Department of Chemical Engineering, Tsinghua University. He has also been a research assistant at International Institute for Applied Systems Analysis (IIASA). He is currently pursuing his PhD Degree at the Department of Industrial Engineering and Management, Tokyo Institute of Technology.

Charla Griffy-Brown is currently an Associate Professor at Pepperdine University, a researcher at the Foundation for Advanced Studies in International Development, Tokyo and a Visiting Fellow at Tokyo Institute of Technology. A former Fulbright Scholar, she graduated from Harvard University and has a PhD in Technology Management from Griffith University in Queenslan, Australia. She has worked for NASA at the Kennedy Space Center and has also worked as a lecturer at the Centre for Technology Management, Griffith University teaching innovation management courses in Australia, Singapore, Indonesia, Malaysia and Japan.



Behrooz Asgari graduated from Sharif University of Technology, Iran with a bachelor's degree in Engineering (Industrial Engineering) in 1990 and received his Master's degree (Industrial Engineering and Management) from Tokyo Institute of Technology, Japan in 1998. He has worked as a engineer at the Data Processing of Iran (DPI)). He is currently pursuing his PhD Degree at the Department of Industrial Engineering and Management, Tokyo Institute of Technology.