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COM8
Techno-economic Systems Institutional Innovation (4)

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COM8: Techno-economic Systems, Institutional Innovation

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AM: 10-12 am PM: 13-15pm

1.	**7 Aug (W)**	**AM**	**Technological innovation, growth, diffusion and consumption**
2.		**PM**	**Productivity, technological progress, competitiveness**
3.	**8 Aug (T)**	**AM**	**Diffusion of technology, Effects of learning**
4.		**PM**	**Technology spillover, Rate of return to R&D investment**
5.	**9 Aug (F)**	**AM**	**Basic concept of institutional innovation**
6.		**PM**	**New Stream for institutional innovation**

Identity: SEARCH Systems approach, **Empirical** approach, **Analytical** approach, challenge to **Rationale, Comprehensive** approach, with **Historical** perspective

5. Technology Spillover

5.1 Technology Spillover and Its Mechanism

5.2 Assimilation Capacity for Spillover Technology

5.3 Assimilation of Spillover Technology

5.4 Measurement of Spillover Technology

5. Technology Spillover

5.1 Technology Spillover and Its Mechanism

(1) Spillover Technology Substitutes for Indigenous Technology

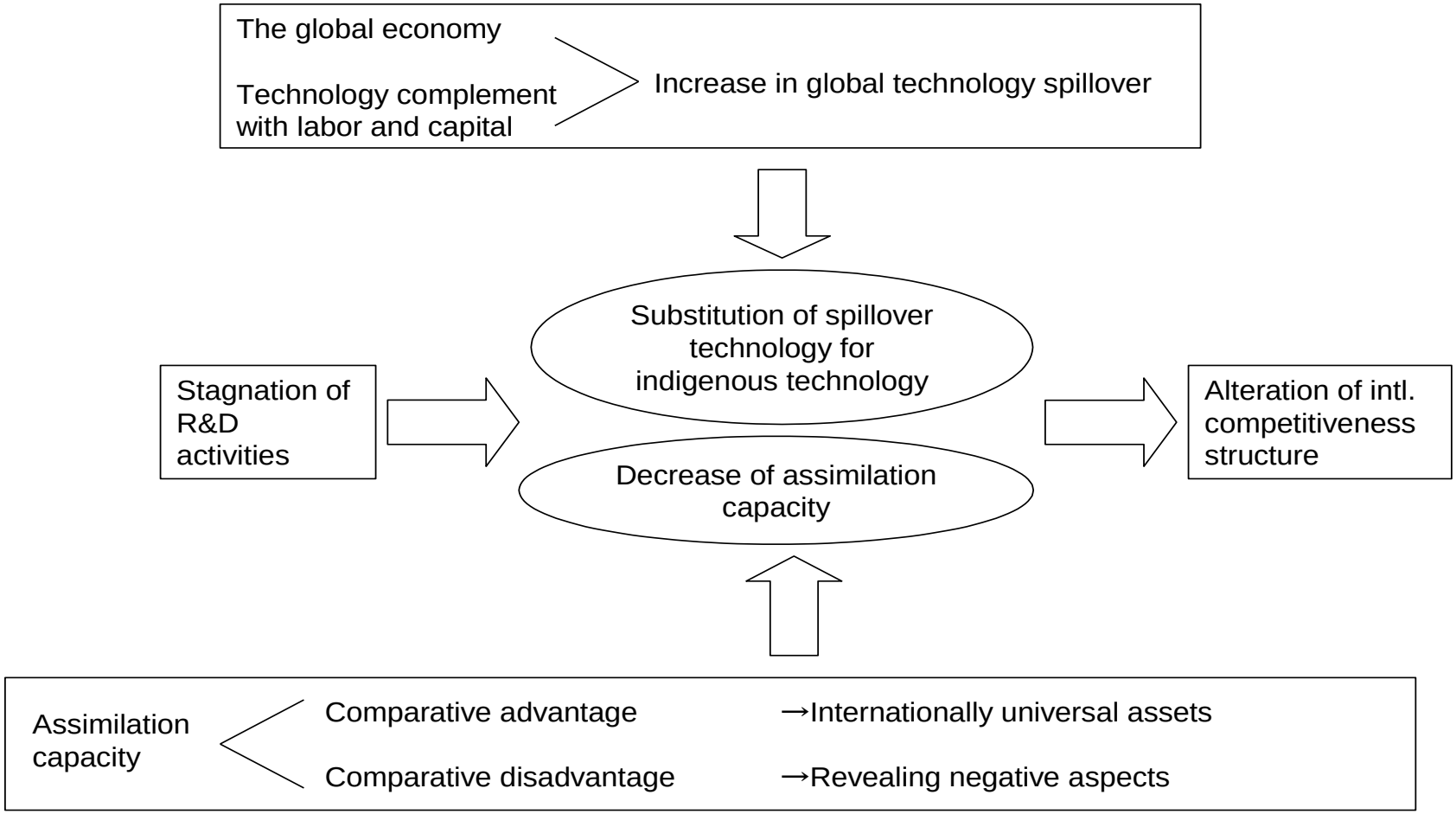
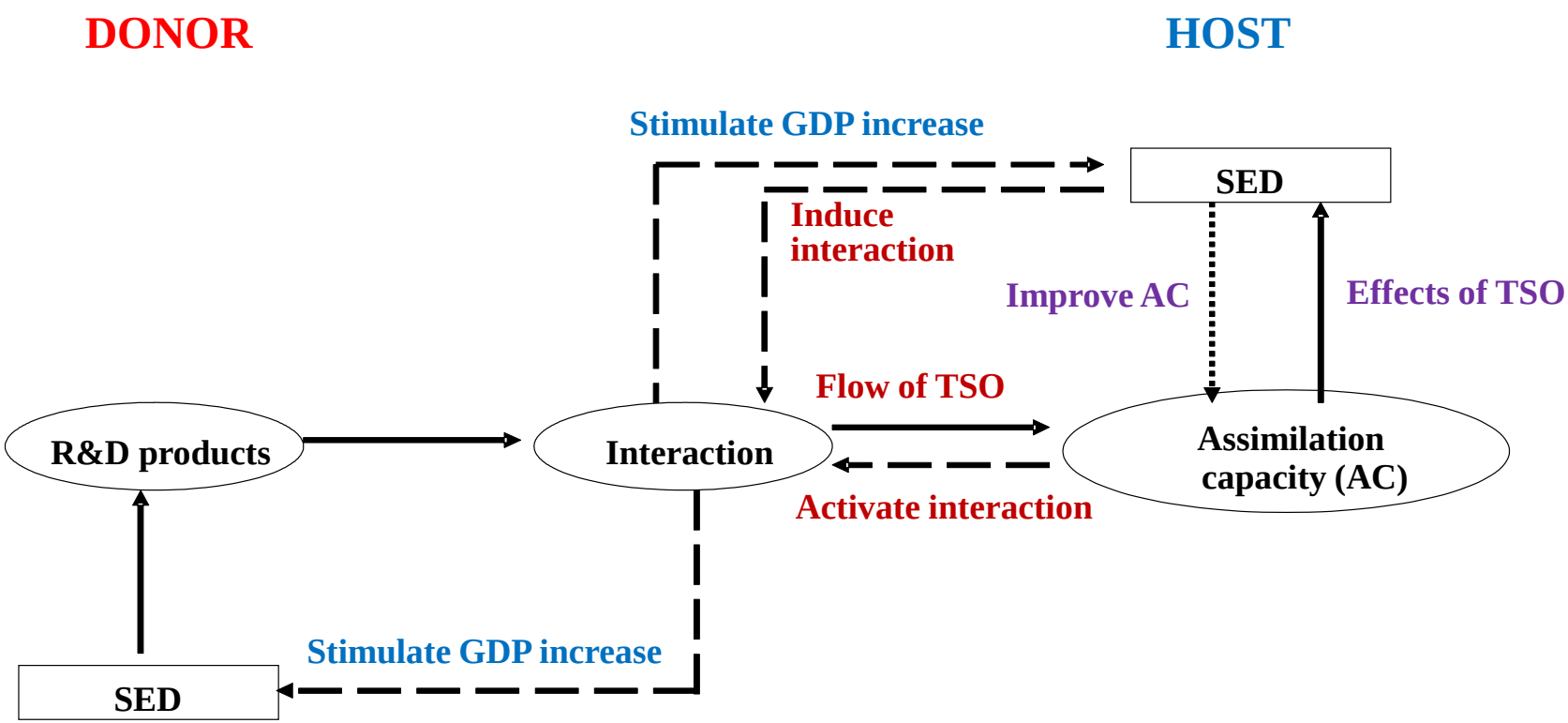


Fig. 1. Scheme of Japan's International Competitive Structure in a Global Economy with respect to Technology Development, Spillovers and Assimilation.

(2) Dynamism of Technology Spillover



SED: Socio economic development ; TSO :Technological spillovers AC: Assimilation capacity

Fig. 2. Dynamism of Technology Spillover.

5.2Assimilation Capacity for Spilling Over Technology

(1) Concept of Assimilation Capacity

1. **Cumulative learning** cultivate the capacity of distinguishing technology spillover flows by assessing and selecting them into
   (i) Should learn,
   (ii) Should not learn, and
   (iii) Can not learn

   leading to **absorptive capacity** to be able to treat accepted spillover technologies homogeneous to own technology stock.

2. Through co-evolutionary exercise of absorption **assimilation capacity** can be developed thereby to be able to embody absorbed technology to whole system in
   (i) Production,
   (ii) Diffusion, and
   (iii) Commercialization.

3. This ability then develop to **domestication** thereby **taming** assimilated spillover technology into the whole institutional system **by activating it through convincing and empowering**.

4. Domesticated technology/knowledge in turn further improve distinguishing capacity, absorption, assimilation and domestication ability in a co-evolutionary way

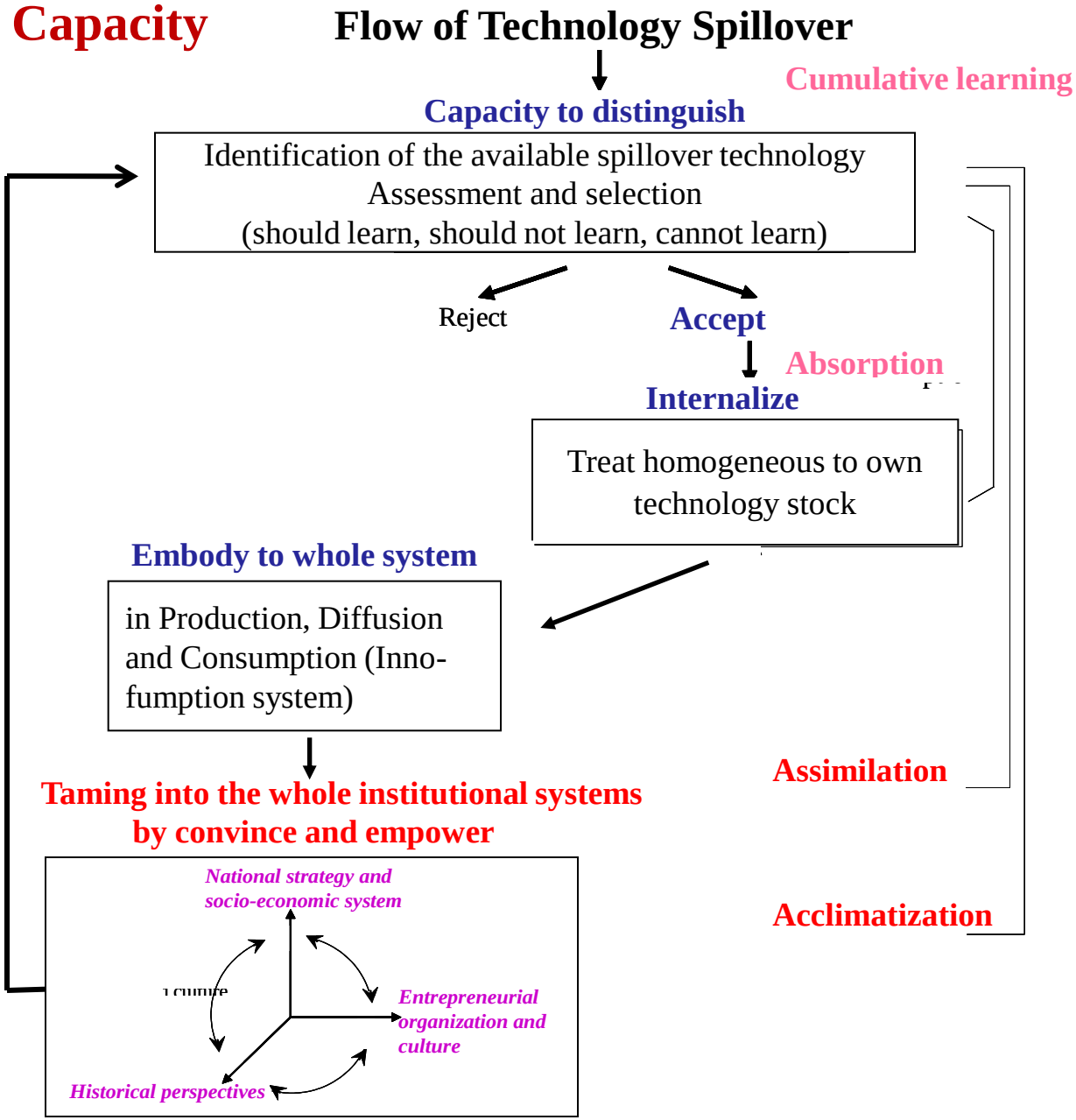


Fig. 3. The Concept of Co-evolutionary Acclimatization.

(2) Institutional Sources Leveraging Co-evolutionary Acclimatization

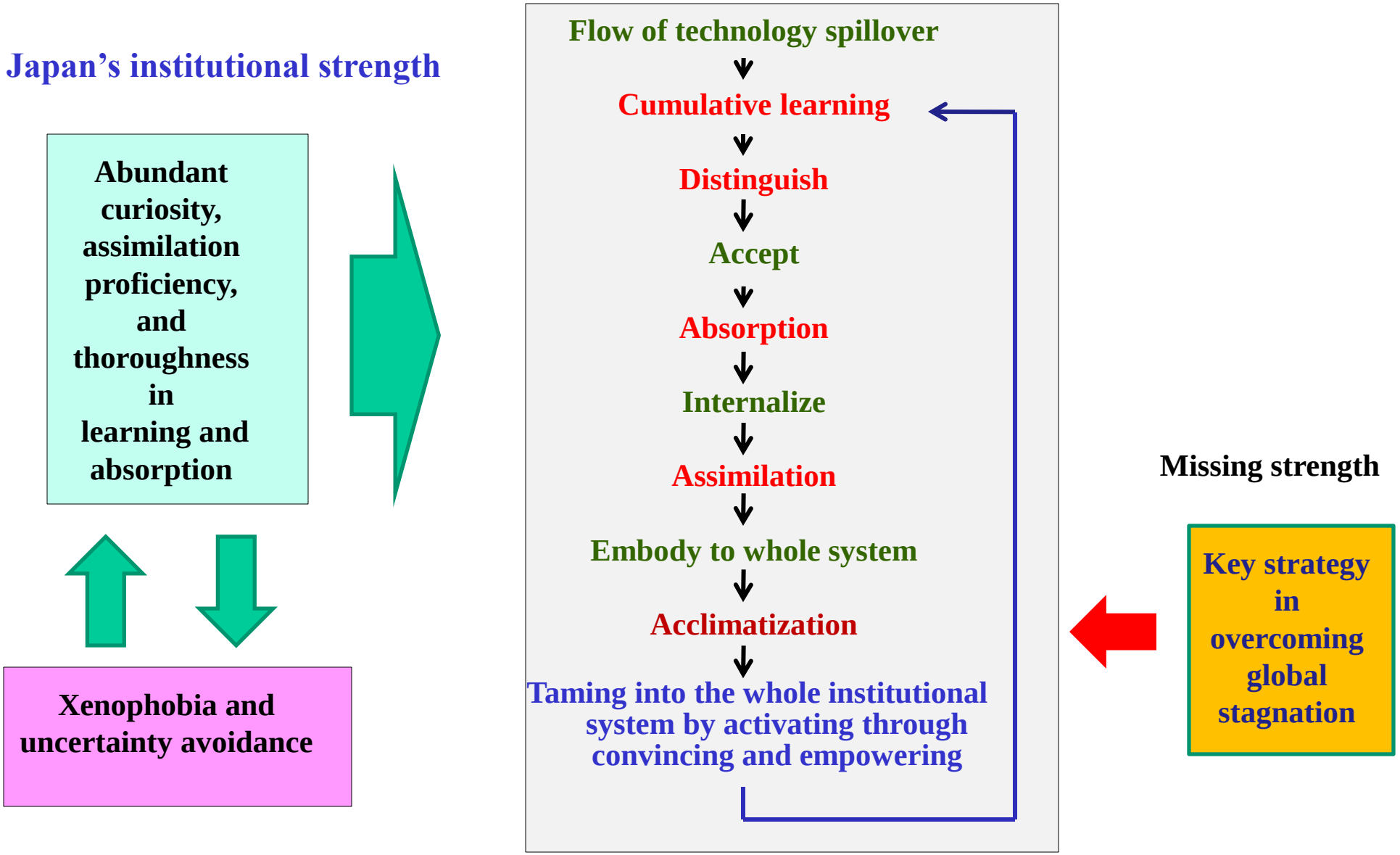


Fig. 4. The Concept of Co-evolutionary Acclimatization.

5.3 Assimilation of Spillover Technology

(1)Technology Distance

Griliches (1979) pointed out that firm's technology knowledge stock that contributes to production is not only generated by its indigenous R&D but also knowledge stock generated by other firms. The latter is called spillover technology.

Production by sector ***i***

$$Y_i = BX_i^{1-\gamma} K_i^{\gamma} K_{ai}^{\mu} \qquad (41)$$

X_i labor, capital ; K_i : indigenous technology knowledge stock

K_{ai}: technology knowledge stock by spillover technology

$$K_{ai} = \sum_j w_{ij} K_j \qquad (42)$$

w_{ij} : *weight function depicting i's possible spillover by sector j.*

Griliches postulated that utilization of spillover technology from others depends on the weight function which is subject to technology distance between *i* andj.

This postulate has two implications:

1.Firms with short technology distance share similar productions and R&D activities leading to higher level of infrastructure such as production/R&D facilities and marketing network enabling them to easier utilization and absorption of spillover technology.

2. Higher possibility to come across technologies looking for.

Thus, efforts to shorten technology distance has been realized significant entrepreneurs strategy.

(2) Technological Position and Technological Proximity

Prompted by Griliches's postulate, Jaffe (1986), based on a concept of technological proximity depicting the commonality of R&D activities between firms, postulated a concept of technological position F_i enabling to measure technology distance between firms *i* and *j* P_{ij} by the following equation:

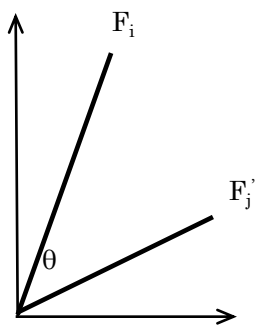
$$P_{ij} = \frac{F_i \cdot F_j^{'}}{\left[\left(F_i \cdot F_i^{'}\right)\left(F_j \cdot F_j^{'}\right)\right]^{1/2}} \qquad (43)$$

Technology distance indicates a value between 0 and 1 suggesting that it closes to 1 as commonality increases.

Given R&D in sector *j* R_j, spillover technology from sector *j* to sector *i* $\left[R_j\right]_j$ can be depicted by the following equation:

$$\left[R_i\right]_j = R_j \cdot P_{ij} \qquad (44)$$

Fi indicates distribution vector of R&D undertaken by firm *i as* $F_i = F(F_{i1}, F_{i2}, \ldots, F_{ij}, \ldots F_{in})$ while F'_i indicates reverse vector and F_{ij} indicates ratio of R&D in *j* field undertaken by firm *i*.



$$F_i \cdot F_j = \left|F_i\right| \cos\theta \cdot \left|F_j\right| = \left|F_i\right| \cdot \left|F_j\right| \cdot \cos\theta$$

$$\left|F_j\right| = \left(F_i^2 + F'^2\right)^{1/2}$$

$$P_{ij} = \cos\theta = \frac{F_i \cdot F_j^{'}}{\left[\left(F_i \cdot F_i^{'}\right)\left(F_j \cdot F_j^{'}\right)\right]^{1/2}}, \qquad \underset{Same}{0} < \cos\theta < \underset{Different}{1}$$

Fig. 5. Concept of Technology Distance and Technological Position.

(3) R&D Diversification and Technology Distance

Based on technology distance measurement by means of technological position derived from technological proximity concept postulated by Jaffe, technology distance can be computed by utilizing R&D diversification ratio.

Given R&D undertaken by sector i R_i and its R&D in the field of j out of R_i as R_{ij},

Indigenous R&D field ratio Di: $$D_i = R_{ii} / R_i \qquad (45)$$

R&D diversification ratio D_{ni}: $$D_{ni} = 1 - D_i = 1 - R_{ii} / R_i \qquad (46)$$

Based on this ratio, technology distance P_{ij} can be computed by the following equation:

$$P_{ij} = \frac{\sum_k \frac{R_{ik}}{R_i} \cdot \frac{R_{jk}}{R_j}}{\left[\sum_j \frac{R_{ij}^2}{R_i} \cdot \sum_i \frac{R_{ji}^2}{R_j} \right]^{1/2}} \qquad (47)$$

R&D diversification depicted by equation (46) can also be computed by the **entropy** as follows:

$$\varepsilon = \sum_{j=1}^{n} D_j \ln \frac{1}{D_j} \qquad D_j = R_{ij} / R_i \quad \text{(monopoly)} \quad 0 < \varepsilon < \ln n \quad \text{(perfect competition)} \qquad (48)$$

This can be also computed by **HHI (Herfindahl-Hirschman Index)** as follows:

$$HHI = 1 - \sum_{i=1}^{n} P_i^2 \qquad P_i = R_{ii} / \sum_{i=1}^{n} R_{ii} \qquad (49)$$

5.4 Measurement of Technology Spillover

- (1) Direct Measurement Approach
  - 1) Technological Distance Method
  - 2) Assimilation Capacity Method
  - 3) Dynamic Assimilation Analysis Method
- (2) Indirect Measurement Approach
  - 1) I-O Metod
  - 2) Translog Cost Function Method
- (3) Patent Data Approach

(1) Direct Measurement Approach

1) Technology Distance Method

Based on technology distance approach, spillover technology in firm *i* received from other firms can be measured as follows:

$$R_{is} = \sum_j P_{ij} \cdot R_{ij} \tag{50}$$

where P_{ij}: technology distance between firm *i* and *j*; R_{ij} :R&D in the field of *j* undertaken by firm *i*.

Assume the following production function:

$$Yi = F(X, T) \quad X = L, K, M, E$$

$$\Delta Y_i \Big/ Y_i = \sum \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} \cdot \frac{\Delta X}{X} + \frac{\partial Y}{\partial T} \cdot \frac{T}{Y} \cdot \frac{\Delta T}{T} \tag{51}$$

Since $\dfrac{\Delta TFP_i}{TFP_i} \approx \dfrac{\partial Y}{\partial T} \cdot \dfrac{R}{T}$

$$\Delta TFP_i / TFP_i = a + b_1 \left(R_{ij} / Y_i \right) + b_2 \left(R_{is} / Y_i \right) \tag{52}$$

where R_{ii}, R_{is} : firm *i*'s indigenous R&D and received spillover R&D, respectively.

2) Assimilation Capacity Method

$(X_i = L, K, M, E)$

Given the indigenous technology knowledge stock T_i, potential technology spillover pool T_s, and assimilation capacity z, gross technology knowledge stock T can be depicted as follows:

$$T = T_i + z \cdot T_s \tag{53}$$

$$Y = A \prod_{X_i}^{L,K,M,E} X_i^{\alpha_i} T^{\beta} \tag{54}$$

$$\begin{aligned}
\ln Y &= \ln A + \sum \alpha_i \ln X_i + \beta \ln T \\
&= \ln A + \sum \alpha_i \ln X_i + \beta \ln(T_i + zT_s) \\
&= \ln A + \sum \alpha_i \ln X_i + \beta \ln T_i (1 + z \cdot T_s / T_i) \\
&\approx \ln A + \sum \alpha_i \ln X_i + \beta \ln T_i + \beta \ z \cdot T_s / T_i \equiv \ln A + \Sigma \alpha_i \ln X_i + \beta \ln T_i + \gamma T_s / T_i \quad (\because \ z \cdot T_s / T_i << 1, \ \gamma \equiv \beta z)
\end{aligned} \tag{55}$$

$$\gamma = \beta z, \quad z = \gamma / \beta = \beta z / \beta$$

- (1) Direct Measurement Approach
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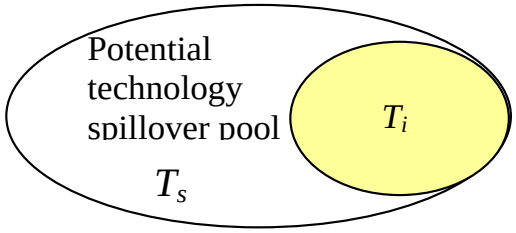
3) Dynamic Assimilation Analysis Method

$$z = \frac{1}{1 + \frac{\Delta T_s}{T_s} \Big/ \frac{\Delta T_i}{T_i}} \cdot \frac{T_i}{T_s} \tag{56}$$



$$T_s = \sum_{\substack{j \\ j \neq i}}^{n} T_j$$

Appendix: Mathematical Development of Dynamic Assimilation Capacity

売上高は技術ストックの関数として表される。

$$S=S(T) \tag{A.1}$$

技術ストックは独自の技術開発による技術ストック（T_i），他社からのスピルオーバーによる技術ストック（$Z \cdot T$）とに分解する。

$$T = T_i + Z \cdot T \tag{A.2}$$

ただし $T_s = \sum_j T_j - T_i$

以下のように近似する。

$$\ln T = \ln T_i \left(1 + Z\frac{T_s}{T_i}\right) \approx \ln T_i + Z\frac{T_s}{T_i} \tag{A.3}$$

技術ストックの成長率は以下のように表せる。

$$\frac{\Delta T}{T} = \frac{\Delta T_i}{T_i} + \Delta Z\frac{T_s}{T_i} + Z\Delta\frac{T_s}{T_i} \approx \frac{\Delta T_i}{T_i} + Z\Delta\frac{T_s}{T_i} \qquad (\Delta Z \approx 0) \tag{A.4}$$

以下の式を展開すると

$$\begin{aligned}
&\frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\frac{\Delta T}{T} \\
&= \frac{\partial S}{\partial T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i} + \frac{\partial S}{\partial(Z\cdot T_s)}\cdot\frac{Z\cdot T_s}{S}\cdot\frac{\Delta(Z\cdot T_s)}{Z\cdot T_s} \\
&= \frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\left(\frac{\Delta T_i}{T_i} + Z\Delta\frac{T_s}{T_i}\right)
\end{aligned} \tag{A.5}$$

技術の限界生産性は以下のように表せる。

$$\frac{\partial S}{\partial T} = \frac{P_t}{P_s},\ \frac{\partial S}{\partial T_i} = \frac{P_{ti}}{P_s},\ \frac{\partial S}{\partial(Z\cdot T_s)} = \frac{P_{ts}}{P_s}$$

$$\phi = \frac{\partial S / \partial(Z\cdot T_s)}{\partial S / \partial T_i} = \frac{P_{ts}}{P_{ti}}, \qquad \phi > 1, \frac{d^2\phi}{dt^2} < 0 \tag{A.6}$$

（A.6）式より次の式が得られる。

$$P_t = \frac{T_i\cdot P_{ti} + Z\cdot T_s\cdot P_{ts}}{T} = \frac{P_{ti}(T_i + Z\cdot\phi\cdot T_s)}{T_i + Z\cdot T_s} \tag{A.7}$$

$$\frac{\partial S}{\partial T_i}\cdot\frac{T_i}{S}\cdot\frac{\Delta T_i}{T_i} + \phi\frac{\partial S}{\partial T_i}\cdot\frac{Z\cdot T_s}{S}\cdot\frac{\Delta(Z\cdot T_s)}{Z\cdot T_s} = \frac{P_{it}(T_i + Z\cdot\phi\cdot T_s)}{(T_i + Z\cdot T_s)P_s}\cdot\frac{T_i + Z\cdot T_s}{S}\cdot\left(\frac{\Delta T_i}{T_i} + Z\Delta\frac{T_s}{T_i}\right)$$

$$\Delta T_i + \phi\Delta(Z\cdot T_s) = (T_i + Z\cdot\phi\cdot T_s)*\left(\frac{\Delta T_i}{T_i} + Z\cdot\Delta\frac{T_s}{T_i}\right) \tag{A.8}$$

$$\phi = \frac{T_i\Delta\frac{T_s}{T_i}}{\Delta T_s - \Delta T_i\frac{T_s}{T_i} - Z\cdot T_s\cdot\Delta\frac{T_s}{T_i}} = \frac{1}{1 - Z\cdot\frac{T_s}{T_i}} \tag{A.9}$$

（A.9） 式より Z を得られる。

$$Z = \left(1 - \frac{1}{\phi}\right)\cdot\frac{T_i}{T_s}, \quad 0 < Z < T_i/T_s \tag{A.10}$$

技術のスピルオーバー効果を最大化する条件下では売上高の変化は以下のように表せる。

$$\frac{dS}{dt} = \frac{\partial S}{\partial T}\cdot\frac{dT}{dt} \tag{A.11}$$

$$\frac{dS}{dt} = \frac{\partial S}{\partial T_i}\cdot\frac{dT_i}{dt} \tag{A.12}$$

$$\frac{dS}{dt} = \frac{\partial S}{\partial(ZT_s)}\cdot\frac{d(ZT_i)}{dt} \approx \frac{\partial S}{\partial(ZT_s)}\cdot\frac{ZdT_s}{dt} \tag{A.13}$$

$$\frac{\partial S}{\partial T_i} = \frac{\Delta S}{\Delta T_i} \tag{A.14}$$

$$\frac{\partial S}{\partial(ZT_s)} = \frac{\Delta S}{Z\Delta T_s} \tag{A.15}$$

（A.14）式，（A.15）式を用いて A6 式は以下のように展開できる。

$$\phi = \frac{\Delta S / Z\Delta T_s}{\Delta S / \Delta T_i} = \frac{\Delta T_i}{Z\Delta T_s} \tag{A.16}$$

$$Z = \left(1 - \frac{Z\cdot T_s}{\Delta T_i}\right)\cdot\frac{T_i}{T_s} \tag{A.17}$$

（A.17）式より Z を得られる。

$$Z = \frac{\Delta T_i\cdot T_i}{\Delta T_i\cdot T_s + \Delta T_s\cdot T_i} = \frac{T_i}{T_s}\cdot\frac{\Delta T_i}{\Delta T_i + \frac{\Delta T_s}{T_s}\cdot T_i} = \frac{1}{1 + \frac{\Delta T_s}{T_s} / \frac{\Delta T_i}{T_i}}\cdot\frac{T_i}{T_s} \tag{A.18}$$

- (1) Direct Measurement Approach
- **(2) Indirect Measurement Approach**
  - 1) Technological Distance Method
  - 2) Assimilation Capacity Method
  - 3) Dynamic Assimilation Analysis Method
  - **1) I-O Metod**
  - 2) Translog Cost Function Method
- (3) Patent Data Approach

(2) Indirect Measurement Approach

1) I-O Method : Input-Output Table

Impacts

$$\underset{\text{Innovation}}{\Delta T_{jx}} \xrightarrow{\text{Supply side industry}} \underset{\text{Productivity}}{\Delta TFP_{jx}} \xrightarrow{\text{Spillover}} \underset{\text{Price down}}{\Delta P_{jx}} \xrightarrow{\text{Recipient industry}} \underset{\text{Cost down}}{\Delta C_i} \longrightarrow \underset{\text{Productivity increase}}{\Delta TFP_i} \tag{57}$$

Based on the postulate of the gross accounting theory that technological progress leads to cost reduction, cost decrease in output is analyzed to examine possible effects of technology spillover as a consequence of the interaction between input (I) and output (O).

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2) Translog Cost Function Method

Assume the translog type cost function incorporating both indigenous technology knowledge stock Ti and spillover technology knowledge stock Ts as follows:

$$C = f(X,\ T_i,\ T_s) \tag{58}$$

Elasticity of spillover technology knowledge stock to cost can be depicted as follows:

$$\partial \ln C / \partial \ln T_s = \omega \tag{59}$$

As growth accounting theory demonstrates that technology increase leads to cost decrease,

$\partial \ln C / \partial \ln T_s = \omega$ < 0 suggests substantial effects of spillover technology, thus spillover technology incorporation can be demonstrated.

$$\frac{\partial \ln C}{\partial \ln T_s} = \frac{d \ln C}{dt} \Big/ \frac{d \ln T_s}{dt} = \frac{dC/dt}{C} \Big/ \frac{dT_s/dt}{T_s} = \frac{\Delta C}{C} \Big/ \frac{\Delta T_s}{T_s}$$

Cost function for sector *i*: $GC^i = C^i(y^i, P_l, P_k, T^i, T^j)$

GC^i : Production cost for sector *i* $GC^i = P_l * L^i + P_k * K^i$

y^i : Production for sector *i*

P_l : Price of labor for sector *i*

P_k : Price of capital for sector *i*

K^i : Capital input for sector *i*

L^i : Labor input for sector *i*

T^i : Technology knowledge stock for sector *i*

$P_l * L^i$: Labor cost for sector *i*

$P_k * K^i$: Capital cost for sector *i*

Taylor expansion to the secondary term leads to the following translog (transdential logistic) cost function:

$$\begin{aligned}\ln C = {} & a_0 + a_y \ln y + a_l \ln P_l + a_k \ln P_k + \sum_{n=i,j} a_n \ln T^n \\ & + \frac{1}{2}\Bigg[\ln P_l \cdot \left(b_{ll} \cdot \ln P_l + b_{lk} \cdot \ln P_k + \sum_{n=i,j} b_{ln} \cdot \ln T^n\right) + \ln P_k \cdot \left(b_{kl} \cdot \ln Pl + b_{kk} \cdot \ln P_k + \sum_{n=i,j} b_{kn} \cdot \ln T^n\right) \\ & + \sum_{n=i,j} \ln T^n \cdot \left(b_{nl} \cdot \ln P_l + b_{nk} \cdot \ln P_k + b_{ni} \cdot \ln T^i + b_{nj} \cdot \ln T^j\right)\Bigg]\end{aligned} \tag{60}$$

Necessary condition for the linear homogeneity with respect to prices of production factors:

$$\begin{aligned} & a_l + a_k + a_i + a_j = 1 \\ & b_{ll} + b_{lk} + b_{li} + b_{lj} = 0,\ b_{kl} + b_{kk} + b_{ki} + b_{kj} = 0 \\ & b_{il} + b_{ik} + b_{ii} + b_{ij} = 0,\ b_{jl} + b_{jk} + b_{ji} + b_{jj} = 0, \end{aligned} \tag{61}$$

Satisfying a necessary condition for secondary differentiation:

$$b_{lk} = b_{kl},\ b_{li} = b_{il},\ b_{lj} = b_{jl},\ b_{ki} = b_{ik},\ b_{kj} = b_{jk},\ b_{ij} = b_{ji} \tag{62}$$

A Case Analysis: Japan's Electric Power Companies

(i) Translog Cost Function

Prices IT stock

$$C = C(Y, Pi, Te, ITe, ITm) \quad \text{(i)}$$

Gross cost Production Technology Stock IT stock in manufacturing ind.

Taylor expansion

$$\begin{aligned} lnC = {} & C0 + \alpha_Y lnY + \sum \alpha_i lnPi + \alpha_{Te} lnTe + \alpha_{ITe} lnITe + \alpha_{ITm} lnITm + \sum\sum \beta ij lnPi lnPj \\ & + \sum \beta_{Yi} lnY lnPi + \sum \beta_{Tei} lnTe lnPi + \sum \beta_{ITei} lnITe lnPi + \sum \beta_{ITmi} lnITm lnPi + \beta_{YTe} lnY lnTe \\ & + \beta_{YITe} lnY lnITe + \beta_{YITm} lnY lnITm + \beta_{TeITe} lnTe lnITe + \beta_{TeITm} lnTe lnITm \end{aligned} \quad \text{(ii)}$$

Spillover effect

$$\partial lnC/\partial lnITm = \alpha_{ITm} + \sum \beta_{ITmi} lnPi + \beta_{YITm} lnY + \beta_{TeITm} lnTe + \beta_{ITeITm} lnITe \quad \text{(iii)}$$

$\partial lnC / \partial lnITm < 0$ **Spillover effect**

(ii) Empirical Analysis

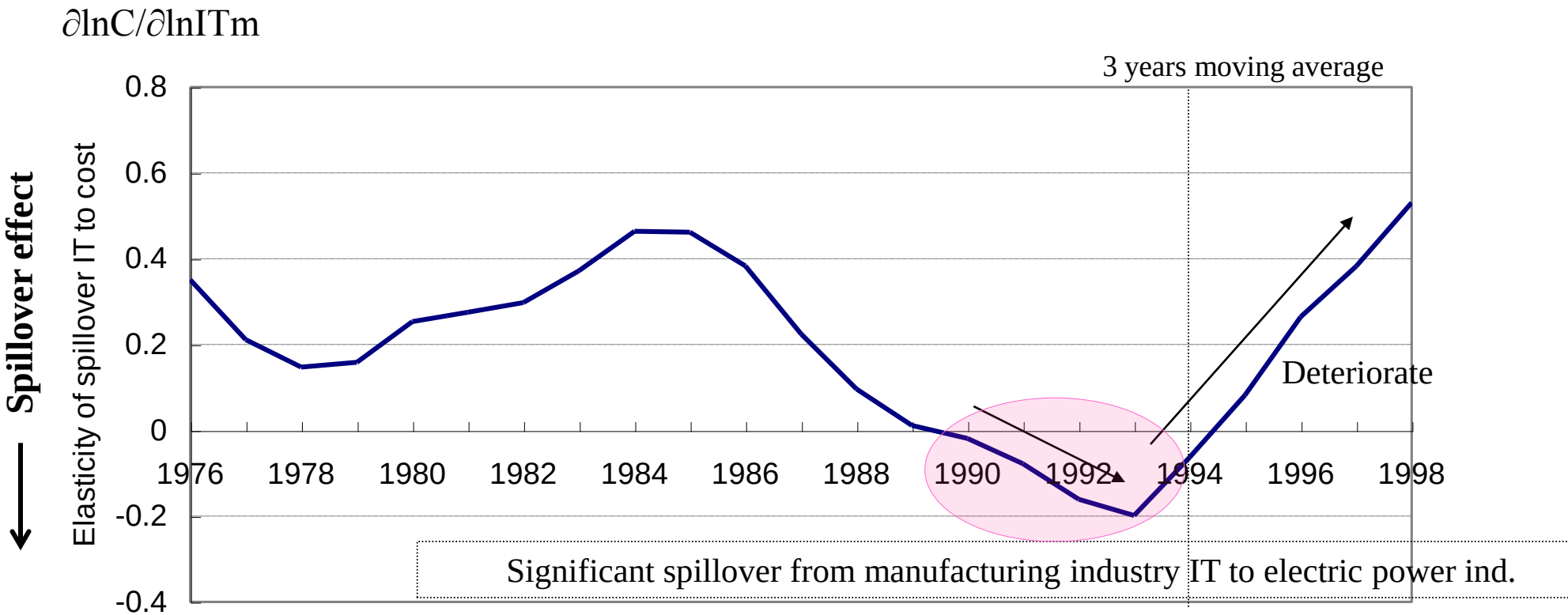

Fig. 6. Trend in Elasticity of Spillover IT to Cost in Japan's Electric Power Companies (1976-1998).

(3) Patent Data Approach

- (1) Direct Measurement Approach
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A Case Analysis: Comparison of High-performance and Structural Fine Ceramics

(i) Hypothesis

	Function	Products	Functionality	Key materials with indigenous functions			
				AlN	*SiC*	Si_3N_4	Al_2O_3
High-performance FCs	Electronic and optical	IC packages and substances (PAS)	Electrical insulating	○	×	×	○
			Thermal conductive	○	△	×	×
	Chemical		Corrosion resistive				○
Structural FCs	Chemical and biochemical		Corrosion resistive		Spillover		○
	Mechanical		Wear resistive	×	○	○	○
	Thermal and nuclear	Parts for IC manf. (PIM)	Corrosion resistive	○	×	×	○
			Thermal shock resistive	△～○	△～○	○	×
			Heat resistive	×	○	○	×

AlN incorporated in PAS has spillovered to PIM instilling PIM similar functionality as PAS.

Fig. 7. Possibility of Cross-functional Spillover of Key Materials Used for the Fine Ceramics

Source: Ohmura and Watanabe *(2006)*.

(ii) Effects of Cross-functional Spillover

Table 1_{-1} Estimation Results for the Diffusion Process Analysis of PAS *(1981-2000)*

K_K	a	b	a_K	b_K	*adj.* R^2	a_K/a
2059.20	2452.00	1.59	467.20	0.22	0.999	**0.19**
(2.08)	(76.11)	(1.63)	(2.69)	(26.94)		

Table 1_{-2} Estimation Results for the Diffusion Process Analysis of PIM *(1995-2000)*

K_K	a	b	a_K	b_K	*adj.* R^2	a_K/a
724.26	713.95	0.43	96.79	0.10	0.992	**0.14**
(1.83)	(2.10)	(5.48)	(1.98)	(15.42)		

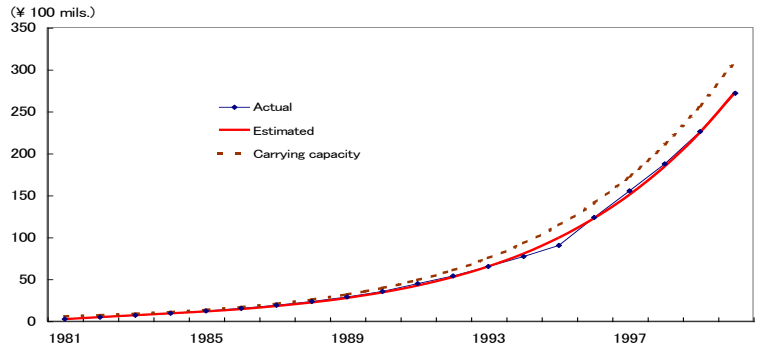


Fig. 8. Trends in the Diffusion Process of PAS ***(1981-2000) - ¥ 100 mils. at 1995 fixed prices.***

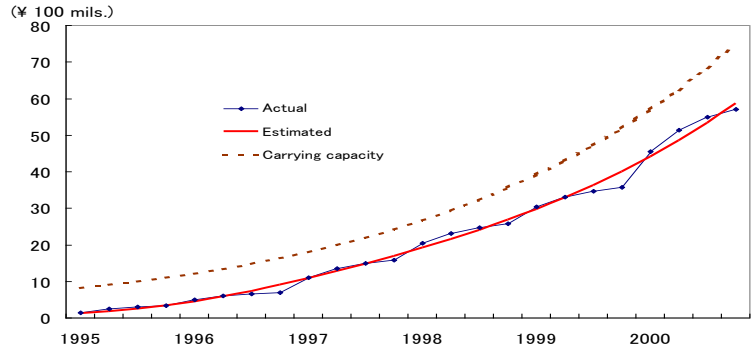


Fig. 8_{-2}. Trends in the Diffusion Process of PIM ***(1995-2000) - ¥ 100 mils. at 1995 fixed prices.***

Table 2 Comparison of Degree of Functionality of the Fine Ceramics in Broad Applications

Products		Degree of functionality (a_K/a)
High-performance FCs	Electronic and optical	0.10
	IC packages and substances (PAS)	**0.19**
	Chemical	0.21
Structural FCs	Chemical and biochemical	0.02
	Mechanical	0.03
	Thermal and nuclear	0.01
	Parts for IC manf. (PIM)	**0.14**

$$Y(t) = \frac{N(t)}{1+be^{-at}}$$

$$N(t) = \frac{N_k}{1+b_k e^{-a_k t}}$$

$$Y(t) = \frac{N_k}{1+be^{-at} + \frac{b_k}{1-\frac{a_k}{a}} e^{-a_k t}}$$

Source: Ohmura and Watanabe *(2006)*.

(iii) Spillover Dynamism

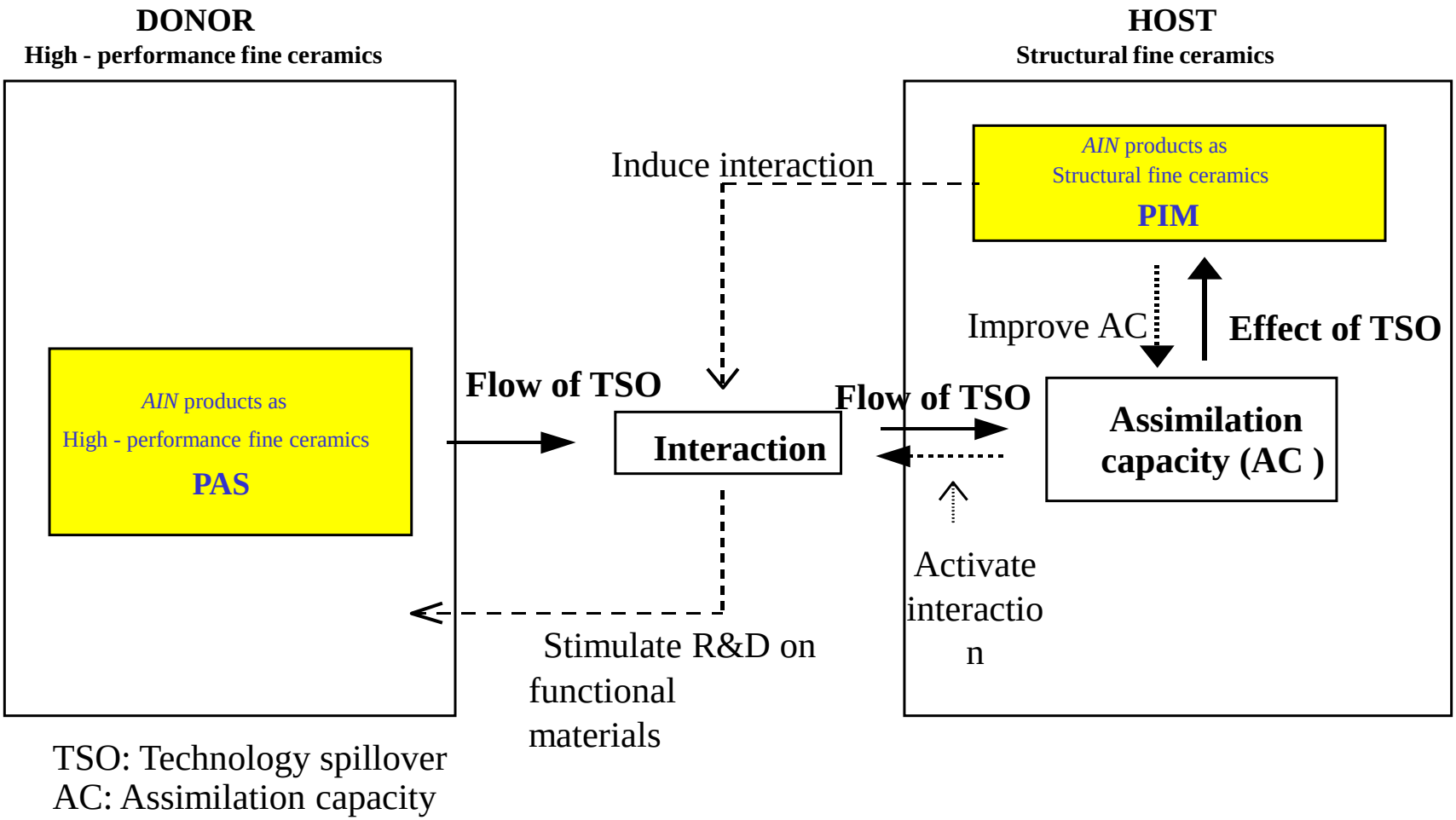
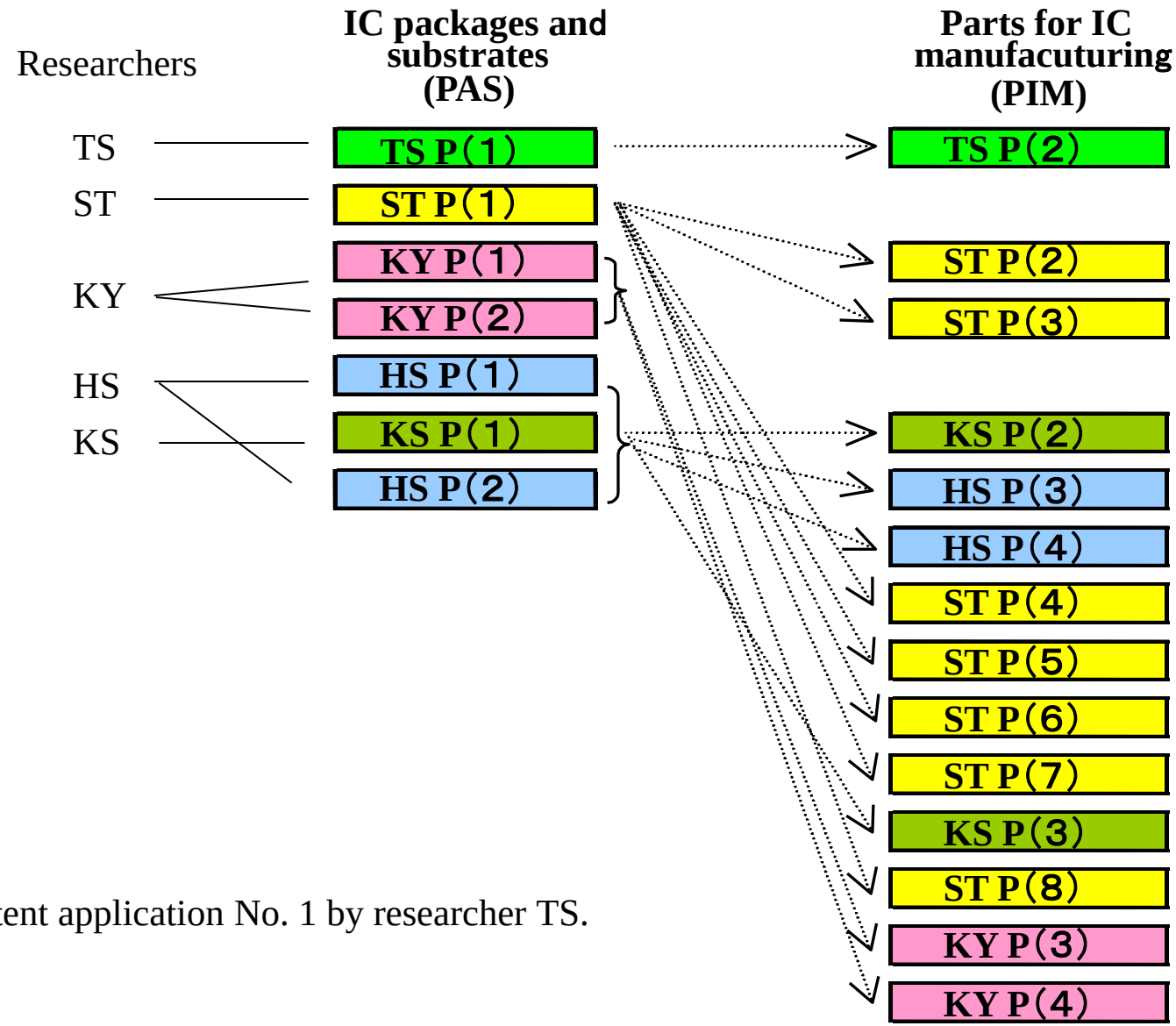


Fig. 9. Dynamism of Technology Spillover of *AlN* Products.

Source: Watanabe et al. (*2001*).

(iv) Sources of Spillover: Cumulative Learning by Interactions



TS P(1): Patent application No. 1 by researcher TS.

Fig. 10. Interaction between Researchers in IC Packages/Substrates Research and Parts for IC Manufacturing Research Identified by Published Patent Application (*1992-2004*).

Source: Ohmura and Watanabe *(2006)*.

6. Rate of Return to R&D Investment

6.1 Evaluation of R&D Investment

6.2 Trends in IRR to R&D Investment

6.3 Metabolic Function of IRR

6.4 Consequence of Techno-metabolism

6.5 Factors Governing IRR to R&D Investment

6.1 Evaluation of R&D Investment

(1) Trade-off between R&D Investment and Manufacturing Investment

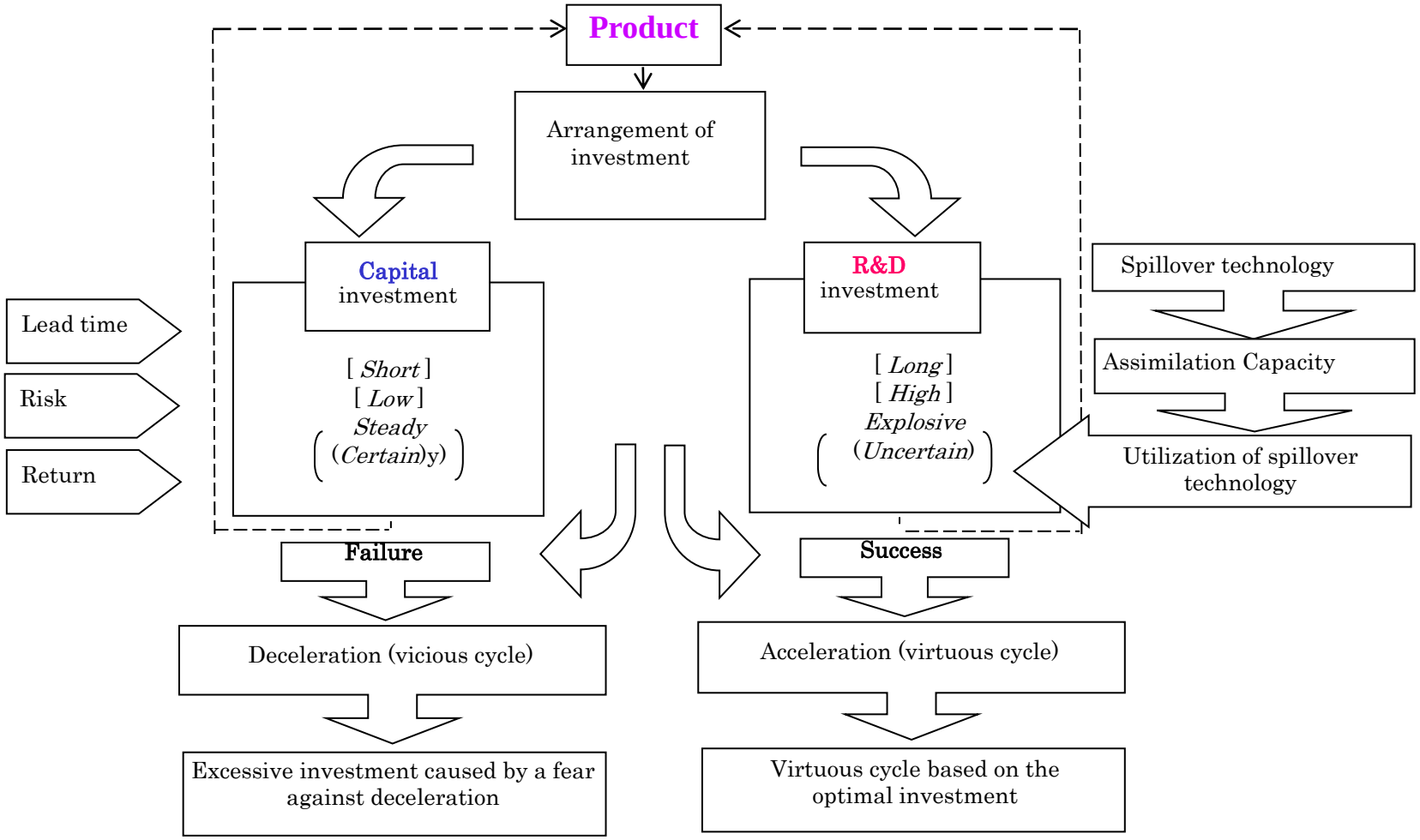


Fig. 11. Dynamic Optimality Principles in R&D Investment.

(2) Firm's R&D investment decision

Contribution to profit maximum

↓

Expected return of R&D investment through new technology/products

↓

Pre-assessment of the annual rate of expected return:

Measurement of internal rate of return to R&D investment

↓

Comparative assessment with other investment opportunities

↓ ↓

Higher rate | Lower rate

↓ ↓

R&D investment | **Other investments**

Fig. 12. General Scheme of Firm's R&D Investment Decision.

(3) Internal Rate of Return: *IRR*

Investment cost: *C*

Subsequent annual revenue for the duration years *n*: $y_1, y_2, y_3, \ldots\ldots\ldots y_n$

Discount rate: *r*

Present value of $y_1 : V_1 = \dfrac{y_1}{(1+r)}$

Present value of total revenue derived from *C*: $V = \sum_{i=1}^{n} V_i = \dfrac{y_1}{(1+r)} + \dfrac{y_2}{(1+r)^2} + \cdots + \dfrac{y_n}{(1+r)^n}$

IRR* is discount rate which leads to *C* = *V

(4) Measurement of IRR

1) Case Study Approach

$$R\&D\ strategy \rightarrow Cost\,(C) \rightarrow V \Rightarrow r\ when\ C = V$$

2) Production/Cost Function Approach

Identify ***r*** that satisfies $C = V$ by means of production and cost functions.

Scheme of Production/Cost Function Approach

Input

One unit of R&D investment

Present value

$$1 \qquad e^{mr}$$

$$-m \qquad 0 \qquad t \qquad \infty$$

R&D undertake ***Commercialization*** ***Obsolescent***

$$\frac{\partial V}{\partial T} \longrightarrow \frac{\partial V}{\partial T}(1-\rho)^t$$

Output

$$\frac{\frac{\partial V}{\partial T}(1-\rho)^t}{(1+r)^t} = \frac{\partial V}{\partial T} e^{-(r+\rho)}$$

Present value

$$\int_0^\infty \frac{\partial V}{\partial T} e^{-(r+\rho)t} dt = \frac{\frac{\partial V}{\partial T}}{(r+\rho)}$$

Whole value in total life (by present value)

$$\frac{1}{(1+r)^{-m}} = (1+r)^m \approx e^{mr}$$

$$V = F(X,T) = \frac{\partial V}{\partial X} \cdot X + \frac{\partial V}{\partial T} \cdot T$$

One unit of R&D → $T = 1$ increase

$\longrightarrow$ Generate $\frac{\partial V}{\partial T}$

$$V = F(X,T) \qquad T_t = R_{t-m} + (1-\rho)T_{t-1}$$

where V: production (value added); T: technology stock; R: R&D investment; m: lead time between R&D and commercialization; and ρ: rate of obsolescence of technology.

Present value of one unit R&D investment (R = 1)at the initial year of the commercialization:

$$1/(1+r)^{-m} = (1+r)^m \approx e^{mr} \qquad \text{where } r\text{: discount rate.} \tag{60}$$

The return of one unit R&D investment at the initial year of the commercialization:

$\frac{\partial V}{\partial T}$; its value at time t: $\frac{\partial V}{\partial T}\cdot(1-\rho)^t$; and its present value at the initial year of commercialization (t = 0):

$$\frac{\frac{\partial V}{\partial T}\cdot(1-\rho)^t}{(1+r)^t} = \frac{\partial V}{\partial T}\cdot(1-\rho)^t(1+r)^{-t} \approx \frac{\partial V}{\partial T}\cdot e^{-\rho}\cdot e^{-t} = \frac{\partial V}{\partial T}\cdot e^{-(r+\rho)}$$

; and whole value in its total life is:

$$\int_0^\infty \frac{\partial V}{\partial T} e^{-(r+\rho)t} dt \tag{61}$$

Discount rate $\boldsymbol{r}$ which equilibrates present values of investment and its return can be identified as IRR to R&D investment.

$$e^{mr} = \int_0^\infty \frac{\partial V}{\partial T} e^{-(r+\rho)t} dt = \frac{\frac{\partial V}{\partial T}}{(r+\rho)} \tag{62}$$

$$1 + mr = \frac{\frac{\partial V}{\partial T}}{(r+\rho)} \tag{63}$$

$$r = \frac{-(1+m\rho) + \sqrt{(1+m\rho)^2 - 4m(\rho - \frac{\partial V}{\partial T})}}{2m} \tag{64}$$

In case when $m = 0$, $\frac{\partial V}{\partial T} = r + \rho$

Equation (64) demonstrates that $\boldsymbol{r}$ (IRR) is a function of . Therefore, given that $MPT(\frac{\partial V}{\partial T}), m, \rho$ are provided externally, r (IRR) can be computed as a function of. $MPT(\frac{\partial V}{\partial T})$ marginal productivity of technology.

In case, when firms seek to maximize their profits in the competitive market, MPT corresponds to relative prices of technology $\frac{Pt}{P\dot{v}}$

Prices of technology (service prices of technology) Pt can be computed as follows by summing up respective prices of R&D investment:

$$\begin{aligned} Pt &= (1-gs)(Rls * Dl + Rks * \frac{Dk^{\#}}{1-ct} + Rms * Dm + \mathrm{Re}s * De) \\ &= (1-gs)(Rls * Dl + Rks * \frac{r+\rho}{1-ct} * Dk + Rms * Dm + \mathrm{Re}s * De) \end{aligned} \tag{65}$$

$$\because Dk = \int_0^{\infty} Dk^{\#} e^{-(r+\rho)t} dt = \frac{Dk^{\#}}{r+\rho}$$

where

Rls, ***Rks***, ***Rms*** and ***Res***: shares of R&D expenditures for labor costs, tangible fixed assets, materials, and energy respectively;
Dl, ***Dk***, ***Dm*** and ***De***: wage index, investment goods deflator, wholesale price indices of materials and energy respectively;
Dk#: service price of technology capital;
$\mathbf{g_s}$: ratio of government financial support; and $\mathbf{c_t}$: ratio of corporate tax.

Factors composing R&D investment and their shares (%) in the Japanese manufacturing industry in 1990.

	Labor	Capital	Materials	Energy
R&D investment factors	Rls (39.1)	Rks (36.7)	Rms (21.8)	Res (2.4)
Prices (Deflator)	Dl	Dk	Dm	De

Thus, provided that m, ρ, Pv are given externally, internal rate of return (IRR) to R&D investment can be computed by solving simultaneous equations (64) and (65) as follows:

$$r = \frac{-(1+m\rho) + \sqrt{(1+m\rho)^2 - 4m(\rho - \frac{\partial V}{\partial T})}}{2m} = \frac{-(1+m\rho) + \sqrt{(1+m\rho)^2 - 4m(\rho - \frac{P_t}{P_v})}}{2m}$$

6.2 Trends in IRR to R&D Investment

(1) Historical Trend in Manufacturing Industry

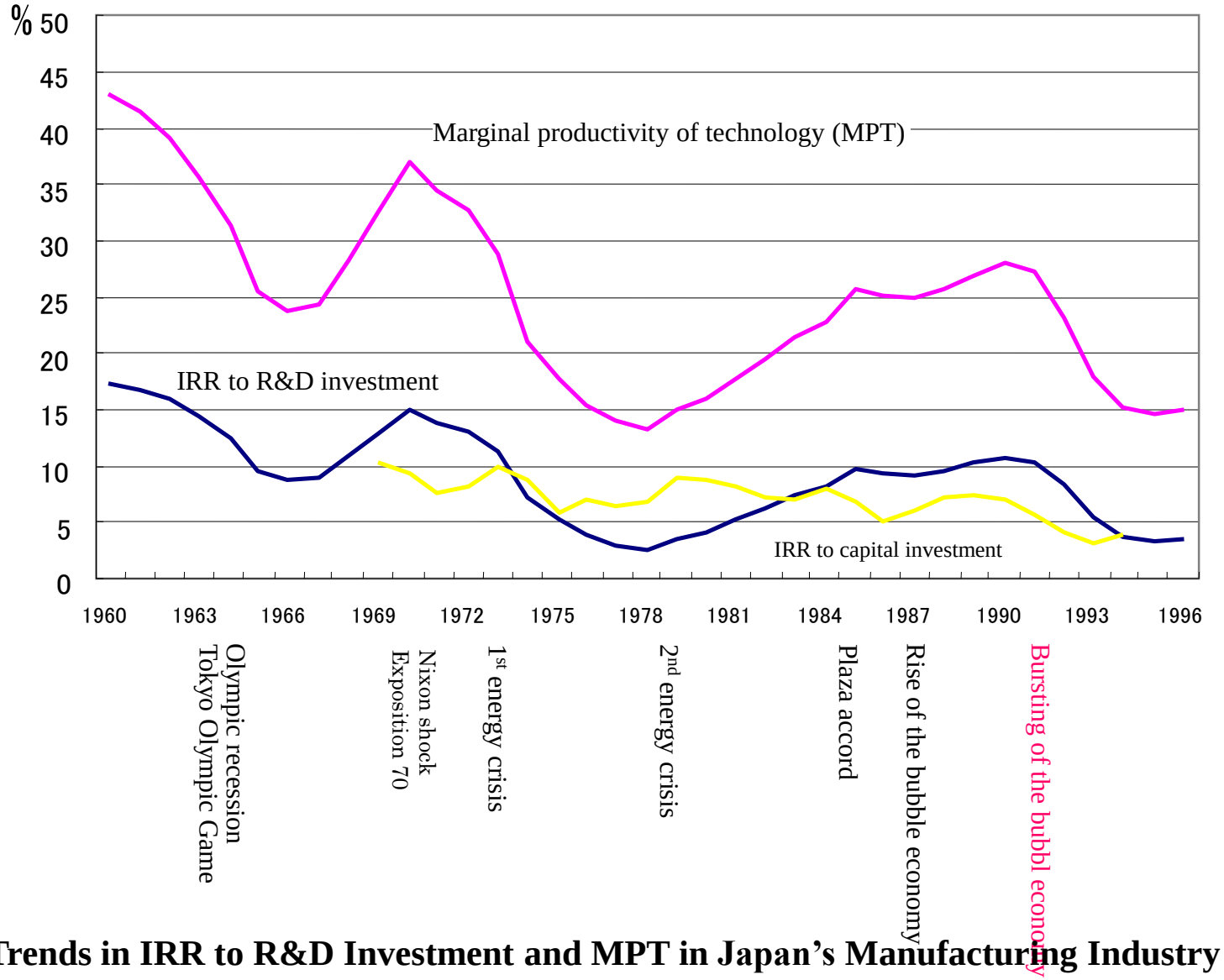


Fig. 13. Trends in IRR to R&D Investment and MPT in Japan's Manufacturing Industry *(1960-1996).*

(2) Sectoral Trends – *Principal components analysis*

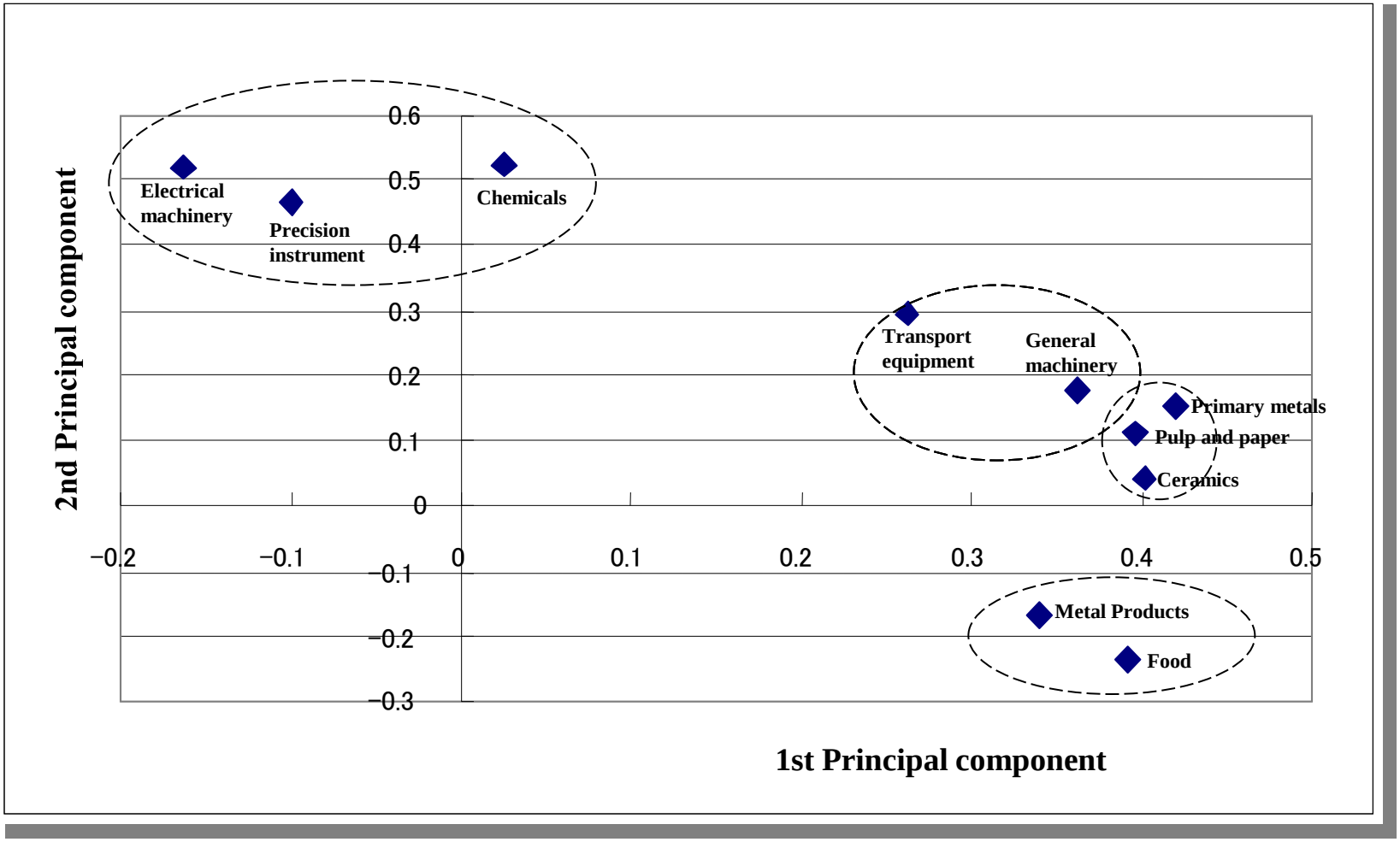


Fig. 14. Classification of Japan's Manufacturing Sectors *(1960-1996).*

1) High-technology Industry

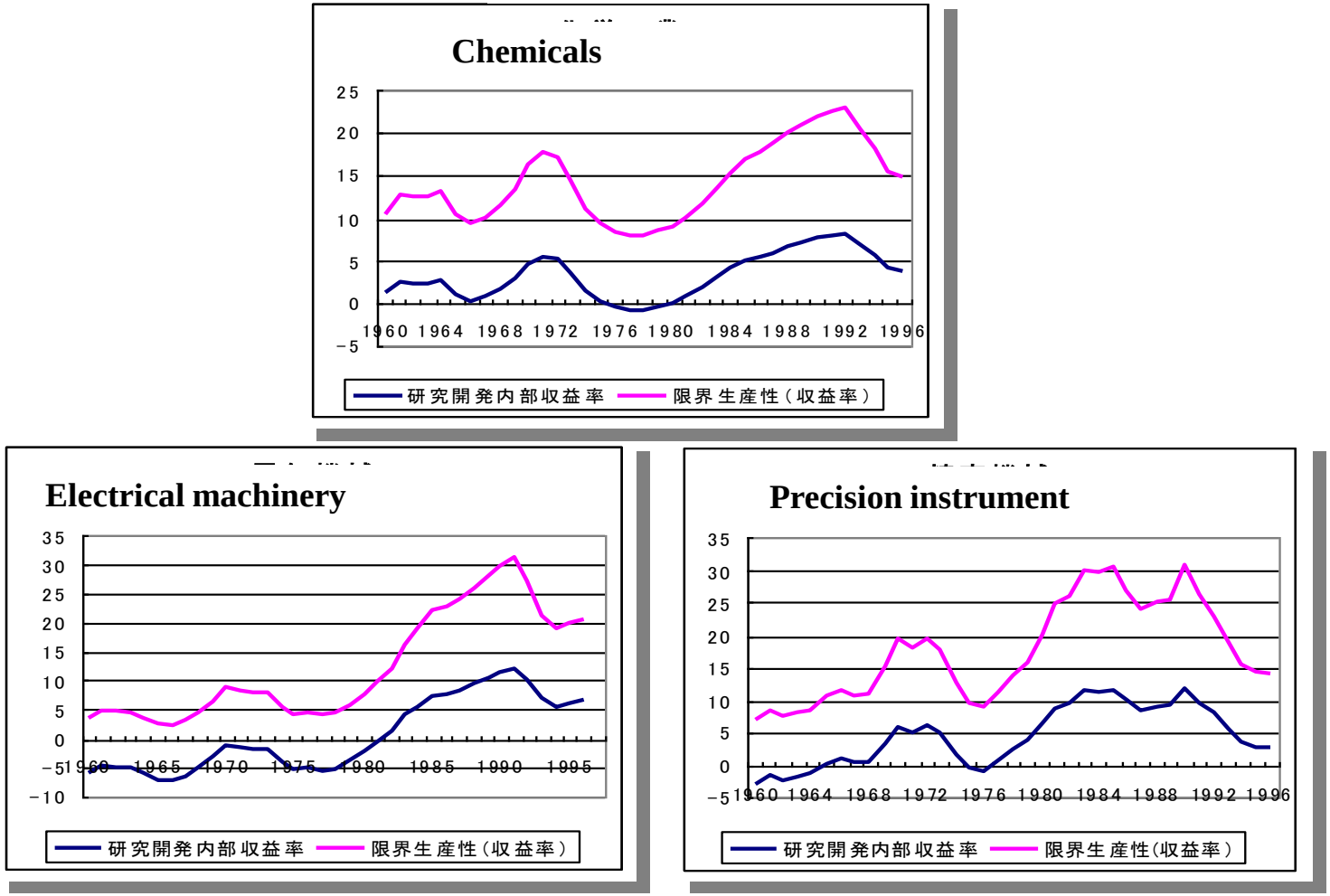


Fig. 15. Trends in IRR to R&D Investment and MPT by Clusters in Japan's Manufacturing Industry (*1960-1996*)

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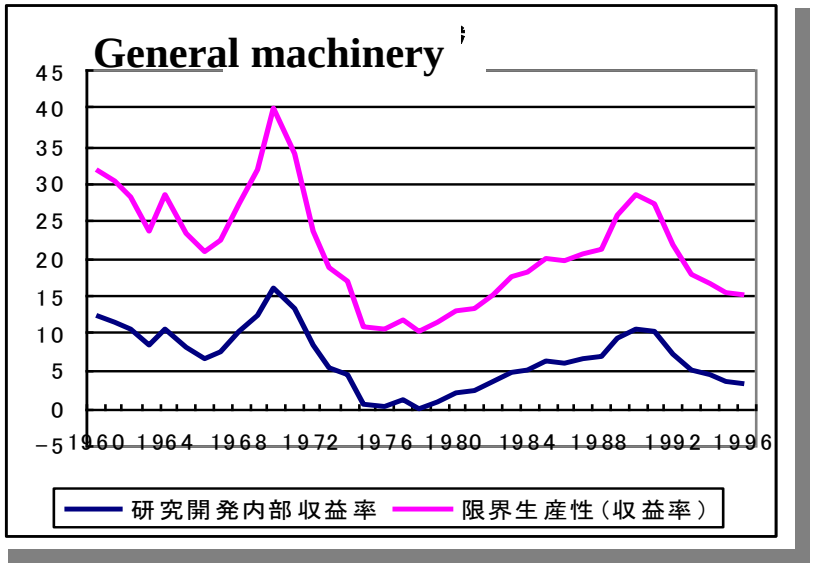
2) Traditional Machinery Industry



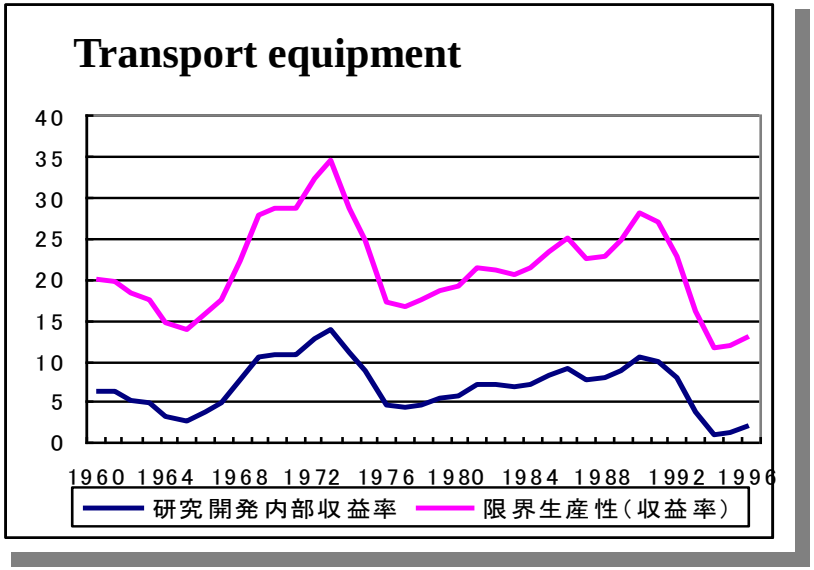


Fig. 16. Trends in IRR to R&D Investment and MPT by Clusters in Japan's Manufacturing Industry (*1960-1996*).

3) Raw Materials Industry

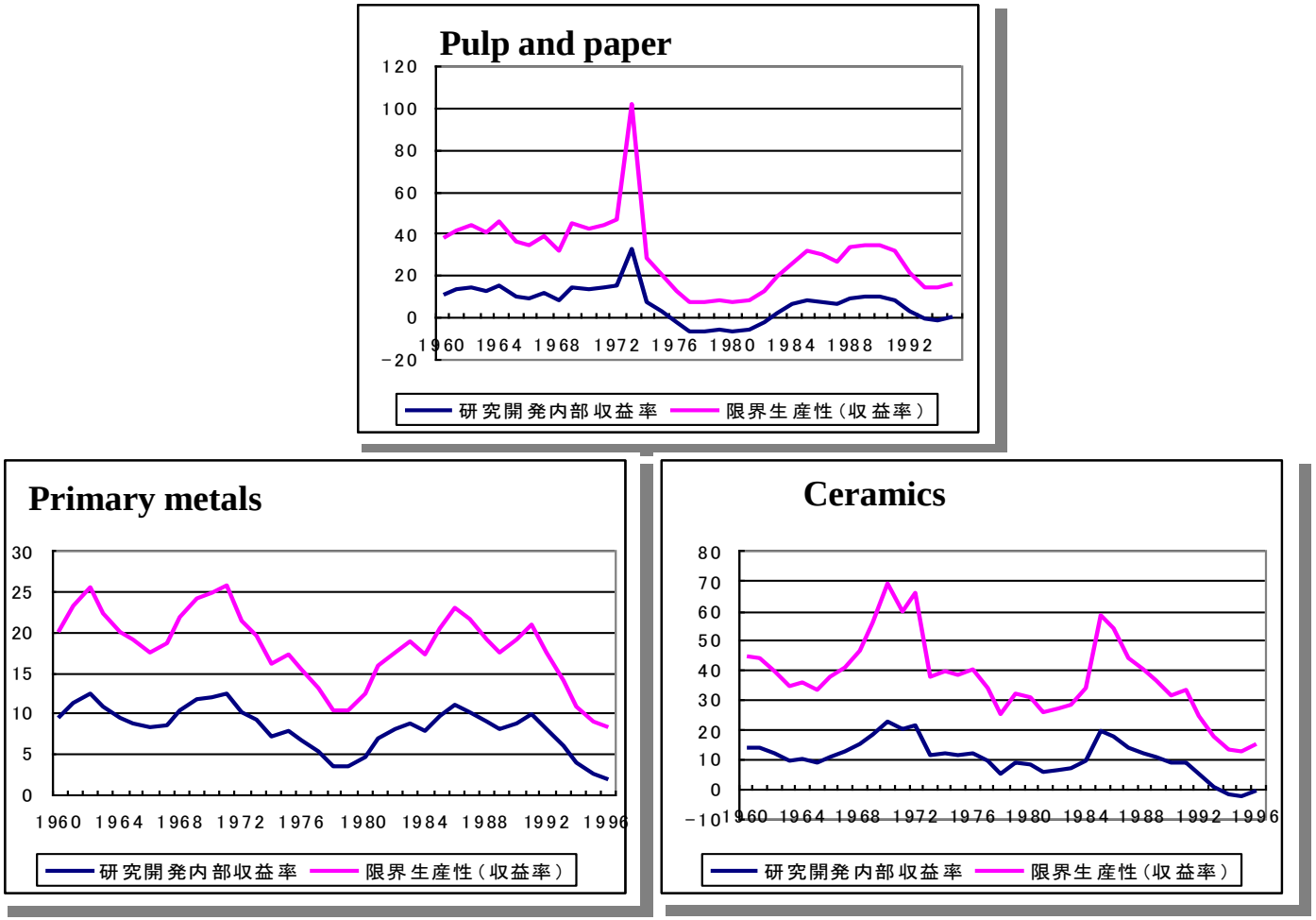


Fig. 17. Trends in IRR to R&D Investment and MPT by Clusters in Japan's Manufacturing Industry (*1960-1996*).

6.3 Metabolic Function of IRR

(1) Organic Cycle between MPT and R&D Intensity

$$V = F(X,T)$$ *V*: *GDP*; *X*: Labor (*L*), Capital (*K*); *T*: Technology Stock

$$\frac{dV}{dt} \equiv \Delta V, \frac{dX}{dt} \equiv \Delta X, \frac{dT}{dt} \equiv \Delta T \approx R \qquad (R\&D.Investment)$$

$$\frac{\Delta V}{V} = \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \underbrace{\left(\frac{\partial V}{\partial T}\cdot\frac{T}{V}\right)}_{\text{Growth rate of TFP}}\frac{\Delta T}{T} \approx \sum_{X=L,K}\left(\frac{\partial V}{\partial X}\cdot\frac{X}{V}\right)\frac{\Delta X}{X} + \underline{\frac{\partial V}{\partial T}\cdot\frac{R}{V}}$$

Virtuous Cycle Leading to Increase in Technology Stock

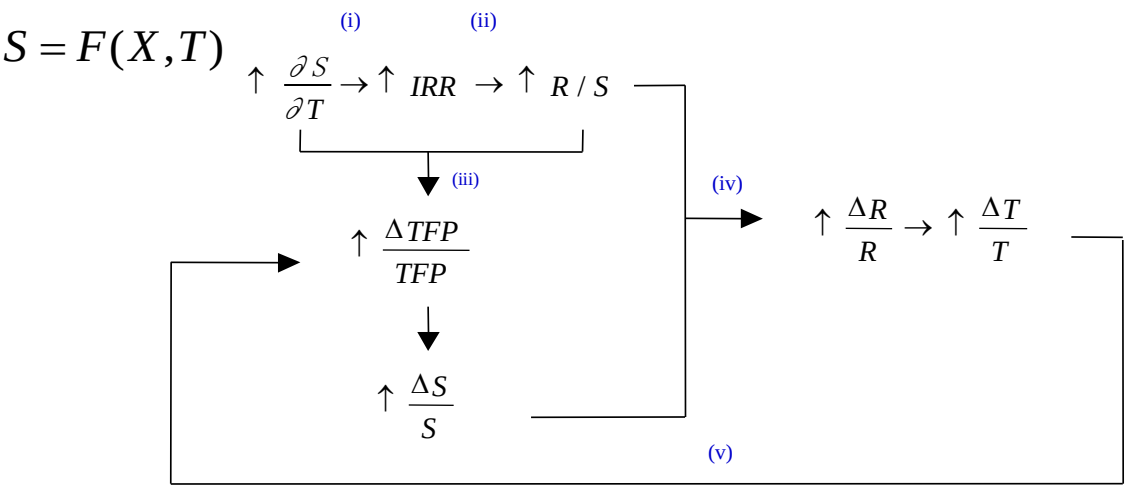


Fig. 18. Organic Cycle between MPT and R&D Intensity.

a $\frac{\partial S}{\partial T}$: marginal productivity of technology; IRR : internal rate of return to R&D investment;

R/S : R&D intensity; $\frac{\Delta TFP}{TFP}$: change rate of total factor productivity; $\frac{\Delta S}{S}$: change rate of sales;

$\frac{\Delta R}{R}$: change rate of R&D investment; and $\frac{\Delta T}{T}$: change rate of technology stock

(i) Increase in marginal productivity of technology (MPT) leads to increase in internal rate of return to R&D investment (IRR) as explicitly depicted by the following equation:

$$r \equiv IRR = \left[\sqrt{4m\frac{\partial S}{\partial T} + (1+m\rho)^2 - 4m\rho} - (1+m\rho)\right] \Big/ 2m \qquad (3)$$

(ii) As demonstrated by the preceding work (W atanabe and Wakabayashi, 1996) increase in IRR induces higher R&D intensity.

(iii) These increases in both MPT and R&D intensity result in increase in TFP as its increasing rate can be approximated by the product of these factors as follows:

$$\frac{\Delta TFP}{TFP} = \frac{\partial S}{\partial T}\cdot\frac{T}{S}\cdot\frac{\Delta T}{T} \approx \frac{\partial S}{\partial T}\cdot\frac{R}{S}$$

(iv) TFP increase contributes to increase in production which together with the foregoing increase in R&D intensity induces R&D investment as simply depicted as follows:.

$$\frac{\Delta R}{R} = \frac{\Delta(R/S)}{R/S} + \frac{\Delta S}{S} \qquad (4)$$

(v) Induced R&D investment contributes to increase in technology stock, which further accelerates TFP increase, thus a virtuous cycle between technology stock and production increase is expected.

(2) Techno-metabolism for Sustainable Growth: Disengagement

1. A decrease in R&D intensity, together with the yen crises, led to a decrease in IRR, resulting in a further decrease in R&D intensity.
2. Decrease in R&D intensity deteriorated energy efficiency resulted in a production decline, leading to a further decrease in R&D intensity.

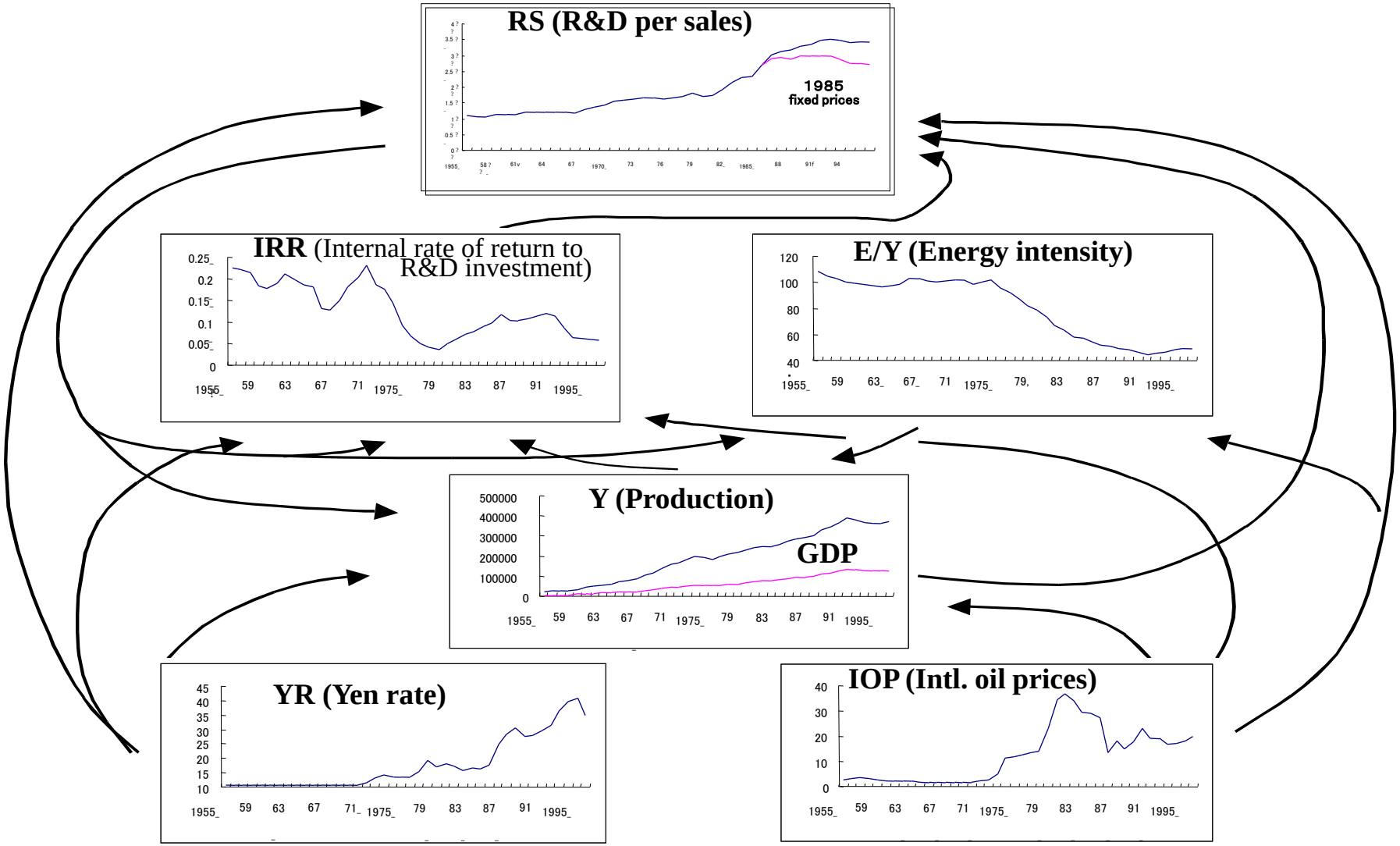


Fig. 19. Metabolic Interpretation of the Interaction between Technology and Economic Development in the Japanese Manufacturing Industry *(1955-1996).* Source: Watanabe *(1997).*

(3) Metabolic Aspect of Techno-economy

1. Industry's R&D intensity is governed by (i) business conditions (e.g. production), (ii) R&D investment circumstances (e.g. IRR), and (iii) external shocks and crises (e.g. energy prices and yen rate).
2. All governing factors are interrelated with each other to construct a metabolic system.

$$Y = F(L, K, M, E, T)$$

$$\frac{\Delta Y}{Y} = \sum \frac{\partial Y}{\partial X_i} \cdot \frac{\Delta X_i}{X_i} + \frac{\Delta TFP}{TFP}$$

$$\frac{\Delta TFP}{TFP} = \lambda + \frac{\partial Y}{\partial T} \cdot \frac{R}{Y} \equiv \lambda + RRR \cdot \frac{R}{Y}$$

$$RRR \approx \rho + (1 + m\ \rho) \cdot IRR$$

$$\ln IRR = 182.53 + 2.97 \ln R/Y - 0.41 \ln Pe - 0.81 \ln YR - 0.10\, t$$
(10.68) (-5.24) (-5.30) (-12.07)

$$\ln R/Y = 0.63 + 0.29 \ln Y_{-1} + 0.23 \ln IRR_{-1} + 0.27 \ln Pe_{-1} + 0.45 \ln YR_{-1}$$
(19.13) (10.74) (8.98) (13.43)

$$\ln E/Y = -0.44 - 0.61 \ln R/Y_{-3} - 0.37 \ln Pe_{-3}$$
(-22.71) (-12.58)

	$adj.R^2$	DW
	0.936	1.50
	0.988	1.27
	0.975	1.01

$$\frac{\Delta R}{R} = \frac{\Delta R/Y}{R/Y} + \frac{\Delta Y}{Y}$$

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

$$\frac{\Delta Y}{Y} = -\frac{\Delta E/Y}{E/Y} - \frac{\Delta C/E}{C/E} + \frac{\Delta C}{C}$$

Y : **Production**
L, K, M, E : Labor, capital, materials and energy
T : **Technology knowledge stock**
X_i: L, K, M, E

TFP : **Total factor productivity**
λ : TFP increase due to institutional change
R : **R&D investment, R/Y: R&D intensity**
$\partial Y / \partial T =$ ***RRR*** **: Rate of return to R&D investment**
(marginal productivity of technology)

IRR : **Internal rate of return to R&D investment**
m: Lead time of R&D to commercialization
ρ : Rate of obsolescence of technology

YR: Yen rate,
Pe: Relative energy prices
t: Time trend

C: CO_2 emission
E/Y : **Energy efficiency**, C/E: Fuel switching

Source: Watanabe and Zhu *(2003).*

Fig. 20. Scheme of Metabolic Aspect of Japanese Manufacturing Industry Techno-Economy *(1955-1995).*

6.4 Consequence of Techno-metabolism

(1) Metabolic Dynamism

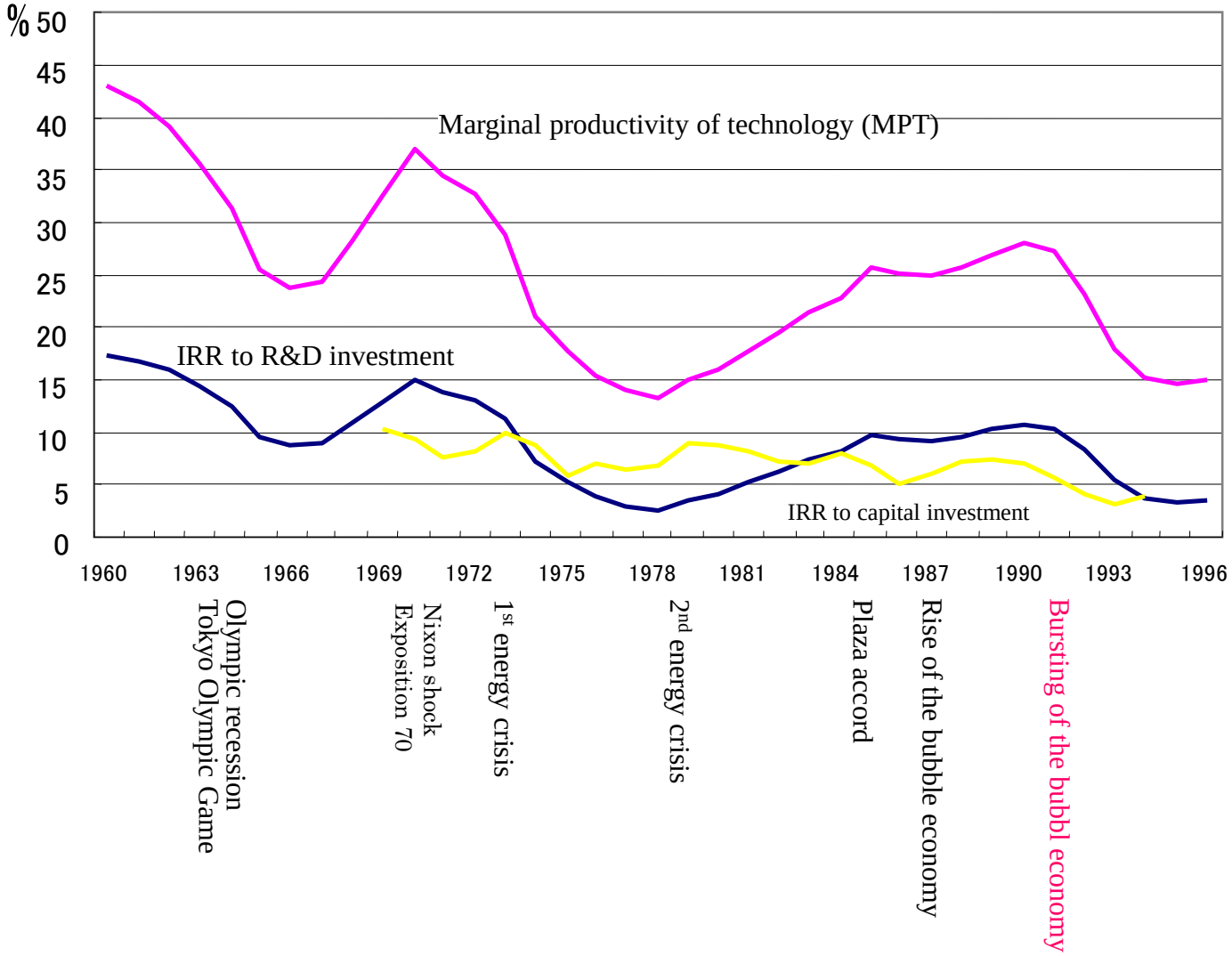


Fig. 21. Trends in IRR to R&D Investment and MPT in Japan's Manufacturing Industry *(1960-1996).*

(2) Reversal of Marginal Productivity of Technology between Japan and USA

Thus, the reversal if MPT between Japan and USA emerged in the 1990s and continued to the beginning of the 2000s.

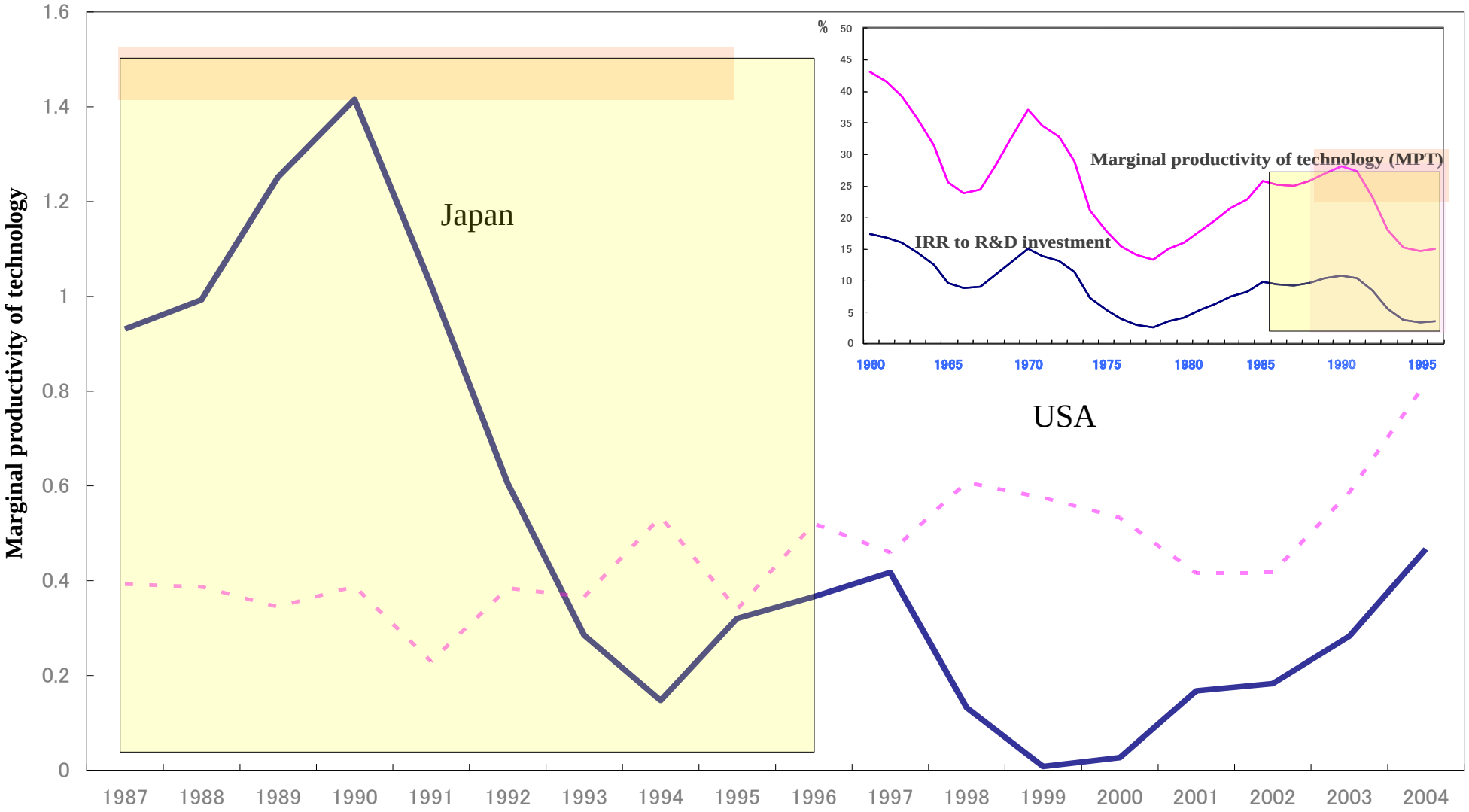


Fig. 22. Trends in Marginal Productivity of Technology of Technology in Japan and USA (1987-2004) - 3 years moving average.

Sources : OECD Fact book 2006, White paper on Japan's science technology, White paper on Japan's ICT.

(3) System Conflict in an Information Society

1. **System conflict** led to an **institutional less-elasticity** in an information society resulting in a **dramatic decrease in MPT**.
2. MPT decrease led to **TFP decrease** resulting in a **decrease in innovation contribution to growth**.
3. Thus, **co-evolution changed to disengagement** in an information society.

(1) Dramatic Decrease in Marginal Productivity of Technology

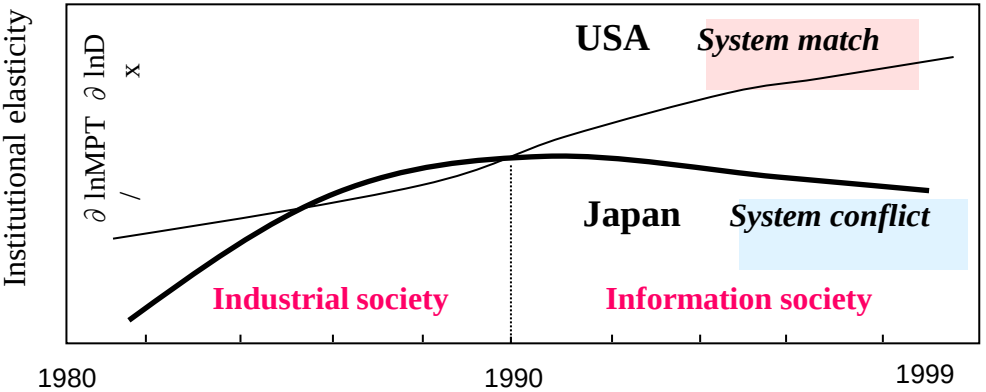


Fig. 8-1. Institutional Elasticity of Manufacturing Technology

- Elasticity of the Shift to an Information Society to Marginal Productivity of Technology *(1980-1999) - Index :1990 =100.*

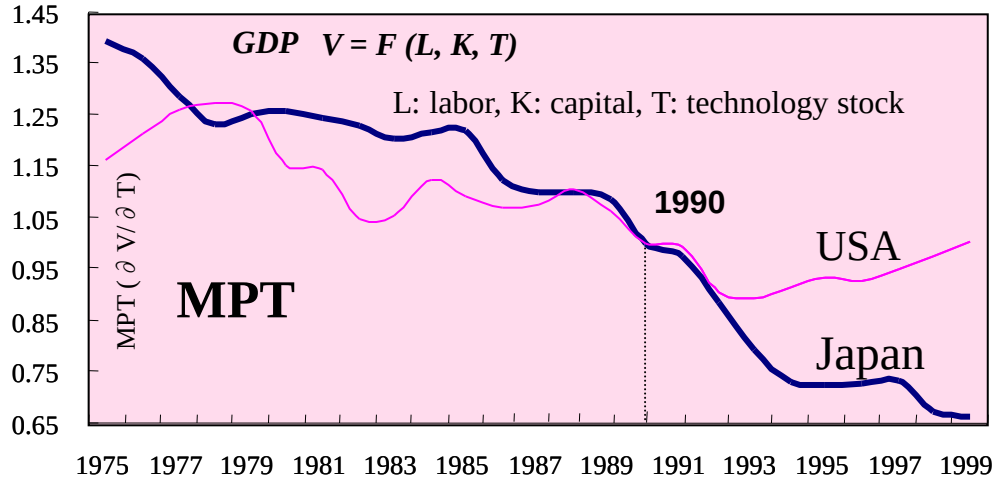


Fig. 8-3. Marginal Productivity of Manufacturing Technology
(1975-1999) - Index: 1990 =1.

(2) Consequent Decrease in Innovation

TFP change rate (ΔTFP/TFP) = R&D intensity (R/V) × Marginal productivity of technology (MPT)

Innovation to GDP growth

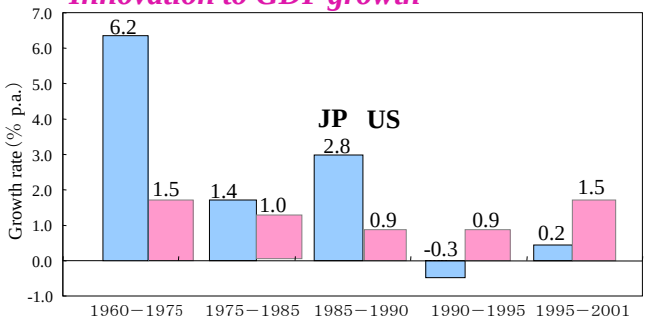


Fig. 9-1. TFP Growth Rate *(1960-2001).*

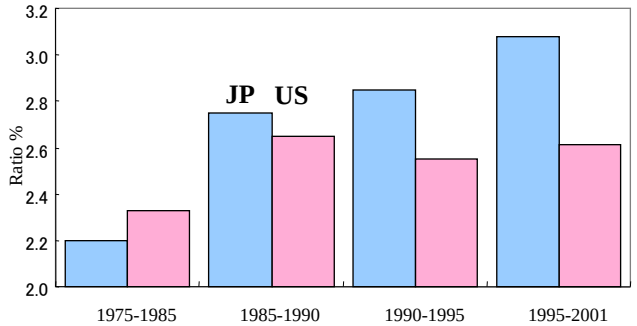


Fig. 9-2. R&D Intensity *(1975-2001).*

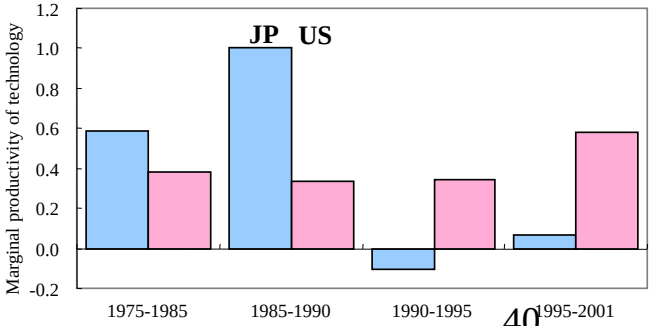


Fig. 9-3. Marginal Productivity of Technology
(1960-2001).

6.4 Factors Governing IRR to R&D Investment

(1) Factors Decisive to IRR to R&D Investment

Table 11 Factors Decisive to IRR to R&D Investment

1. Internal technology

(i) R&D expenditure (*R*), its composition, respective prices

(ii) Sate of technology knowledge stock (*T*)

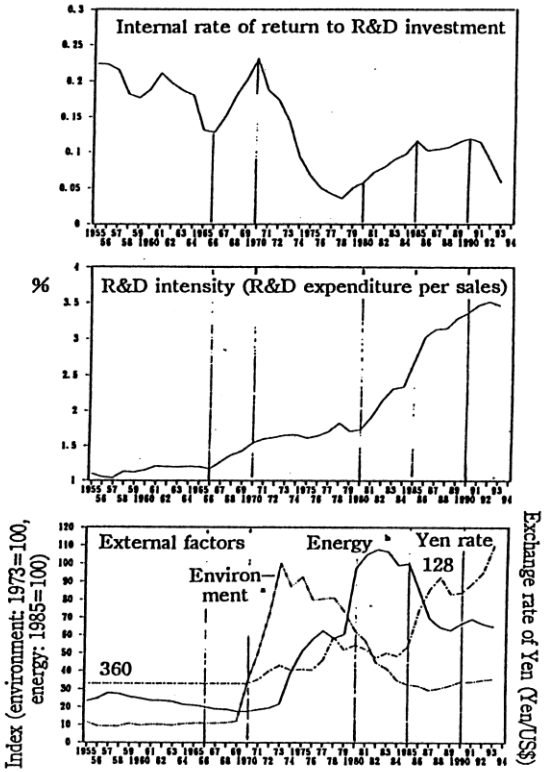
2. Technology spillovers

3. External technology

(i) State of production , its factors (*V, L, K*), respective costs
(ii) Rate of obsolescence of technology (ρ), time-lag from R&D to commercialization (*m*)
(iii) Ratios of government support, tax
(iv) External factors governing production (e.g. , exchange rate, international oil prices)

4. Interaction between internal technology and external technology

(2) Trends in Governing Factors to IRR to R&D Investment



Trends in Internal Rate of Return to R&D Investment, and Factors Governing its Change in the Japanese Manufacturing Industry (1955–1993)

a Ratio of R&D expenditure for environmental protection and total R&D expenditure.
b Prices of energy.

IRR (internal rate of return to R&D investment)

$$\ln(IRR) = 140.346 - 0.075\,t + 2.831 \ln(RS) - 0.287 \ln(Pe) - 0.091 \ln(Env) - 1.038 \ln(YR) - 0.559\,D$$
$$(-7.71) \quad (9.46) \quad (-5.42) \quad (-2.33) \quad (-5.99) \quad (-6.50)$$

adj.R^2 0.943 DW 1.63

where t: time trend, RS: R&D intensity, Pe: prices of energy, Env: ratio of R&D expenditure for environmental protection and total R&D expenditure, YR: Yen value (US$/Yen), and D: dummy variable (1976–78 =1, other years =0).

Fig. 23. Trends in IRR to R&D Investment and Factors Governing Its Change in the Japanese Manufacturing Industry (*1955-1993*).

(3) Factors Governing IRR to R&D Investment

Table 3 Correlation between IRR to R&D Investment and Factors Governing Its Change in the Japanese Manufacturing Industry (*1955-1993*).

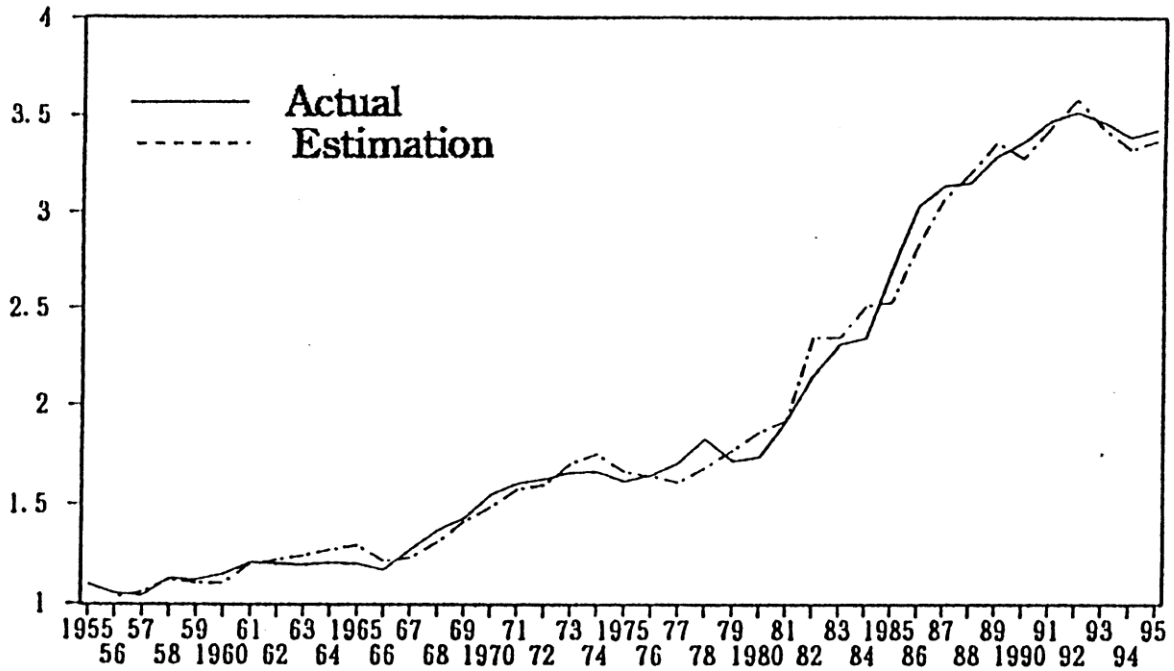
$$\ln IRR = 154.84 + 2.89 \ln RS - 1.01 \ln YR - 0.41 \ln Pe/Py - 0.12 \ln Env - 0.08\, t$$

(9.74) (-5.82) (-5.48) (-2.96) (-8.89)

adj. R^2 0.944, *DW* 1.63

where IRR: internal rate of return to R&D investment, RS: R&D intensity, YR: Yen value (US$/Yen), Pe/Py: relative energy prices, Env: ratio of R&D expenditure for environmental protection and total R&D expenditure, and t: time trend.

(4) IRR to R&D Investment and R&D Investment



	adj.R2	DW
$\ln R/S = 0.63 + \underset{(10.74)}{0.23} \ln(IRR_{-1}) + \underset{(8.98)}{0.27} \ln(Pe_{-1}) + \underset{(13.43)}{0.45} \ln(1/YR_{-1}) + \underset{(19.13)}{0.29} \ln(V_{-1})$	0.998	1.27

R&D intensity — Internal rate of return to R&D investment — Prices of energy — Yen rate — Value added

Fig. 24. Trends in R&D Intensity in Japan's Manufacturing Industry *(1955-1995) - Actual and estimation.*