23rd Jyvaskyla
Summer School
7-9 Aug.. 2013, University of Jyvaskyla, Jyvaskyla

COM8
Techno-economic Systems Institutional Innovation (3)

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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** **S**ystems approach, **E**mpirical approach, **A**nalytical approach, challenge to **R**ationale, **C**omprehensive approach, with **H**istorical perspective

3. Diffusion of Technology

3.1 Epidemic Function

3.2 Application of Epidemic Function

3.3 Variation of Diffusion Function

3.4 Functionality Development

3.5 Integration of Production Function and Diffusion Function - Innofusion

3.6 Sustainable Functionality Development in Open Innovation

3. Diffusion of Technology

3.1 Epidemic Function

Diffusion trajectory of innovation, innovative goods and also new products resemble to diffusion process of an epidemic disease which can be depicted by the epidemic function (Verhulst, 1845)**.**

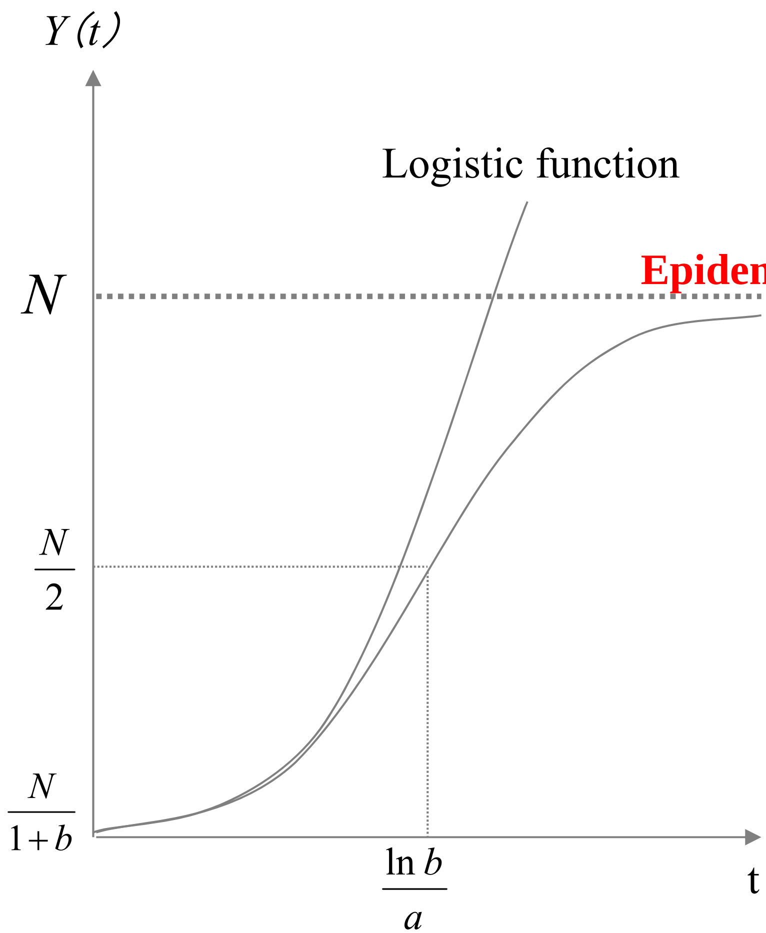


Fig. 1. Comparison between Logistic Function and Epidemic Function.

Pierre Francois Verhulst (1804-1849) Mathematician in Belgium Mathematical Researches into the Law of Population Growth Increase (1845).

Epidemic function : $Y(t) = \dfrac{N}{1 + be^{-at}}$

$Y(t)$: Diffusion level at time t

N : Upper limit of diffusion (Carrying capacity)

a : Diffusion velocity

b : Diffusion level at initial period

Changed notations

$N(t) \rightarrow Y(t)$

$\overline{N} \rightarrow N$

(1) Development of Epidemic Function

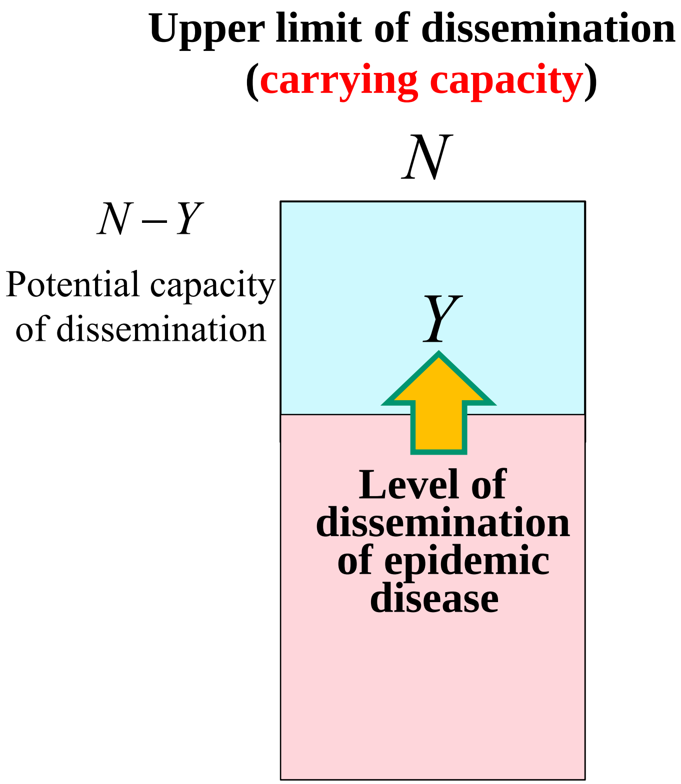


Fig. 2. Diffusion Process of Epidemic Disease.

1. Epidemic disease diffuses proportional to potential capacity of dissemination

$$a'(N-Y) \qquad \text{where } a'\text{: coefficient}$$

2. Increase of epidemic disease N during the unit period dt

$$dY = [a'(N-Y)]\cdot Y \cdot dt$$

3. Develop this balance

$$\frac{dY}{dt} = aY\left(1-\frac{Y}{N}\right) \quad \text{where} \quad a \equiv a'N \qquad (21)$$

4. Solving this differential equation leads to the following logistic growth function (epidemic function) illustrating a sigmoid curve:

$$Y = \frac{N}{1+be^{-at}} \quad \text{where } b\text{: coefficient} \qquad (22)$$

$$\frac{dY}{dt} = \Delta Y = a'Y(N-Y), \quad \frac{\Delta Y}{Y} = a'(N-Y), \quad X \equiv \frac{(N-Y)}{Y}, \quad \Delta X = -\frac{N\cdot\Delta Y}{Y^2}, \quad \therefore \frac{\Delta Y}{Y} = a'(N-Y) = a'YX = -\frac{Y}{N}\Delta X, \quad \frac{\Delta X}{X} = a'N, \quad \frac{1}{X}\frac{dX}{dt} = -a'N$$

$$\int \frac{1}{X}dX = \int -a'Ndt, \quad \ln X = -(a'Nt+b') = -(at+b'), \quad X = e^{-(at+b')} = \frac{N-Y}{Y} = \frac{N}{Y}-1, \quad Y = \frac{N}{1+e^{-(at+b')}} = \frac{N}{1+be^{-at}} \quad b = e^{-b'}$$

(2) Structure of Epidemic Function

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

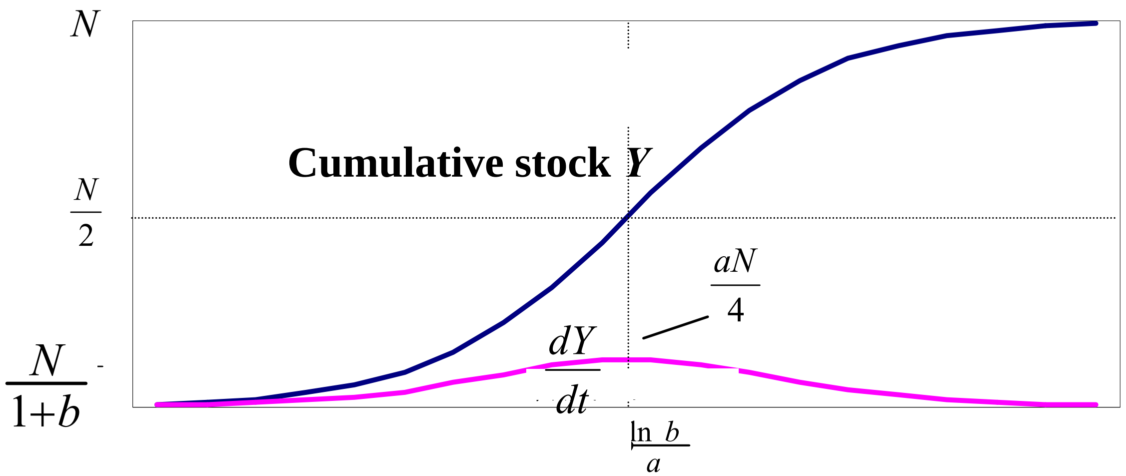


Fig. 3. Diffusion Trajectories of Epidemic Disease by Increase and Cumulative Stock.

(3) Fisher-Pry Transform

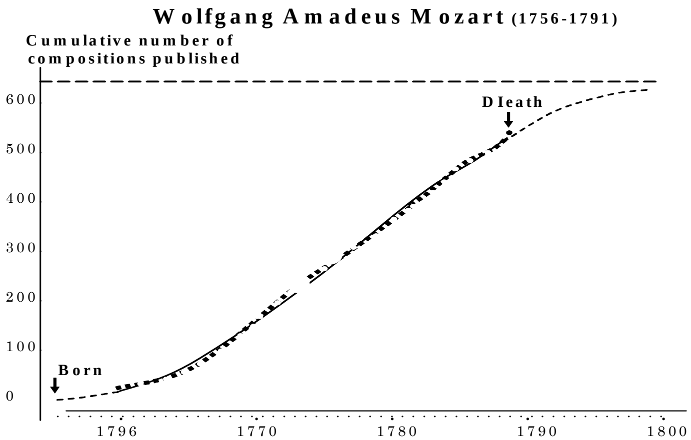
$$F \equiv \frac{Y}{N} = \frac{1}{1 + be^{-at}} \qquad be^{-at} = \frac{1 - F}{F} \qquad at - \ln b = \ln \frac{F}{1 - F}$$

(4) Identification of Carrying Capacity

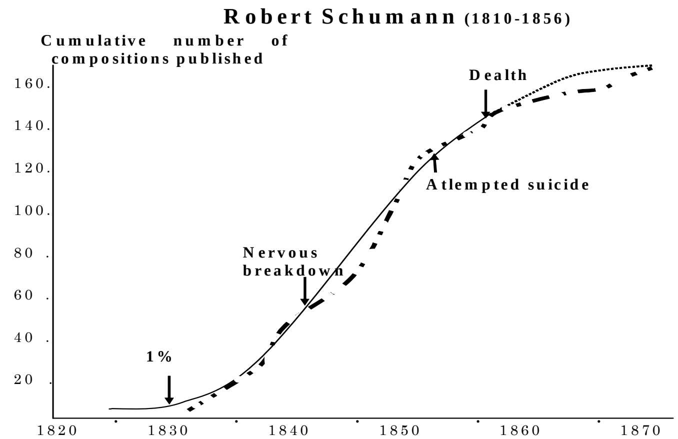
time $t^{\#}$ when $\frac{dY}{dt^{\#}} = 0$ $\qquad \frac{dY}{dt^{\#}} = aY(t^{\#})(1 - \frac{Y(t^{\#})}{N}) = 0 \qquad Y(t^{\#}) = N$

3.2 Application of Epidemic Function

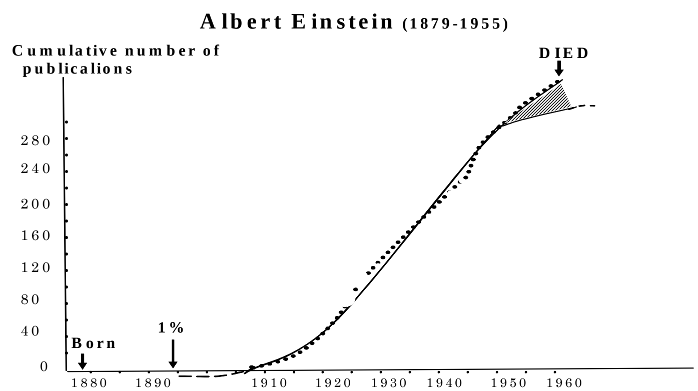
The social and economic operation of our society can be decomposed in a very large number of sub-diffusion processes summing up into an almost inextricable whole *(Cesare Marchetti,1996)***.**

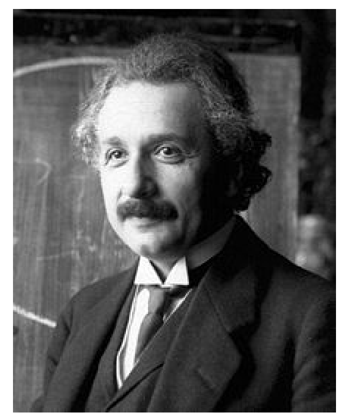


The best-fitting S-curve implies 18 compositons " missing " be-tween 1756 and 1762. The nominal beginning of the curve---the 1% level-points at Mozart's birthday. The nominal end the 99% level indicates a potential of 644 works.



The publication of Schumann's compositions. The fitted curve begins around 1826 and aims at a ceiling of 173. Schumann 's publications reached 170, sixteen years after his death.





Einstein 's cumulative publications and the best-fitting S-curve. The fit indicates 13 publications " missing " between the beginning of the curve, 1894, and Einstcin 's first publication in 1900. The ceiling is estimated as 279.

Fig. 4. Epidemic Process of Mozart, Schumann and Einstein.

Source: Theodore Modis, Prediction (Simon & Schuster, New York, 1992).

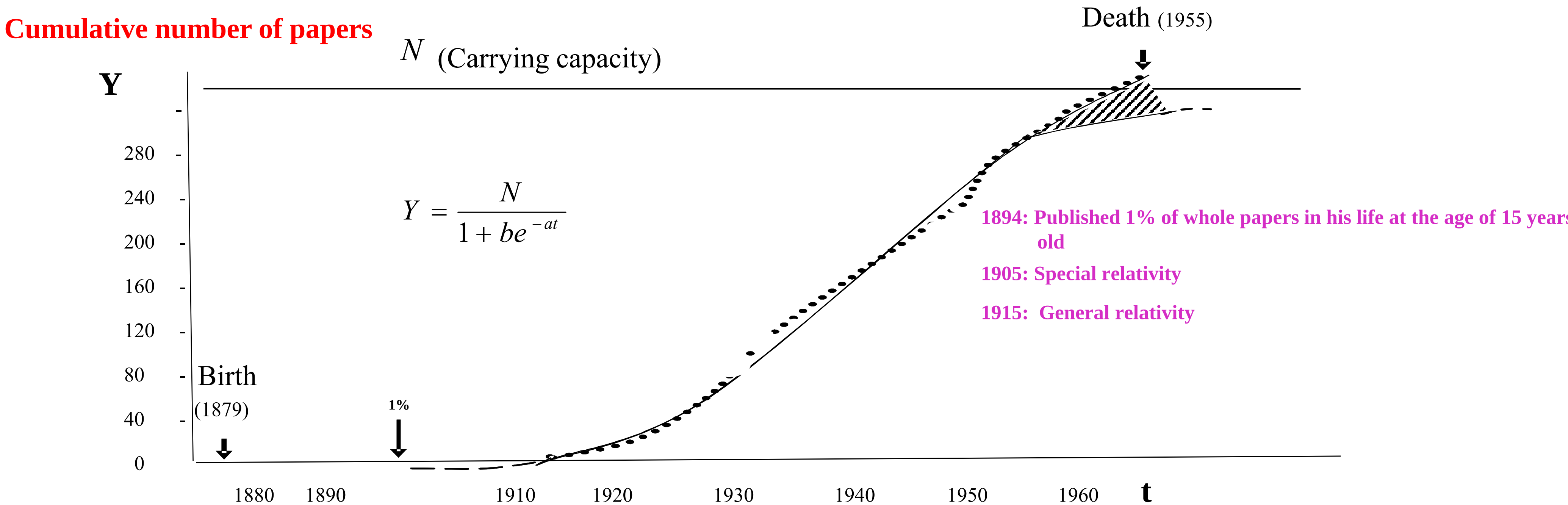


Fig. 5. Einstein's Epidemic Trajectory by Cumulative Number of Papers *(1879-1955).*

Source: Theodore Modis, Prediction (Simon & Schuster, New York,1992).

3.3 Variation of Diffusion Function

(1) Simple Logistic Growth Function (*SLF*)

$$\frac{dY(t)}{dt} = aY(t)(1-\frac{Y(t)}{N}) \qquad (23)$$

Y(t): Diffusion level of innovative goods at time *t*; *N*: Upper limit of diffusion level (carrying capacity); *a*: Coefficient.

$$Y(t) = \frac{N}{1+be^{-at}} \qquad (24)$$

$$\frac{\frac{dY(t)}{dt}}{Y(t)} \equiv \frac{\Delta Y(t)}{Y(t)} = a(1-\frac{Y(t)}{N})$$

a governs diffusion velocity.

Diffusion level at the initial timing.

$$Y(0) = \frac{N}{1+b} \qquad b = \frac{N}{Y(0)} - 1$$

b indicates initial level of diffusion.

$$\frac{dY}{dt} = aY(1-\frac{Y}{N}) = \frac{aN}{1+be^{-at}}(1-\frac{1}{1+be^{-at}})$$

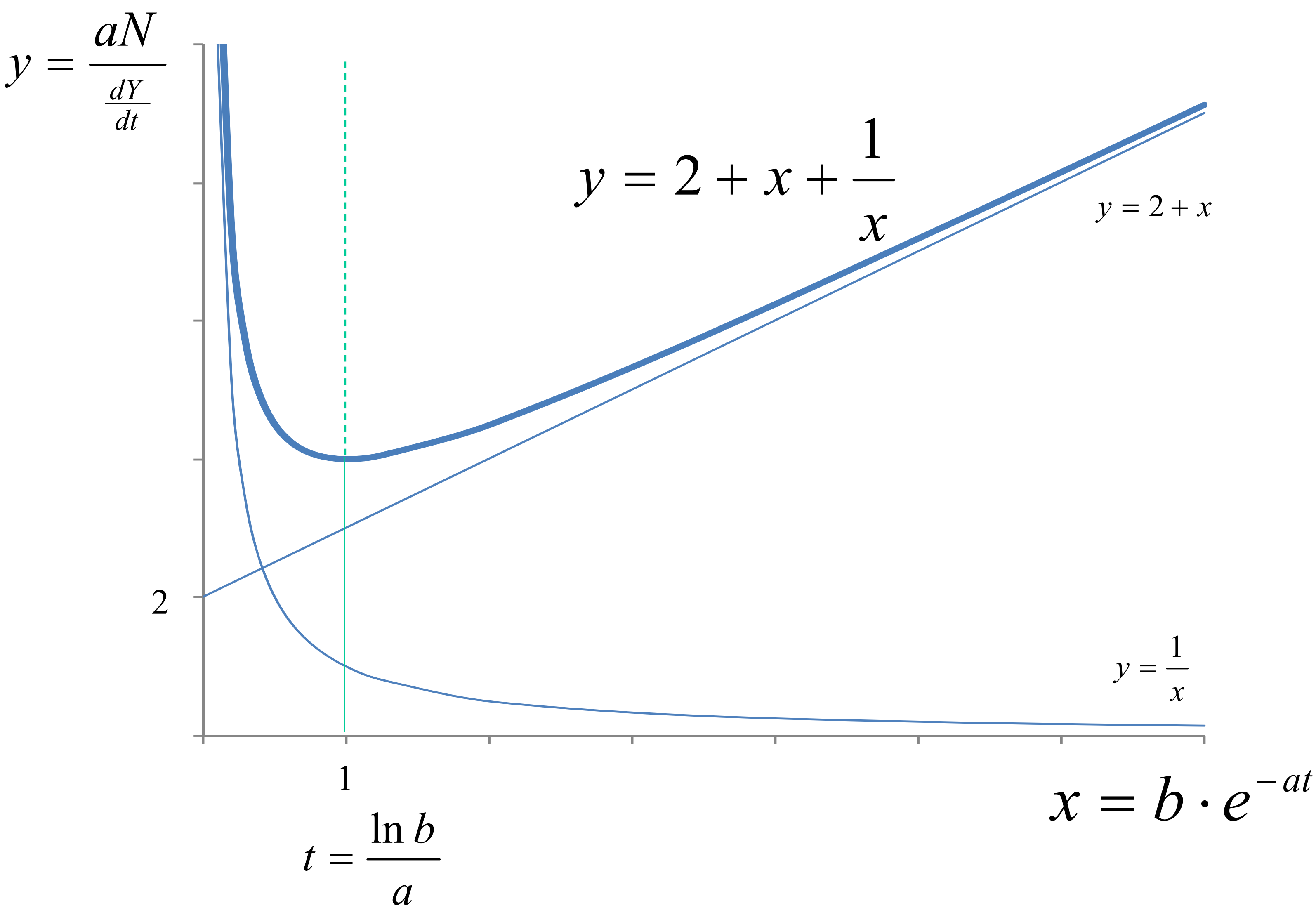
$$= \frac{aN}{(1+be^{-at})} \cdot \frac{be^{-at}}{(1+be^{-at})} = \frac{aN}{(1+be^{-at})} \cdot \frac{1}{(1+\frac{1}{b}e^{at})}$$

$$= \frac{aN}{(2+be^{-at}+\frac{1}{be^{-at}})}$$

$$\frac{aN}{\frac{dY}{dt}} = 2+be^{-at}+\frac{1}{be^{-at}}$$

$$y = 2+x+\frac{1}{x} \qquad y \equiv \frac{aN}{\frac{dY}{dt}},\ x \equiv be^{-at}$$

Bi-polarization Diffusion Trajectory



Case 1: GDP per capita vs Marginal productivity of investment per capita

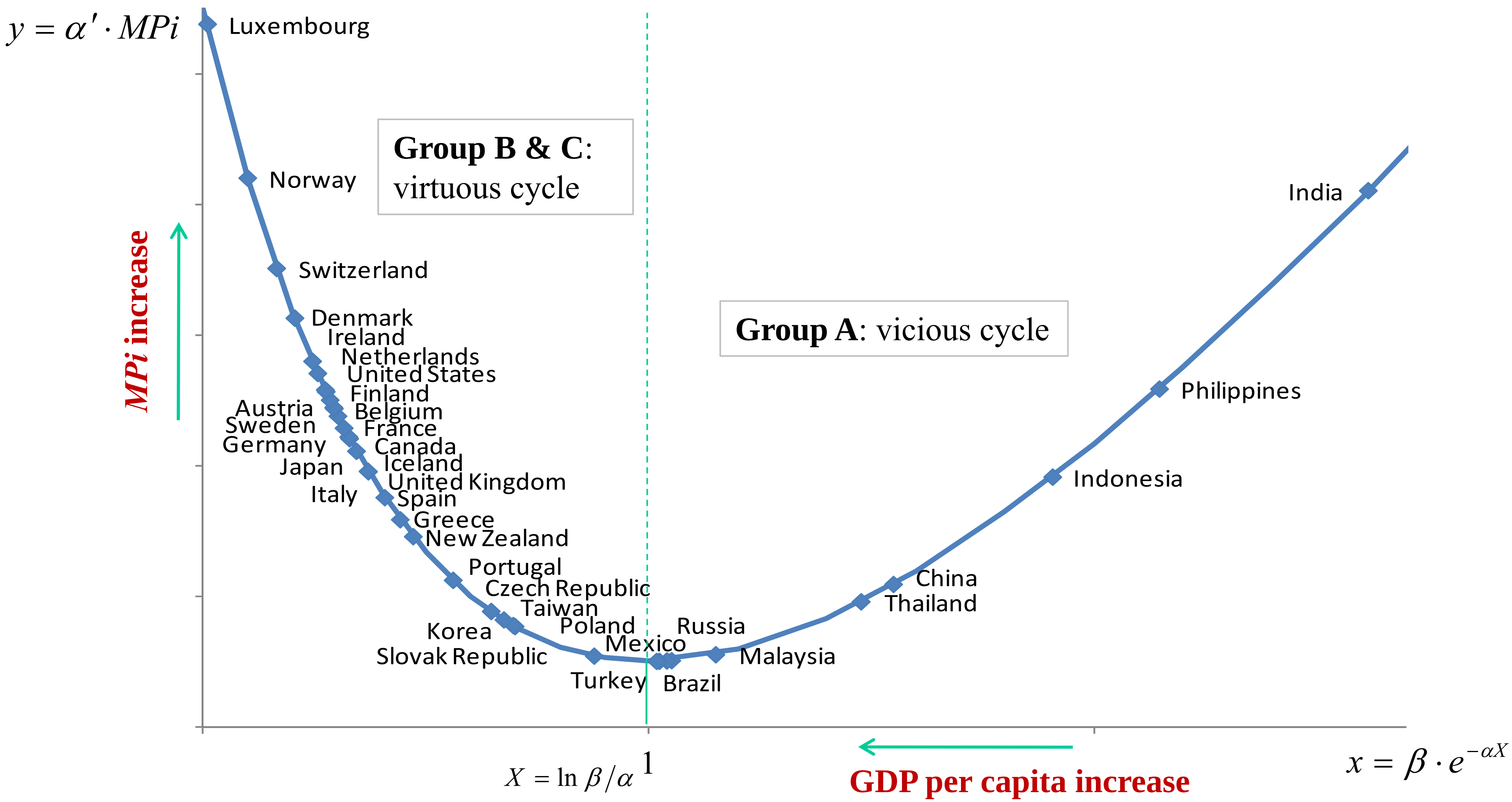
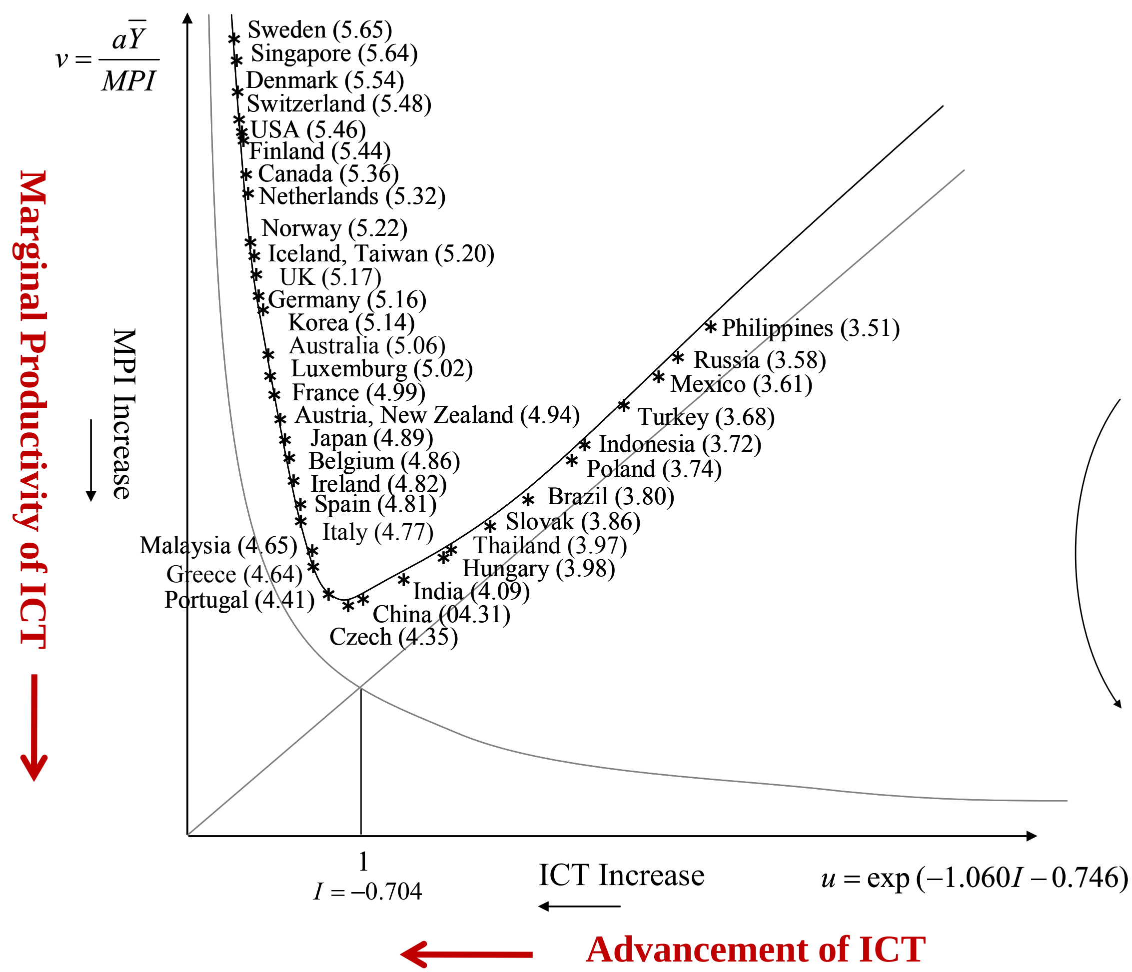


Fig. 6. Development Trajectory of Investment induced by GDP of 37 Countries *(2009)*.

Case 2: Advancement of ICT vs Marginal Productivity of ICT



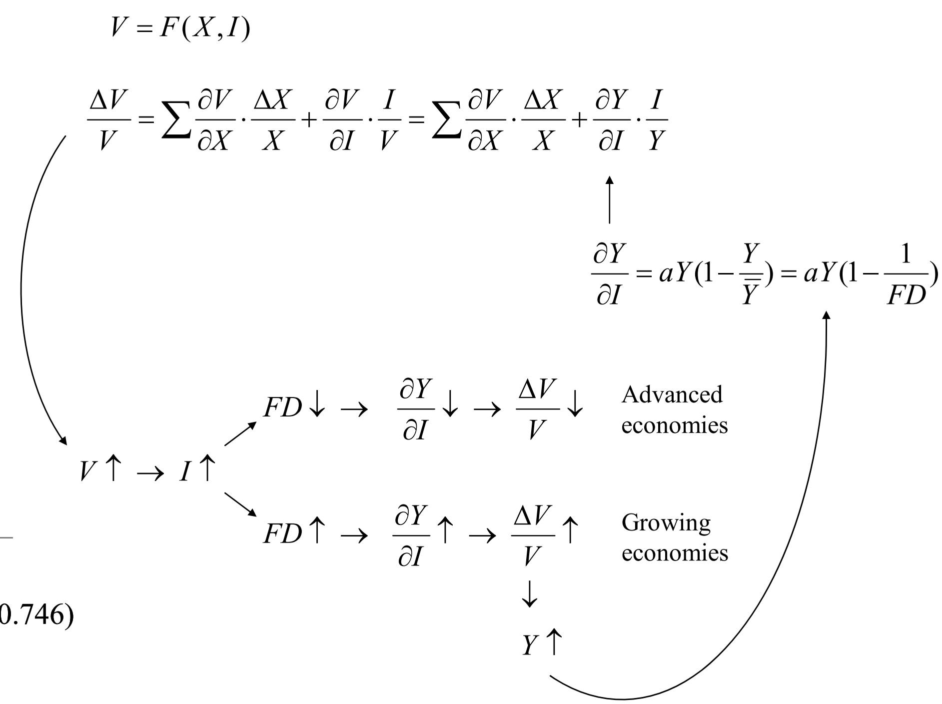
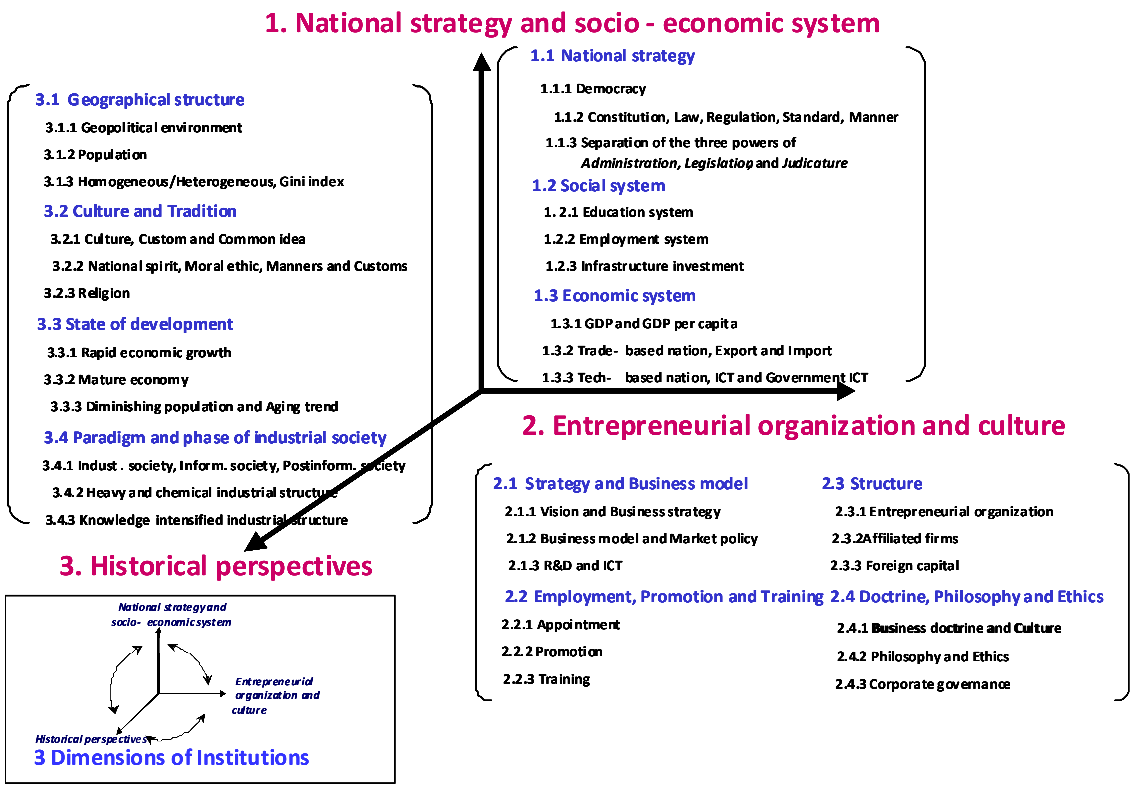


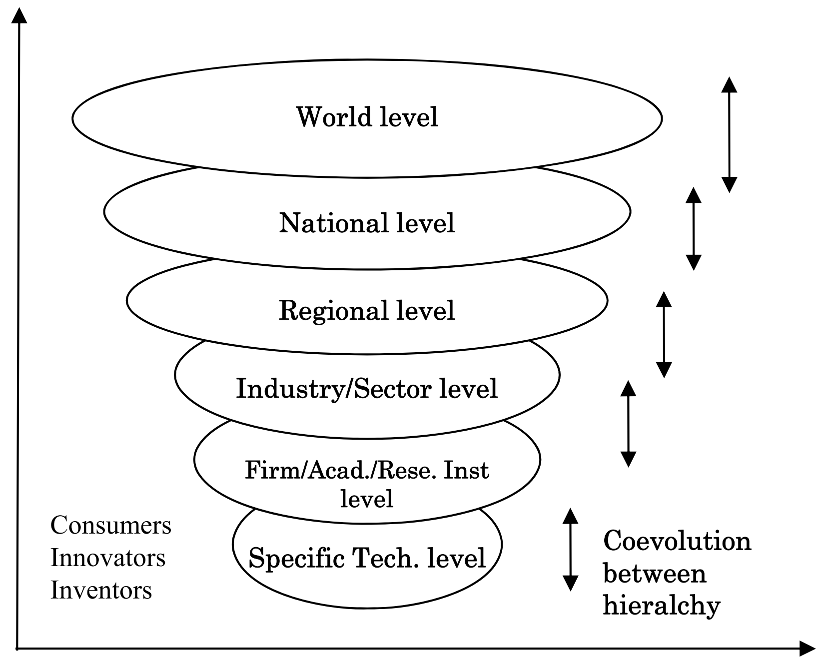
Fig. 7. ICT Driven Growth Trajectory in 40 Countries *(2009)*.

Global co-evolution with emerging economies
MOP (Middle of the pyramid), BOP (Bottom of the pyramid)
Frugal engineering

Three Dimensional Constitution and Hierarchical Structure of Institutional Systems



1. Each respective level of institutions incorporate three dimensional structure.
2. In order for the property emerge, three dimensional components at the lower level should interact with those at the higher level.



Sources leading to bi-polarization
- *Institutional innovation*

Invention becomes **innovation** when the invention becomes a commercial product, which in turn becomes a successful product when **consumers** by it.

(2) Bass Model (F.M. Bass, 1969) – *Diffusion with innovator* ***(leader)*** *and imitator* ***(follower)*** *dynamism*

➡ **Diffusion in open innovation**

1) Model Structure

$$\frac{dY(t)}{dt} = P(t) + Q(t)$$ where *P(t)*: innovator, and *Q(t)*: imitator.

$$P(t) \equiv p(N - Y(t)) = pN(1 - \frac{Y(t)}{N})$$ where p: innovation coefficient.

$$Q(t) \equiv qY(t)(1 - \frac{Y(t)}{N})$$ where q: imitation coefficient

$$\frac{dY(t)}{dt} = P(t) + Q(t) = (pN + qY(t))(1 - \frac{Y(t)}{N}) \quad (25)$$

$$Y(t) = \frac{N[1 - e^{-(p+q)t}]}{1 + \frac{q}{p}e^{-(p+q)t}} \quad (26)$$

$$= \frac{N}{1 + be^{-at}} - \frac{b'N}{1 + b'e^{-a't}} \quad (26')$$

$a = p + q$, $a' = -(p + q)$, b $= q/p$, b' $= p/q$

4.1 (1)

1. Epidemic disease diffuses proportional to potential capacity of dissemination

$$a'(N - Y)$$

3. Develop this balance

$$\frac{dY}{dt} = aY(1 - \frac{Y}{N})$$

2) Self-propagating Dynamism

FD: Functionality development *(Ability to improve performance of production processes, goods and services by means of innovation)*

$$Y = \frac{N(1-e^{-(p+q)\cdot t})}{1+\frac{q}{p}e^{-(p+q)\cdot t}} \quad \Rightarrow \quad FD = \frac{1+\frac{q}{p}e^{-(p+q)\cdot t}}{1-e^{-(p+q)\cdot t}}$$

$\frac{dFD}{dq/p} > 0$ ⇒ q/p increase ⇒ FD increase

p: Innovafor (leader)

q: Immitator (follower)

Y: production of innovative products, N: carrying capacity

$q/p \equiv x$ and $e^{-(p+q)t} \equiv y$ $\qquad FD = \frac{1+xy}{1-y}$

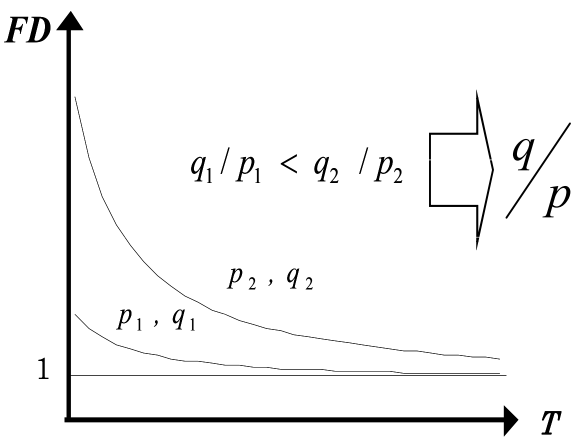
$$\frac{dFD}{dx} = -\frac{-\frac{dy}{dx}(1+xy)}{(1-y)^2} + \frac{y + x\frac{dy}{dx}}{(1-y)} = \frac{(1+x)\frac{dy}{dx} + y - y^2}{(1-y)^2}$$

$$\frac{dFD}{dx} = \frac{y}{(1-y)^2}\left[1-\left\{p+\frac{dp}{dx}(1+x)\right\}(1+x)t - y\right] = \frac{y}{(1-y)^2}\left[1-p(1+x)t-\frac{dp}{dx}(1+x)^2 t - y\right]$$

Since $e^{-(p+q)} = y^{-t}$ and $p+q \ll 1$, $\quad y = [e^{-(p+q)}]^t = [1-(p+q)]^t = [1-p(1+x)]^t \approx 1-p(1+x)t$

$$\frac{dFD}{dx} = -\frac{y(1+x)^2}{(1-y)^2}t \cdot \frac{dp}{dx} > 0 \quad \text{when} \quad \frac{dp}{dx} < 0 \text{ (Open innovation)}$$

3) Sustainable FD



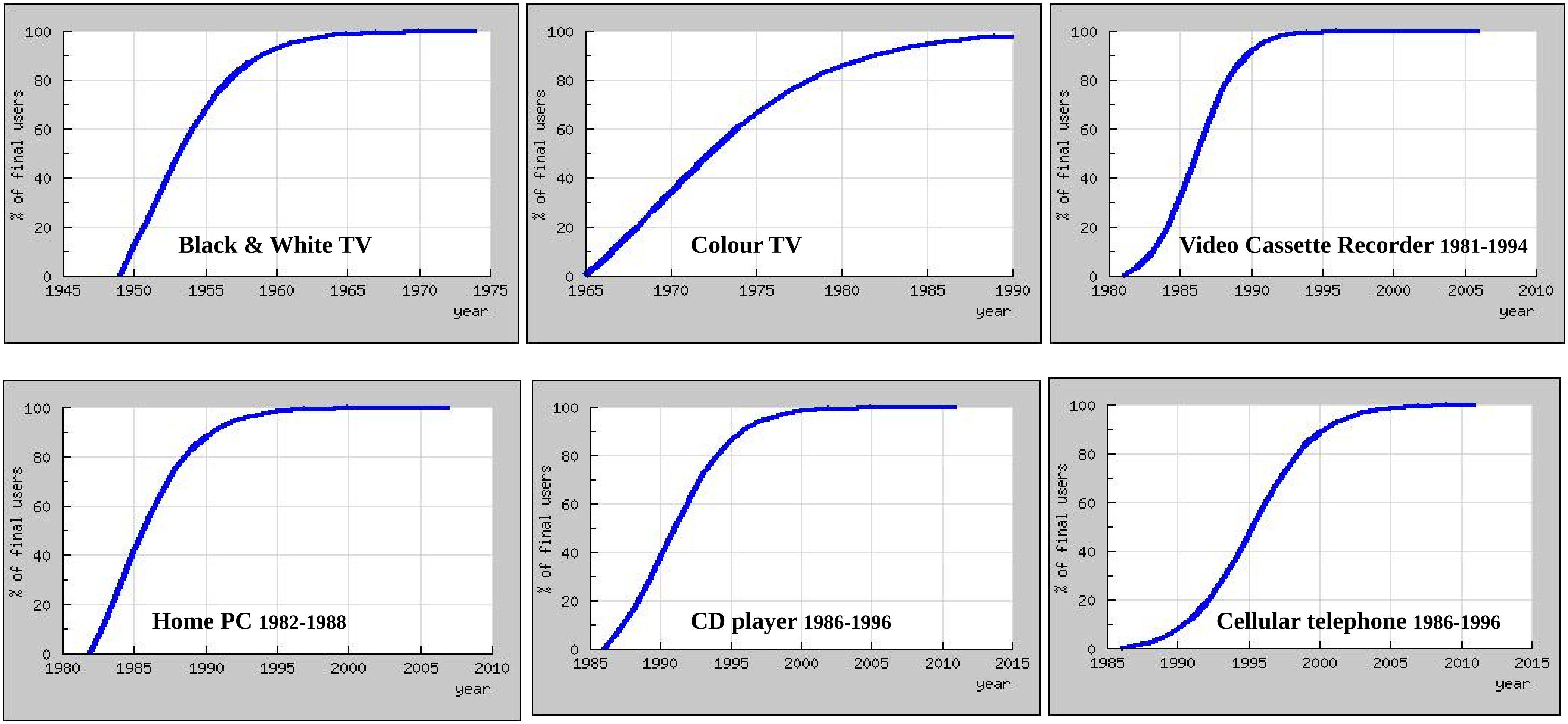
⇒ q/p increase ➡ FD increase ⇒

FD through Innofusion by means of Effective utilization of external resources based on Coopetition (q/p increase)

➡ Earlier emergence of FD

Fig. 8. Declining Nature of FD and Its Sustaining Efforts.

Speed of technology introduction: The Bass model of technology diffusion



"Diffusion models: Managerial applications and software" (1999), G. Lilien and C. Van den Bulte, Institute for the Study of Business Markets (University of Pennsylvania), ISBN Report 7-1999.
Introduction to the Bass Model and its extensions together with several **examples** of innovation and imitation factors **for particular technologies**.

http://isbm.smeal.psu.edu/library/working-paper-articles/1999-working-papers/07-1999-diffusion-models.pdf

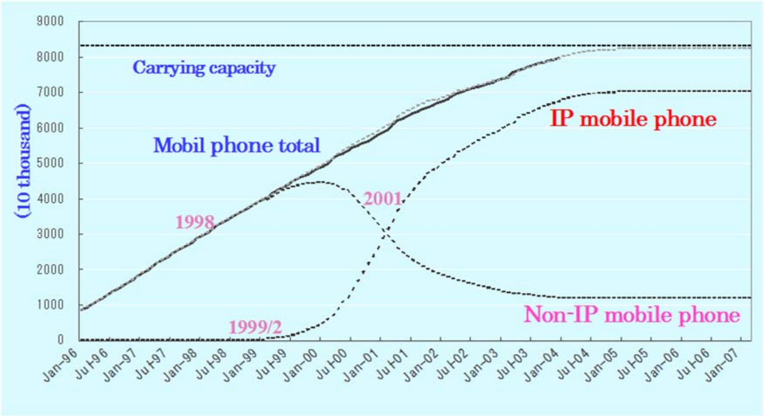
(3) Bi-Logistic Growth Function *(BLF)* – *Diffusion of two co-existing innovation* *(eg. carriage and car)*

$$Y(t) = Y_1(t) + Y_2(t) = \frac{N_1}{1+b_1 e^{-a_1 t}} + \frac{N_2}{1+b_2 e^{-a_2 t}} \qquad (27)$$

Application of BLF

1. Monthly diffusion trajectory of Japan's mobile phones (MP) over the last decade can be traced by the bi-logistic growth model.
2. This suggests that Japan's MP diffusion in the last decade was initiated by two waves Y_1 and Y_2.

IP: Internet Protocol Service



$$Y = Y_1 + Y_2 = \frac{N_1}{1+b_1 e^{-a_1 t}} + \frac{N_2}{1+b_2 e^{-a_2 t}}$$

$Y(t)$: cumulative number of MP diffusion at time t;
N_1, N_2: carrying capacities; a_1, a_2: velocity of diffusion;
b_1, b_2: initial stage of diffusion; and t: time trend by month (Dec. 95 =0, Jan. 96 =1).

Table 1 Estimation of Japan's Mobile Phones Diffusion by the Bi-logistic Growth Model

(January 1996-December 2006)

	N_1	a_1	b_1	N_2	a_2	b_2	adj. R^2
Parameter	35.147	0.074	5.198	65.418	0.036	14.028	0.999
t-value	2.25	4.59	3.26	3.81	6.74	1.33	

(4) Bi-Bass Model – *Diffusion of successive innovation with leader and follower dynamism*

$$Y(t)=\frac{N_1(1-e^{-(p_1+q_1)t})}{1+\frac{q_1}{p_1}e^{-(p_1+q_1)t}}+\frac{N_2(1-e^{-(p_2+q_2)t})}{1+\frac{q_2}{p_2}e^{-(p_2+q_2)t}} \quad (28)$$

Table 2 Diffusion Parameters in Major Innovative Goods and Services

		N	p	q	*adj.* R^2	$x=q/p$	$\varepsilon=\frac{d\ln p}{d\ln x}$	Trigger of new innovation
Printer [a]	**LLBP** (*1975-1994*)	1581 (19.33)	5.43×10^{-3} (15.13)	5.8×10^{-2} (9.94)	0.999	10.7	0.03	
	LBP/BJ (*1987-2005*)	97205 (166.57)	1.47×10^{-3} (2.27)	2.9×10^{-2} (37.96)	0.999	19.3	-0.35	
MP (*1990-2006*)	**MP 1**	38216 (149.45)	0.12×10^{-1} (5358.9)	0.58×10^{-1} (2616.7)	0.999	5.0	2.59	**Sky Walker** (*1997/10*)
	MP 2	65741 (170.24)	0.22×10^{-2} (1270.1)	0.35×10^{-1} (438.3)		15.6	-0.24	
LCD (*2000-2008*)	**LCD 1**	2.4×10^{3} (1654.3)	0.3×10^{-2} (1654.3)	0.2×10^{-1} (1654.3)	0.999	7.3	0.60	
	LCD 2	2.4×10^{3} (656.1)	0.4×10^{-4} (1654.3)	0.8×10^{-1} (1654.3)		1.9×10^{3}	-0.83	
Web (*1993-2006*)	**Web 1.0**	2.42×10^{5} (145.87)	1.38×10^{-5} (8.35)	1.08×10^{-1} (58.33)	0.999	7.8×10^{3}	-0.87	**RSS 2.0** (*2003/7*)
	Web 2.0	2.49×10^{5} (75.66)	0.25×10^{-5} (2.60)	0.55×10^{-1} (22.74)		22.0×10^{3}	-0.89	
PV (*1976-2007*)	**PV 1**	0.50×10^{5} (8.81)	19.36×10^{-5} (3.87)	2.66×10^{-1} (45.22)	0.999	0.1×10^{4}	-0.83	**NGPVs** (*2006*)
	PV 2	12.71×10^{5} (8.82)	0.04×10^{-5} (5.72)	4.11×10^{-1} (47.89)		105.4×10^{4}	-0.92	

[a] Since the period of co-existence of LLDP and LBP/BJ was limited, simple Bas model was used for respective innovation.
[b] Figures in parentheses indicate t-value. All demonstrates statically significant at the 5% level.
[c] LLBP: Large-scale Laser Beam Printer; LBP: Laser Beam Printer; BJ: Bubble Jet Printer; LCD: Liquid Crystal Display; MP: Mobile phone; and Web: Internet dependency based on the number of co.jp domains.
[d] Sky Walker: Triggered e-mail transmission by mobile phone; RSS 2.0 (Really Simple Syndication): Triggered publishing updated works in a standardized form as blog and video; NGPVs (Next Generation PV System): Triggered acceleration of customers initiative in PV development and introduction by means of highly advanced next generation technology.

(5) Logistic Growth Function within a Dynamic Carrying Capacity *(LGFDCC)*

- Diffusion with dynamically developing carrying capacity

$$Y(t) = \frac{N(t)}{1 + be^{-at}} \tag{24'}$$

$$N(t) = \frac{N_k}{1 + b_k e^{-a_k t}} \quad \text{where } N_k\text{: ultimate carrying capacity} \tag{29}$$

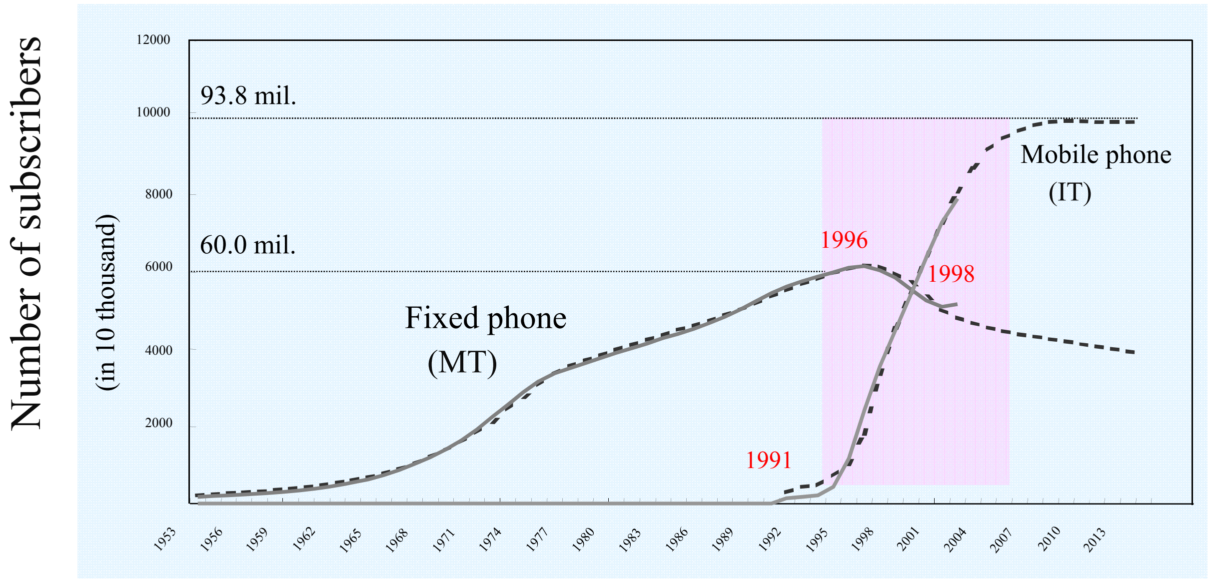
$$Y(t) = \frac{N_k}{1 + be^{-at} + \frac{a \cdot b_k}{a - a_k} e^{-a_k t}} = \frac{N_k}{1 + be^{-at} + \frac{b_k}{1 - \frac{a_k}{a}} e^{-a_k t}} \tag{30}$$

Application of LGFDCC

1) Features Differences between Manufacturing Technology and IT

Table 3 Comparison of Features between Manufacturing Technology and IT

	1980s	1990s
Paradigm	**Industrial society**	**Information society**
Core technology	**Manufacturing technology (MT)**	**IT**
1. Optimization	Within firms/Organizations	In the market
2. Key features formation process	Provided by suppliers	Formed through the interacting with institutions
3. Fundamental nature	As given	Self-propagating
4. Actors forming features	Individual firms/organizations	Institutions as a whole
5. Objectives	Productivity	Functionality
6. Development trajectory	**Growth oriented trajectory**	**Functionality development initiated trajectory**



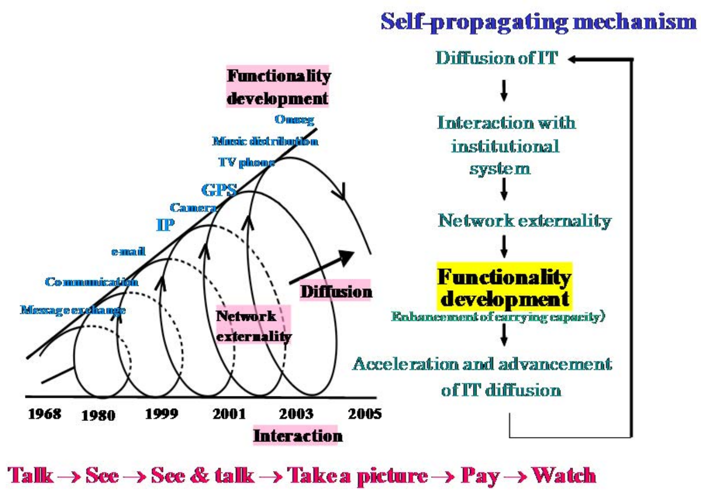


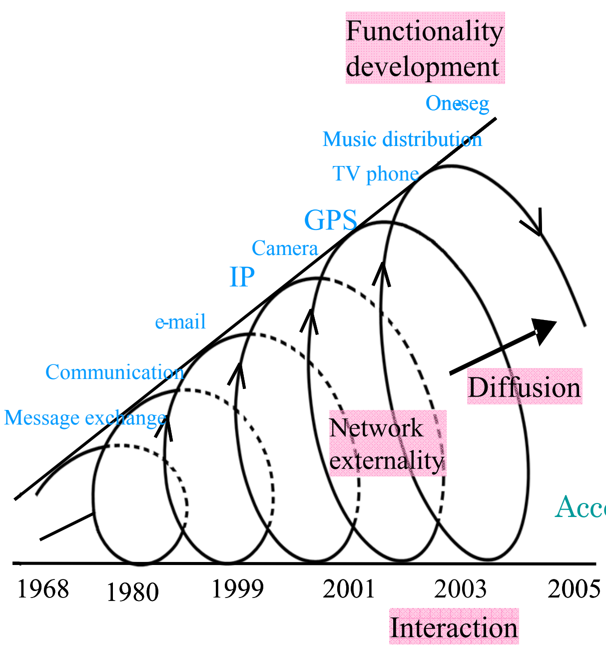
Fig. 10. Diffusion Trajectories in Japan's Fixed and Mobile Phones.

2) Self-propagating Functionality Development through Innofusion

In mobile driven innovation, new functionality emerged in a self-propagating way in a process of diffusion, not at development stage, as from *talk* to *see*, *see & talk*, *take a picture*, *pay* and *watch*.

$$\frac{dY}{dt} = aY(1-\frac{Y}{N}) \quad \Rightarrow \quad Y = \frac{N}{1+be^{-at}} \quad \Rightarrow \quad \frac{dN}{dt} = a_k N(1-\frac{N}{N_k}) \quad \Rightarrow \quad Y = \frac{N_k}{1+be^{-at} + \frac{b_k}{1-a_k/a}e^{-a_k t}}$$

Self-propagating mechanism



Diffusion of IT

↓

Interaction with institutional system

↓

Network externality

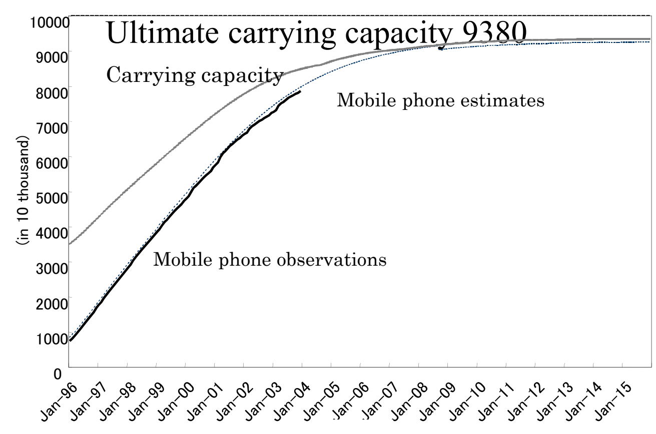
↓

Functionality development
(Enhancement of carrying capacity)

↓

Acceleration and advancement of IT diffusion

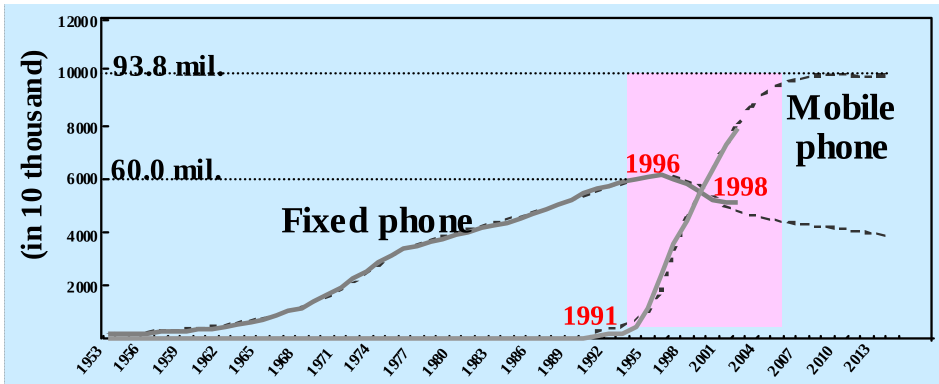
Parameter	Estimate	t-value	*adj.* R^2
a	1.48×10^{-1}	8.94	0.998
b	1.44×10^{2}	9.85	
a_k	3.43×10^{-2}	7.63	
b_k	4.21×10^{0}	8.65	
N_k	9.38×10^{3}	10.89	



Talk → See → See & talk → Take a picture → Pay → Watch

Fig. 11. Self-propagating Dynamism in Functionality Development of Japan's Mobile Phones.

3) Contrasting Diffusion Trajectories

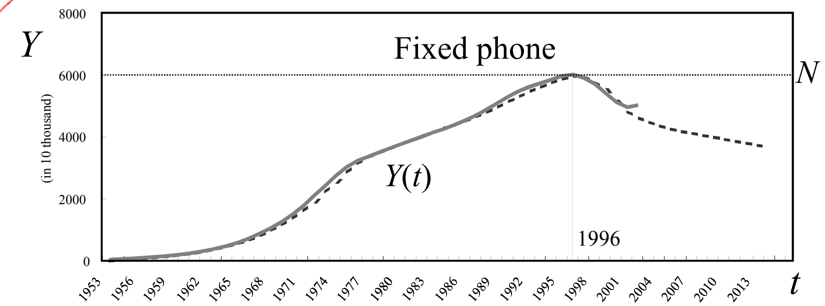


N	a	b	$adj.\ R^2$
6.00×10^3 (5.07)	1.74×10^{-1} (28.20)	0.64×10^2 (22.96)	0.952

$$\frac{dY}{dt} = aY\left(1 - \frac{Y}{N}\right)$$

N fixed → SLG → M T

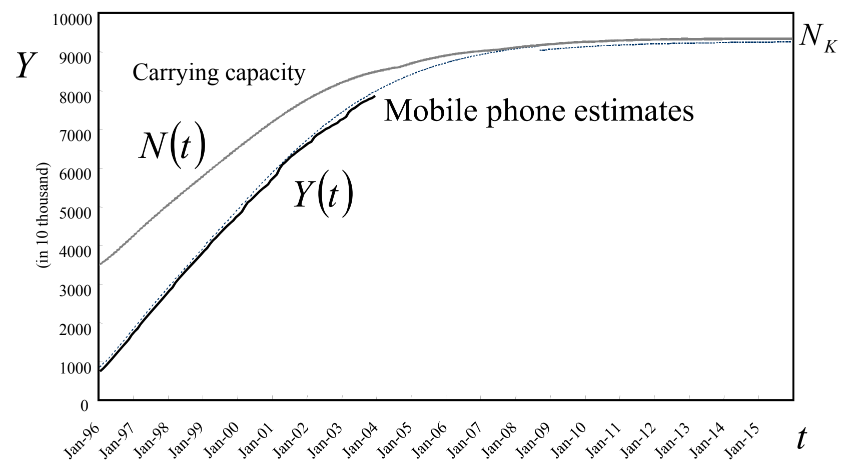
$$Y = \frac{N}{1+be^{-at}}$$



N dynamic

$$\frac{dN}{dt} = aN\left(1 - \frac{N}{N_K}\right)$$

→ LGDCC → I T



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

N_K	a	b	a_K	b_K	$adj.\ R^2$
9.38×10^3 (10.89)	1.48×10^{-1} (8.94)	1.44×10^2 (9.85)	3.43×10^{-2} (7.63)	4.21×10^0 (8.65)	0.998

Y: Production of innovative goods
N: Carrying capacity (Upper ceiling)
a: Velocity of diffusion

MT: Manufacturing technology
IT: Information technology

SLG: Simple logistic growth
LGDCC: Logistic growth within dynamic carrying capacity

Fig. 12. Self-propagating FD Dynamics.

3.4 Functionality Development

(1) Functionality Development Concept

Functionality development can be depicted by the following diffusion trajectory

1. Diffusion trajectory can be depicted by an epidemic function

$$\frac{dY}{dt} = aY(1 - \frac{Y}{N}) \Rightarrow Y = \frac{N}{1 + be^{-at}}$$

where Y: Production of innovative goods; N: Carrying capacity; and a: Velocity of diffusion.

2. Functionality development (FD)

Y continues to diffuse as far as it incorporates

"Ability to improve performance of production processes, goods and services by means of innovation" = FD

3. Measurement of FD

Y terminates to diffuse when it reaches N

(i) $Y \rightarrow N \Rightarrow \frac{dY}{dt} = 0$ (obsolescent stage of FD)

(ii) FD can be defined as "Potential capacity before reaching obsolescent stage"

(iii) Degree of FD = $N/Y = 1 + be^{-at}$ ⇒ Declining nature

4. Functionality development strategy

Efforts to prolong higher level of FD ⇒ Sustainable FD ⇒ Self-propagating FD

(2) Timing of Functionality Development Emergence

1) Timing in Overcoming CHASM

FD emergence contributes to overcome CHASM thereby enables IPO (Initial Public Offering) accomplishment.

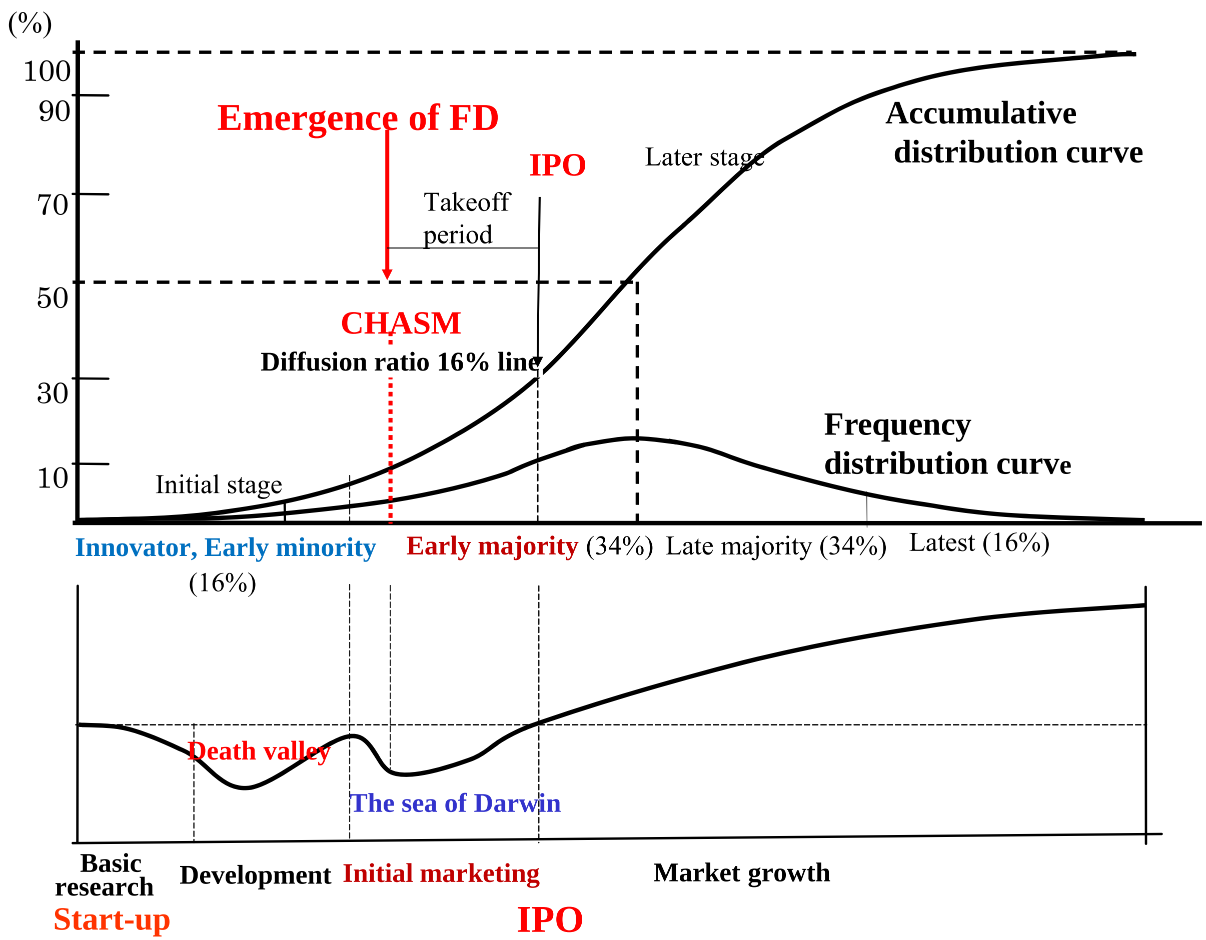


Fig. 13. Scheme of the Breeding Stage of New Ventures.

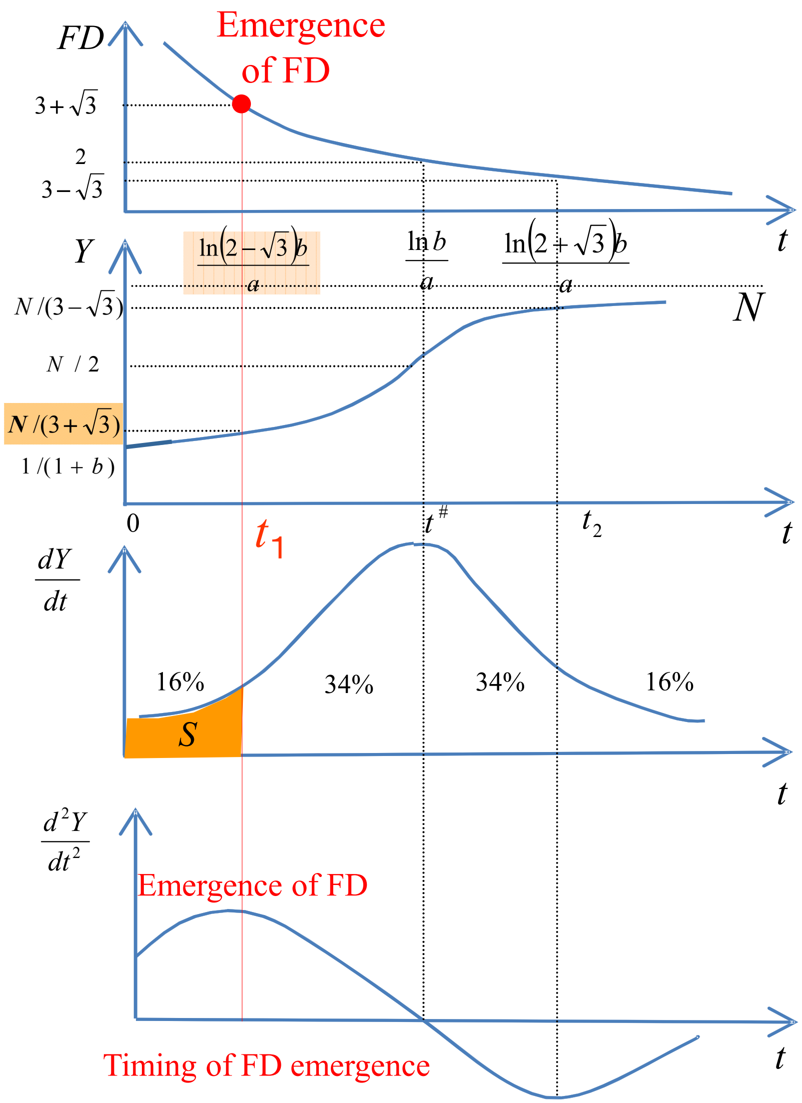
CHASM: Deep trench compelling new ventures start-up (Moore, 1991).

Timing of FD emergence corresponds to that of CHASM.

Emergence of FD
→ Overcoming CHASM
→ Take off leading to IPO

2) Timing of Functionality Development Emergence *by Logistic Growth Function*

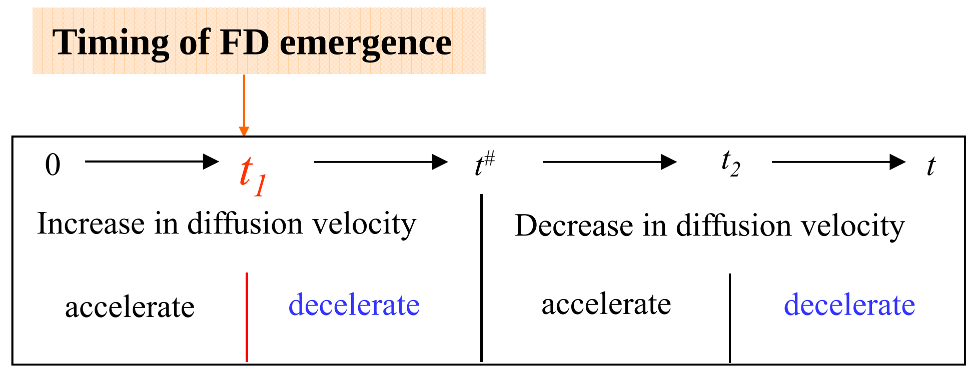
Diffusion model $Y = \frac{N}{1+be^{-at}}$, $FD = \frac{N}{Y} = 1 + be^{-at}$



Timing of FD emergence corresponds to the timing that maximizes the secondary derivative of the diffusion trajectory, and its level is

$3+\sqrt{3}$ (Rogers, Mahajan, Moore)

1. Following Rogers, Mahajan and Moore, timing of FD emergence can be identified as follows:



where t_1: inflection point of diffusion velocity in its increasing period; $t^{\#}$: inflection point of diffusion; and t_2: inflection point of diffusion velocity in its decreasing period.

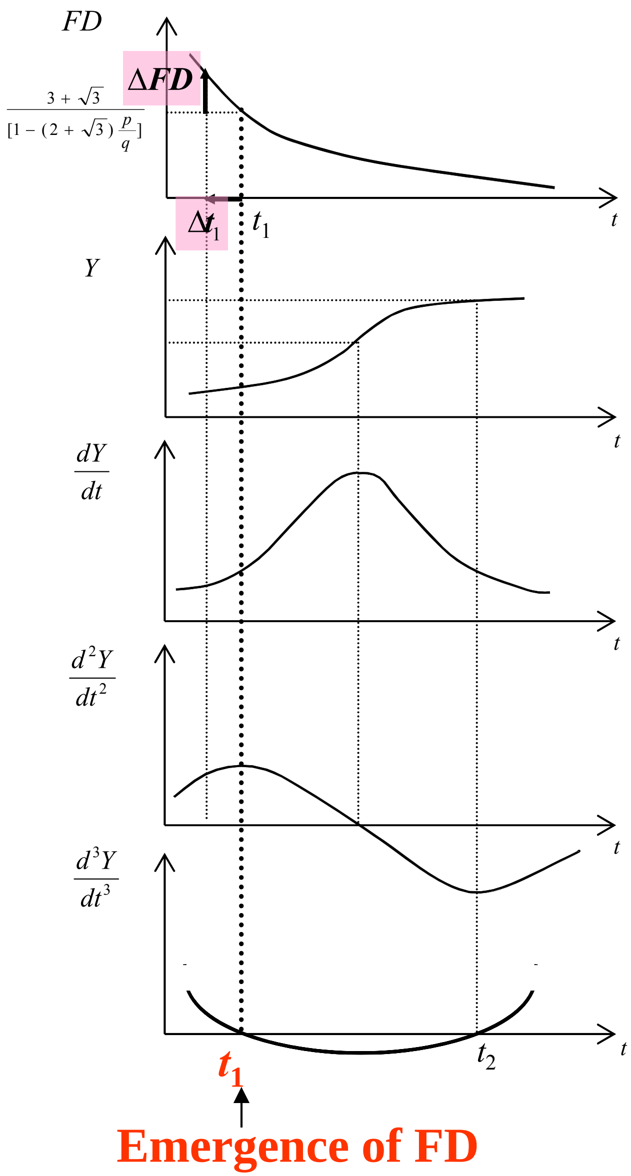
2. This time corresponds to CHASM.

$$S = \int_0^{t_1} \frac{dY}{dt} dS = [Y]_0^{t_1} = [\frac{N}{1+be^{-at}}]_0^{t_1} = N[\frac{2-\sqrt{3}}{3-\sqrt{3}} - \frac{1}{1+b}]$$

Given the initial level of diffusion 1/(1+b) = 0.05, $\frac{S}{N} \approx 0.16$ CHASM

Fig. 14. Level and Timing of Inflection in Diffusion Trajectory.

3) Timing of Functionality Development Emergence *by Bass Model*



$$FD = \frac{1+\frac{q}{p}e^{-(p+q)\cdot t}}{1-e^{-(p+q)\cdot t}}$$

$$Y = \frac{N(1-e^{-(p+q)\cdot t})}{1+\frac{q}{p}e^{-(p+q)\cdot t}}$$

Earlier Emergence of FD

$\Delta t_1 \downarrow \;\Rightarrow\; \Delta FD \uparrow$

$$t_1 = -\frac{1}{(p+q)}\ln\left[\left(2+\sqrt{3}\right)\frac{p}{q}\right]$$

Emergence of FD

$$t_2 = -\frac{1}{(p+q)}\ln\left[\frac{1}{\left(2+\sqrt{3}\right)}\frac{p}{q}\right]$$

Shifting to the successive FD

Fig. 15. Timing of the Emergence of Functionality Development.

3.5 Integration of Production Function and Diffusion Function - *Innofusion*

(1) Production Diffusion Integration

As paradigm shifts to an information society, spot where innovation takes place shifts from production site to diffusion process leading to the significance of production diffusion integration: innofusion function.

Y: Prod. of innovative goods
X: L(Labor), K(Capital), M(Material), E(Energy)
T: Technology
R: R&D investment
FD: Functionality development $= N/Y$
N: Carrying capacity
a: Diffusion velocity
b: Diffusion at the initial stage

(i) Production Function

$$Y = F(X, T) \Rightarrow \frac{\Delta Y}{Y} = \sum \left(\frac{\partial Y}{\partial X} \cdot \frac{X}{Y} \right) \frac{\Delta X}{X} + \frac{\partial Y}{\partial T} \cdot \frac{R}{Y}$$

(ii) Diffusion Function (Cumulative Y diffuses as a function of T in high-tech. firms)

$$\frac{\partial Y}{\partial T} = aY\left(1 - \frac{Y}{N}\right) = aY\left(1 - \frac{1}{FD}\right) \qquad FD = N/Y \qquad (31)$$

In high-tech. firms, T is proportional to t and $\frac{dY}{dT} = \frac{\partial Y}{\partial T}$ (see next page)

(iii) Production Diffusion Integration – *Innofusion Function* in which Functionality Development is only an option.

Growth rate | Traditional production factors | TFP | increase rate

$$\frac{\Delta Y}{Y} = \sum \left(\frac{\partial Y}{\partial X} \cdot \frac{X}{Y} \right) \frac{\Delta X}{X} + \frac{\partial Y}{\partial T} \cdot \frac{R}{Y}$$

MPT — R&D intensity

$$\frac{\partial Y}{\partial T} = aY\left(1 - \frac{1}{FD}\right)$$

↑ Functionality development

Growth
- **Traditional production factors** (Labor, Capital)
- **TFP**
  - **R&D intensity** (R/Y)
  - **Marginal productivity of technology (MPT)**
    - Production (Y)
    - Diffusion velocity (a)
    - **Functionality development** (FD)

Ability to improve performance of production processes, goods and services by means of innovation

Fig. 16. Integration of Production and Diffusion Functions.

(2) Selection of Development Trajectory

Production function in high-tech firms can be depicted as follows:

$$Y = F(X,T) = F(X(T)) \approx F(T)$$

$$T \approx \alpha + \beta t$$

$$\frac{dY}{dt} = \frac{dY}{dT}\cdot\frac{dT}{dt} = \beta\frac{dY}{dT} = \beta\frac{\partial Y}{\partial T}\cdot\frac{dT}{dT} = \beta\frac{\partial Y}{\partial T}$$

$$= aY\left(1-\frac{Y}{N}\right)$$

$$\therefore \frac{\partial Y}{\partial T} = \frac{a}{\beta}Y\left(1-\frac{Y}{N}\right) = a'Y\left(1-\frac{Y}{N}\right) = a'Y\left(1-\frac{1}{FD}\right)$$

$$\frac{d\sum Y}{dt} = a\sum Y\left(1-\frac{\sum Y}{\sum N}\right) \Rightarrow \frac{dY}{dt} = aY\left(1-\frac{Y}{N}\right)$$

Y: Production of innovative goods; X: Labor, Capital, material and energy T: Technology stock

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

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

$$T_t = R_{t-m} + \frac{1-\rho}{\rho+g}R_{t-m} = R_0(1+g)^{t-m}\frac{1+g}{\rho+g}.$$

$$T_t \approx R_0(1-mg+gt)(1+g)/(\rho+g) = \alpha + \beta t$$

$$\alpha = R_0(1-mg)\frac{1+g}{\rho+g} \qquad \beta = R_0 g\frac{1+g}{\rho+g}$$

T_t: technology stock at time t; R_t: R&D investment at time t; m: time lag between R&D and commercialization; ρ: rate of obsolescence of technology; and g: growth rate of R&D investment at the initial period.

Economic growth dependent model: Depend on Y
- *Growth Oriented Trajectory*

Contribution to labor and capital — TFP growth rate (technological progress)

$$\frac{\Delta Y}{Y} = \sum_{X=L,K,M,E}\left(\frac{\partial Y}{\partial X}\cdot\frac{X}{Y}\right)\frac{\Delta X}{X} + \frac{\partial Y}{\partial T}\cdot\frac{R}{Y}$$

$$\frac{\partial Y}{\partial T} = aY\left(1-\frac{1}{FD}\right)$$

Marginal productivity of technology (MPT)

New functionality development model: Stimulate FD
- *New Functionality Development Initiated Trajectory*

$$\frac{\Delta Y}{Y} = \sum_{X=L,K,M,E}\left(\frac{\partial Y}{\partial X}\cdot\frac{X}{Y}\right)\frac{\Delta X}{X} + \frac{\partial Y}{\partial T}\cdot\frac{R}{Y}$$

$$\frac{\partial Y}{\partial T} = aY\left(1-\frac{1}{FD}\right)$$

Y: Prod. of innov. goods
L: Labor, K: Capital
M: Material, E: Energy
T: Technology stock
R: R&D investment
FD: Functionality development
a: Diffusion velocity

Japan (1980s, 1990s) US (1980s) → US (1990s)

System conflict — System match

MPT: Marginal productivity of technology

Fig. 17. Scheme Leading Japan to Lose Its Institutional Elasticity.

Source: Watanabe et al. (2003).

(3) US Locomotive Leveraging Transformation to FD Initiated Trajectory

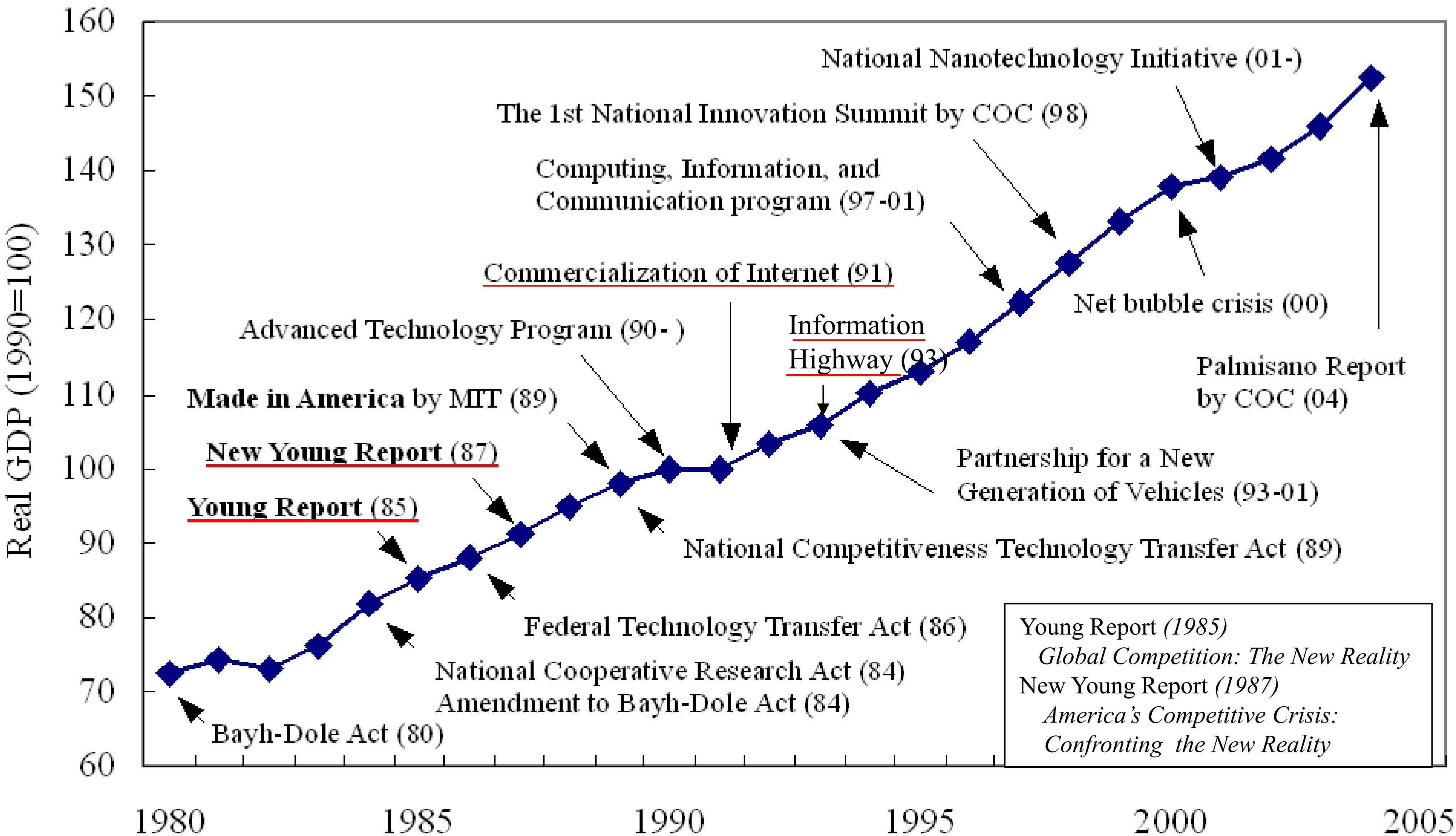


Fig. 18. Trends in the US Policy for Enhancement of Competitiveness ***(1980-2004)*****.**

(4) 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.

MPT: Marginal Productivity of Technology

(i) Dramatic Decrease in Marginal Productivity of Technology

TFP: Total Factor Productivity

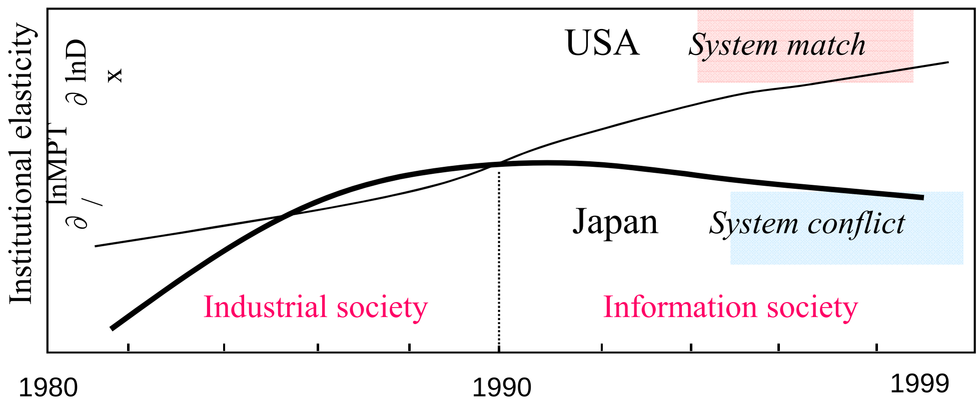


Fig. 6-1. Institutional Elasticity of Manufacturing Technology
- Elasticity of the Shift to an Information Society to Marginal Productivity of Technology *(1980-1999) - Index :1990＝100.*

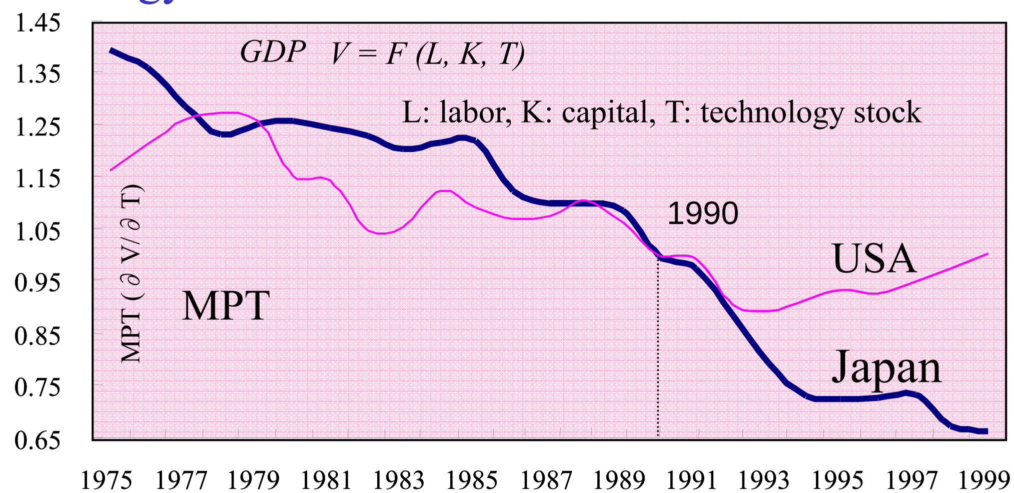


Fig. 6-2. Marginal Productivity of Manufacturing Technology
(1975-1999) - Index: 1990 =1.

(ii) Consequent Decrease in Innovation

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

Innovation to GDP growth

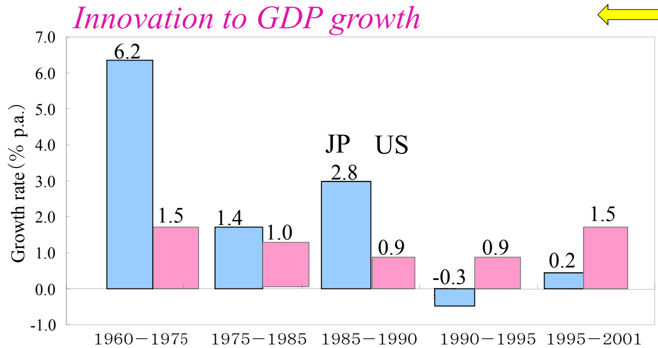


Fig. 6-3. TFP Growth Rate *(1960-2001).*

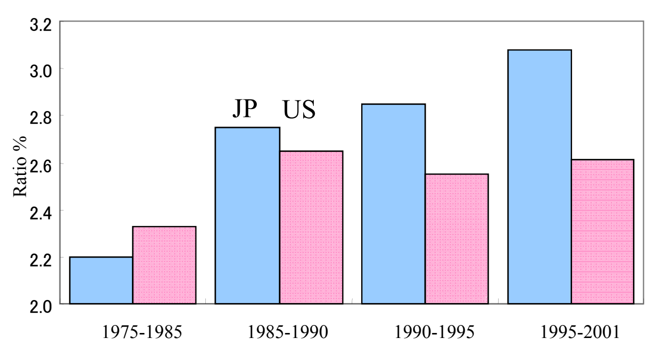


Fig. 6-4. R&D Intensity *(1975-2001).*

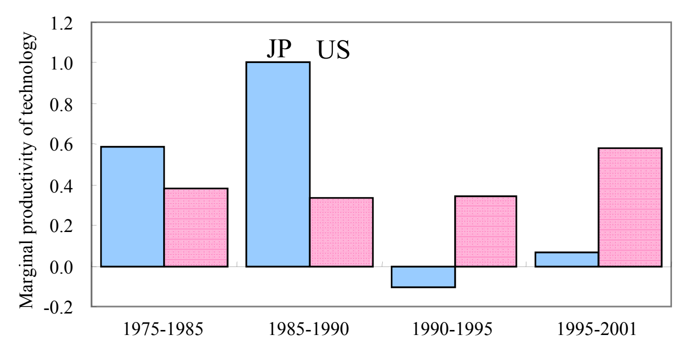


Fig. 6-5. Marginal Productivity of Technology
(1960-2001).

(5) Swell of Japan's Institutional MOT toward a Post-information Society

As a consequence of hybrid management fusing "East" and "West", Japan's indigenous MOT is again responding to a co-evolutionary dynamism between innovation and institutional systems corresponds to a ubiquitous economy.

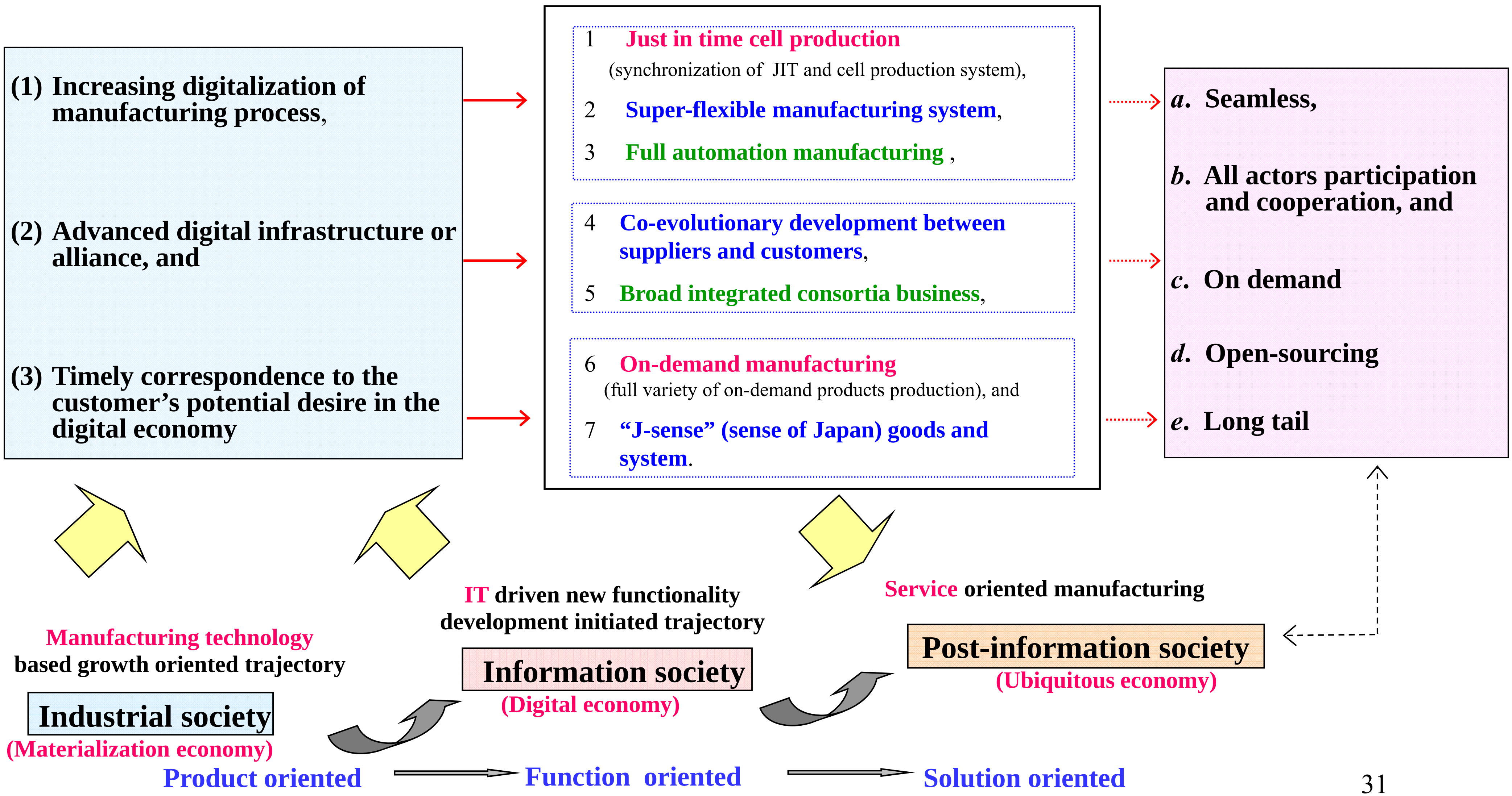


Fig.19 . Swell of Japan's New Innovation.

(6) Governing Factors to Functionality Development

Under the competitive circumstance where firms aim at maximizing their profits, equation (31) should be equivalent to relative prices as follows:

$$\frac{\partial Y}{\partial T} = aY\left(1-\frac{Y}{N}\right) = aY\left(1-\frac{1}{FD}\right) \qquad (31)$$

$$\frac{\partial Y}{\partial T} = P = P_T / P_Y \qquad (32)$$

where P : relative prices of technology; P_T : technology prices of innovative goods; and P_Y : prices of innov. goods.

Equation (31) can be developed as follows:

$$\frac{\partial Y}{\partial T} = \frac{\Delta Y}{\Delta T} = aY(1-\frac{Y}{N}) = aY - a\frac{Y^2}{N} = P \qquad (33)$$

where $\Delta Y = \frac{dY}{dt}$.

Differentiate equation (32) by time t,

$$\Delta P = a\Delta Y - 2a\Delta Y\frac{Y}{N} = a\Delta Y(1-2\frac{Y}{N}) = aP\Delta T(1-\frac{2}{FD})$$

$$\frac{\Delta P}{P} = a\Delta T(1-\frac{2}{FD}) \qquad (34)$$

Functionality development (FD) can be depicted as follows:

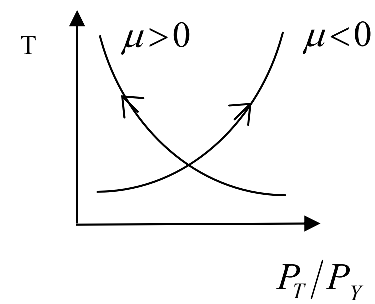
$$FD = \frac{2}{1-\frac{1}{a\Delta T}\frac{\Delta P}{P}} = \frac{2}{1-\frac{1}{aT}\frac{\Delta P/P}{\Delta T/T}} = \frac{2}{1-\frac{1}{aT}\frac{\partial \ln P}{\partial \ln T}} = \frac{2}{1+\frac{1}{aT\mu}} \qquad (35)$$

where a: diffusion velocity; and $\mu = -\frac{\partial \ln T}{\partial \ln P} = -\frac{\partial T}{\partial P}\frac{P}{T}$: price elasticity to technology (PET).

(7) Prices of Technology and Functionality Development

$$FD = \frac{2}{1-\frac{1}{a\Delta T}\frac{\Delta P}{P}} = \frac{2}{1-\frac{1}{aT}\frac{\Delta P/P}{\Delta T/T}} = \frac{2}{1-\frac{1}{aT}\frac{\partial \ln P}{\partial \ln T}} = \frac{2}{1+\frac{1}{aT\mu}} \qquad (35)$$

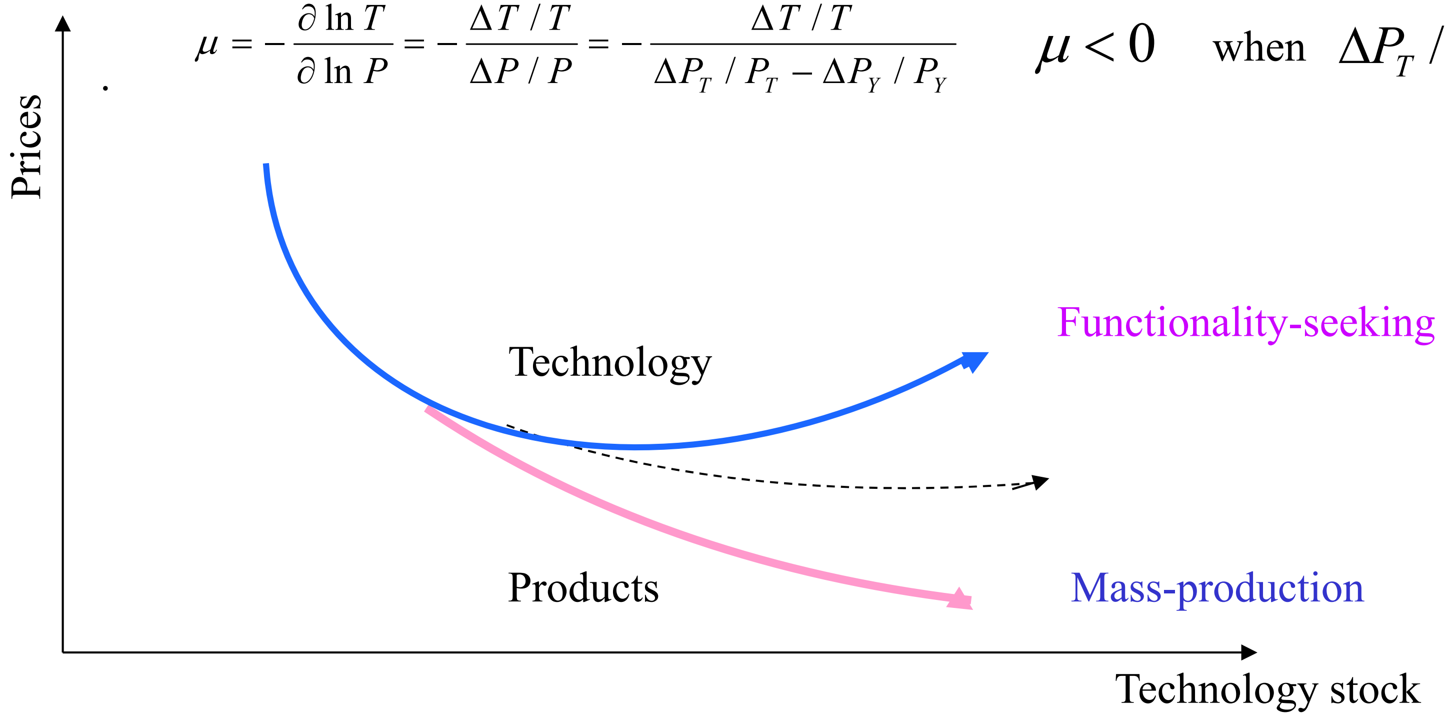
$\mu = -\frac{\partial \ln T}{\partial \ln P} = -\frac{\partial T}{\partial P}\frac{P}{T}$: price elasticity to technology (PET).

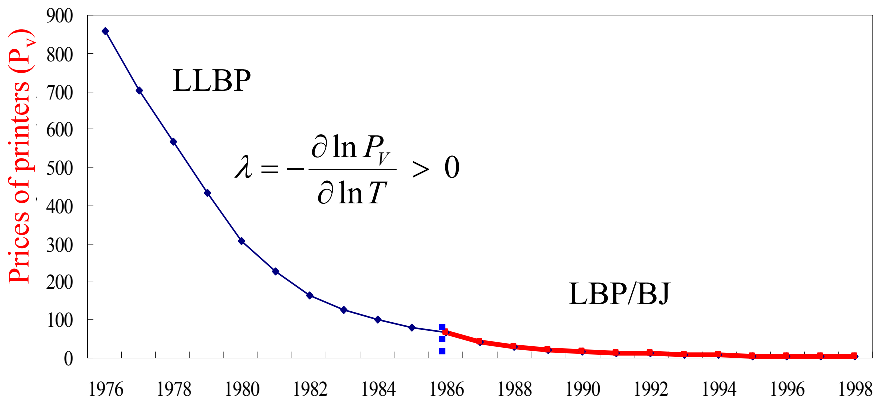


$$\underset{(\mu>0)}{0 < FD_1} < 2 \leq \underset{(\mu<0)}{FD_2} < \infty$$

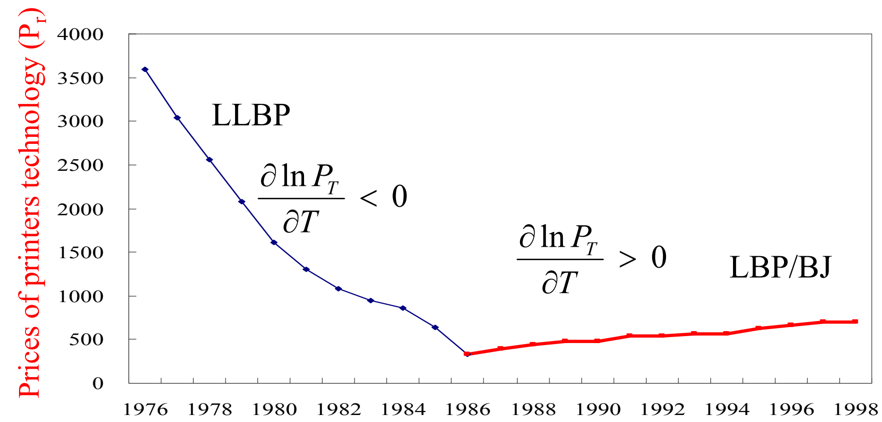
$$\mu = -\frac{\partial \ln T}{\partial \ln P} = -\frac{\Delta T/T}{\Delta P/P} = -\frac{\Delta T/T}{\Delta P_T/P_T - \Delta P_Y/P_Y}$$

$\mu < 0$ when $\Delta P_T/P_T > \Delta P_Y/P_Y$





Trends in Prices of Printers Corresponding to their Technology Stock in Canon Printers *(1976 – 1998)*.



Trends in Prices of Printers Technology Corresponding to their Technology Stock in Canon Printers *(1976 – 1998)*.

LLBP (1976-1985): $\Delta P_T / P_T - \Delta P_Y / P_Y < 0$ $\mu > 0$ $0 < \text{FD} < 2$

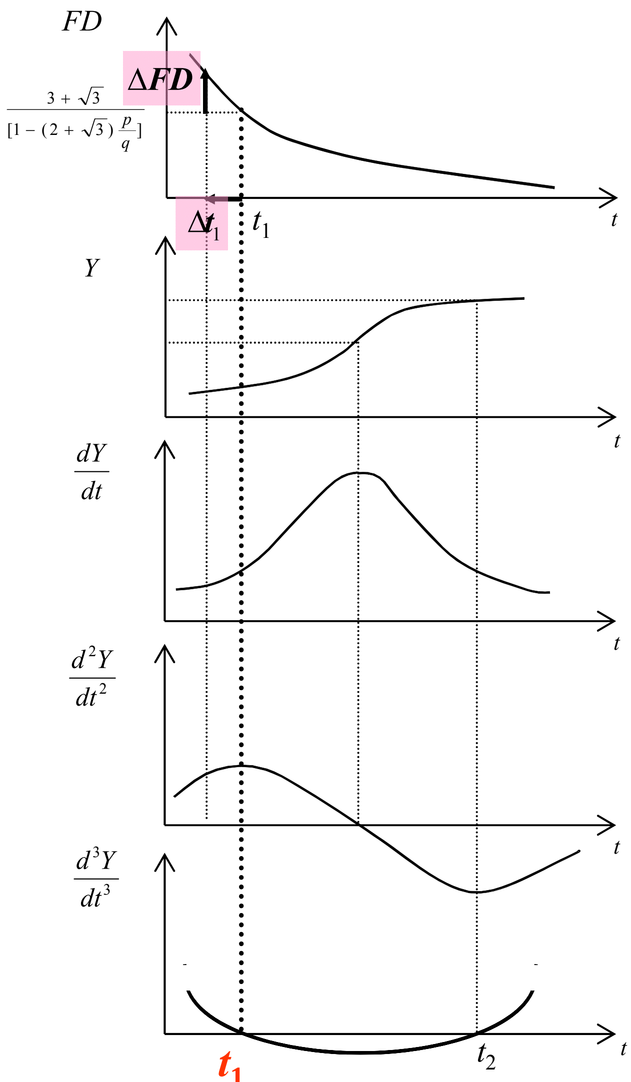
LBP/BJ (1985-1998): . $\Delta P_T / P_T - \Delta P_Y / P_Y > 0$ $\mu < 0$ $2 < \text{FD}$

4.6 Sustainable FD in Open Innovation

(1) Timing of the Functionality Development

→ **Earlier FD emergence**

→ **Sustainable FD**



$$FD = \frac{1 + \frac{q}{p} e^{-(p+q)\cdot t}}{1 - e^{-(p+q)\cdot t}}$$

$$Y = \frac{N(1 - e^{-(p+q)\cdot t})}{1 + \frac{q}{p} e^{-(p+q)\cdot t}}$$

Earlier Emergence of FD

$\Delta t_1 \downarrow$ ➡ $\Delta FD \uparrow$

$$t_1 = -\frac{1}{(p+q)} \ln\left[\left(2+\sqrt{3}\right)\frac{p}{q}\right]$$

Emergence of FD

$$t_2 = -\frac{1}{(p+q)} \ln\left[\frac{1}{\left(2+\sqrt{3}\right)}\frac{p}{q}\right]$$

Shifting to the successive FD

t_1 ↑ **Emergence of FD**

Fig. 15. Timing of the Emergence of Functionality Development.

(2) Requirement for Earlier Functionality Development Emergence

$$\frac{d^3Y}{dt^3}=0 \Rightarrow t_1=-\frac{1}{(p+q)}\ln\left[\frac{1}{(2+\sqrt{3})}\frac{p}{q}\right]=y\ln[\frac{x}{(2+\sqrt{3})}]$$

where $q/p=x$ and $\frac{1}{p+q}=y$.

p: innovator

q: imitator

$$\frac{dt_1}{dq/p}=\frac{dt_1}{dx}=\frac{dy}{dx}\ln[\frac{x}{(2+\sqrt{3})}]+\frac{y}{x}$$

where $y=\frac{1}{p(1+x)}$, $\frac{y}{x}=\frac{1}{p(1+x)x}$, $\frac{dy}{dx}=\frac{-[(1+x)\frac{dp}{dx}+p]}{[p(1+x)]^2}$.

Therefore, $\frac{dt_1}{dq/p}$ can be developed as follows:

$$\frac{dt_1}{dq/p}=\frac{-[(1+x)\frac{dp}{dx}+p]}{[p(1+x)]^2}\ln[\frac{x}{(2+\sqrt{3})}]+\frac{1}{px(1+x)}=\frac{1}{px(1+x)}\left[1+\frac{[(1+x)\frac{dp}{dx}+p]\ln[\frac{(2+\sqrt{3})}{x}]x}{p(1+x)}\right]$$

In case when $W(x)=\frac{[(1+x)\frac{dp}{dx}+p]\ln[\frac{(2+\sqrt{3})}{x}]x}{p(1+x)}<-1$, $\frac{dt_1}{dq/p}<0$

Necessary condition for earlier functionality development emergence

***q/p* increase induces earlier FD emergence leading to sustainable FD**

(3) Boundary Satisfying Earlier FD Emergence

Aiming at identifying the boundary condition satisfying earlier FD emergence in the Bass model, the following analysis is attempted:

$$\frac{dt_1}{dq/p}<0 \Leftrightarrow \frac{[(1+x)\frac{dp}{dx}+p]\ln[\frac{(2+\sqrt{3})}{x}]x}{p(1+x)}<-1$$

$$\Leftrightarrow \frac{(1+x)\frac{dp}{dx}\ln[\frac{(2+\sqrt{3})}{x}]x}{p(1+x)}+\frac{p\ln[\frac{(2+\sqrt{3})}{x}]x}{p(1+x)}<-1$$

$$\Leftrightarrow \frac{\frac{dp}{dx}\ln[\frac{(2+\sqrt{3})}{x}]x}{p}+\frac{\ln[\frac{(2+\sqrt{3})}{x}]x}{(1+x)}<-1$$

If $1<x<2+\sqrt{3}$, then $\ln[\frac{(2+\sqrt{3})}{x}]>0$, and so

$$\frac{dt_1}{dq/p}<0 \Leftrightarrow \frac{dp}{dx}\frac{1}{p}<-\frac{1}{\ln[\frac{(2+\sqrt{3})}{x}]x}-\frac{1}{(1+x)}$$

$$\Leftrightarrow \boxed{\varepsilon\equiv\frac{dp}{dx}\frac{x}{p}<-\frac{1}{\ln[\frac{(2+\sqrt{3})}{x}]}-\frac{x}{(1+x)}}$$

where ε: x elasticity to p.

If $x>2+\sqrt{3}$, then $\ln[\frac{(2+\sqrt{3})}{x}]<0$, and we get

$$\frac{dt_1}{dq/p}<0 \Leftrightarrow \frac{dp}{dx}\frac{1}{p}>-\frac{1}{\ln[\frac{(2+\sqrt{3})}{x}]x}-\frac{1}{(1+x)}$$

$$\Leftrightarrow \boxed{\varepsilon\equiv\frac{dp}{dx}\frac{x}{p}>-\frac{1}{\ln[\frac{(2+\sqrt{3})}{x}]}-\frac{x}{(1+x)}}$$

Table 4 Conditions of Boundary Function by Areas

Area	$\frac{dp}{dx}$	$\frac{dt_1}{dx}$	x	ε
I	+	+	$1<x<2+\sqrt{3}$	$\varepsilon>0$
II	+	-	$x>2+\sqrt{3}$	$\varepsilon>0$
III	-	-	$x>11.1$	$-1<\varepsilon<0$
IV	-	-	$1<x<2+\sqrt{3}$	$\varepsilon<0$
V	-	+	$x>2+\sqrt{3}$	$\varepsilon<0$

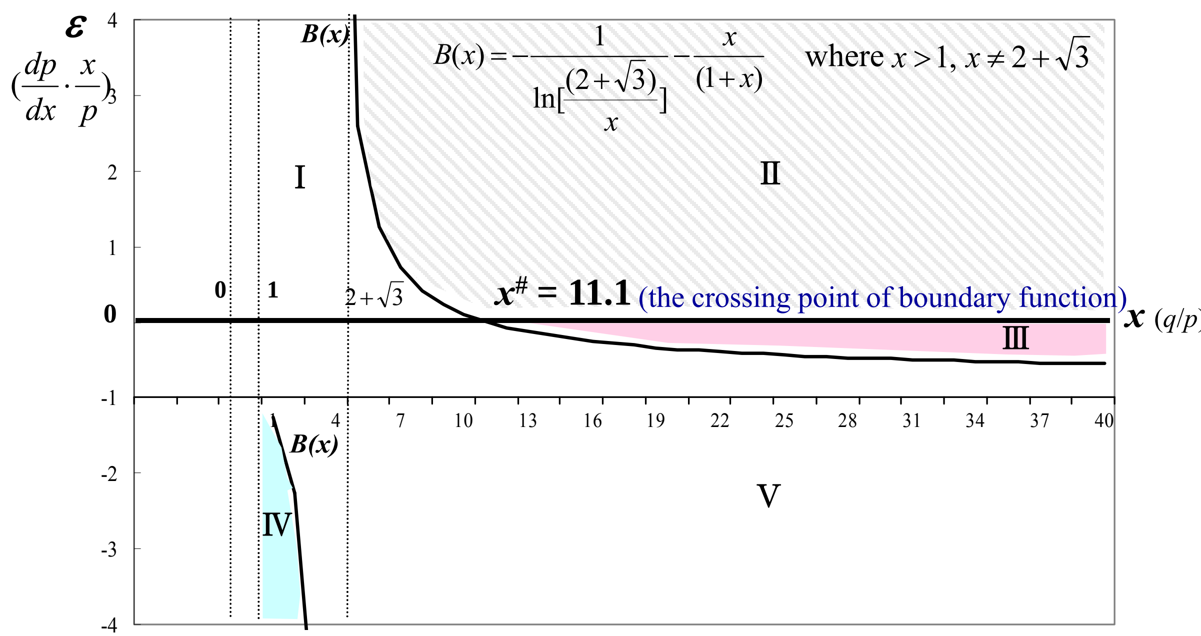


Fig. 20. Areas Satisfying Earlier FD Emergence.

(4) Diffusion Dynamics in Major Innovation

$$Y(t) = \frac{N_1(1-e^{-(p_1+q_1)t})}{1+\frac{q_1}{p_1}e^{-(p_1+q_1)t}} + \frac{N_2(1-e^{-(p_2+q_2)t})}{1+\frac{q_2}{p_2}e^{-(p_2+q_2)t}} \quad (28)$$

Table 5 Diffusion Parameters in Major Innovative Goods and Services

		N	p	q	*adj.* R^2	$x = q/p$	$\varepsilon = \frac{d \ln p}{d \ln x}$	Trigger of new innovation
Printer [a]	**LLBP** (*1975-1994*)	1581 (19.33)	5.43×10^{-3} (15.13)	5.8×10^{-2} (9.94)	0.999	10.7	0.03	
	LBP/BJ (*1987-2005*)	97205 (166.57)	1.47×10^{-3} (2.27)	2.9×10^{-2} (37.96)	0.999	19.3	-0.35	
MP (*1990-2006*)	**MP 1**	38216 (149.45)	0.12×10^{-1} (5358.9)	0.58×10^{-1} (2616.7)	0.999	5.0	2.59	**Sky Walker** (*1997/10*)
	MP 2	65741 (170.24)	0.22×10^{-2} (1270.1)	0.35×10^{-1} (438.3)		15.6	-0.24	
LCD (*2000-2008*)	**LCD 1**	2.4×10^{3} (1654.3)	0.3×10^{-2} (1654.3)	0.2×10^{-1} (1654.3)	0.999	7.3	0.60	
	LCD 2	2.4×10^{3} (656.1)	0.4×10^{-4} (1654.3)	0.8×10^{-1} (1654.3)		1.9×10^{3}	-0.83	
Web (*1993-2006*)	**Web 1.0**	2.42×10^{5} (145.87)	1.38×10^{-5} (8.35)	1.08×10^{-1} (58.33)	0.999	7.8×10^{3}	-0.87	**RSS 2.0** (*2003/7*)
	Web 2.0	2.49×10^{5} (75.66)	0.25×10^{-5} (2.60)	0.55×10^{-1} (22.74)		22.0×10^{3}	-0.89	
PV (*1976-2007*)	**PV 1**	0.50×10^{5} (8.81)	19.36×10^{-5} (3.87)	2.66×10^{-1} (45.22)	0.999	0.1×10^{4}	-0.83	**NGPVs** (*2006*)
	PV 2	12.71×10^{5} (8.82)	0.04×10^{-5} (5.72)	4.11×10^{-1} (47.89)		105.4×10^{4}	-0.92	

[a] Since the period of co-existence of LLDP and LBP/BJ was limited, simple Bas model was used for respective innovation.
[b] Figures in parentheses indicate *t*-value. All demonstrates statically significant at the 5% level.
[c] LLBP: Large-scale Laser Beam Printer; LBP: Laser Beam Printer; BJ: Bubble Jet Printer; LCD: Liquid Crystal Display; MP: Mobile phone; and Web: Internet dependency based on the number of co.jp domains.
[d] Sky Walker: Triggered e-mail transmission by mobile phone; RSS 2.0 (Really Simple Syndication): Triggered publishing updated works in a standardized form as blog and video; NGPVs (Next Generation PV System): Triggered acceleration of customers initiative in PV development and introduction by means of highly advanced next generation technology.

(5) Sustainable FD by Major Innovation

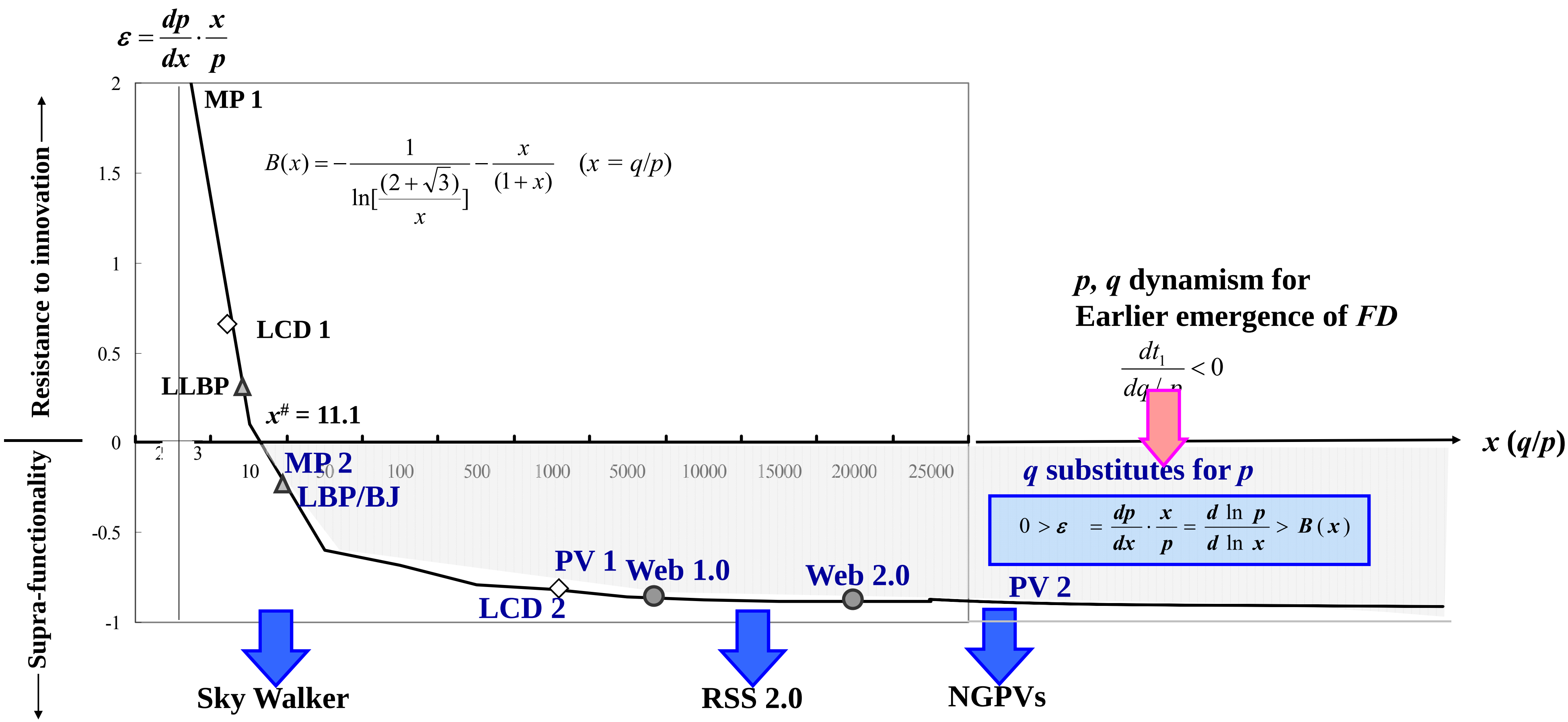


Fig. 21. Sustainable Functionality Development Condition.

1. While latest high-technology products as LBP/BJ, MP 2, LCD 2, Web 1.0, Web 2.0, PV 1 and PV 2 satisfy conditions for sustainable functionality development, LLBP (1976), MP 1 (1996) and LCD 1 () do not satisfy these conditions resulting in being substituted by LBP, BJ, MP 2 and LCD 2.

2. This can be considered as substitution from 'resistance to innovation' in the early introduction to market, to supra-functionality with customers own initiative.

(6) New FD Frontier

Printers
Depend on
Print office

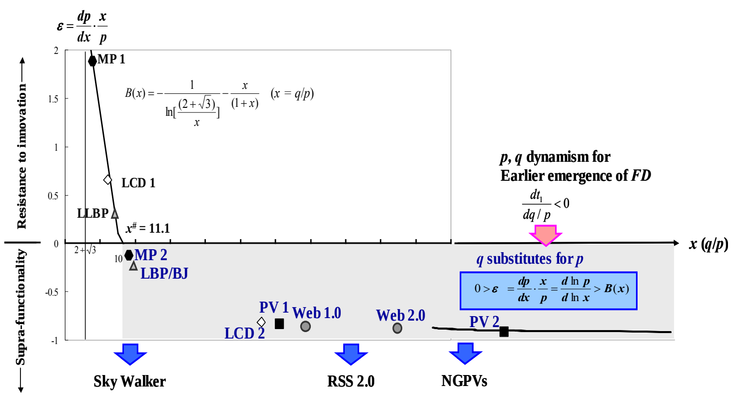
Mobile phone
Communication
only

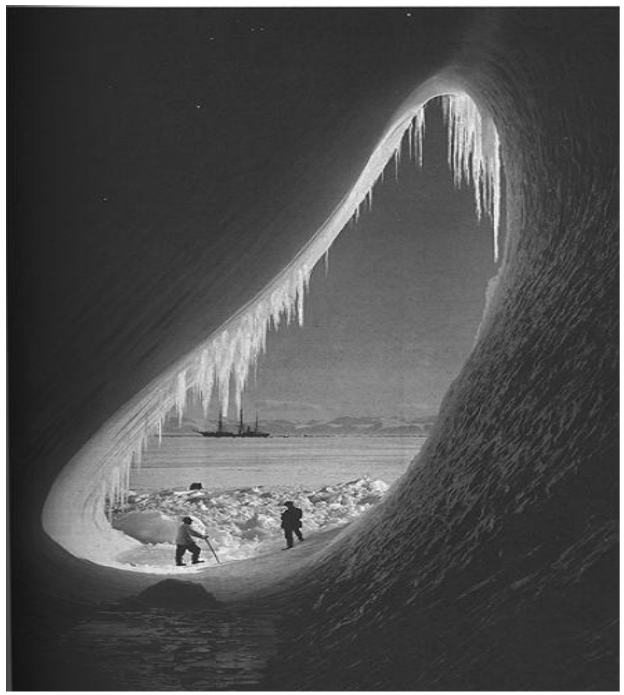
LCD
Watch
only

Web
Passive information
dependent

PV
Purchase from
Electric power company

Explore new FD frontier





Instills customers "*exciting story with their initiative as heroes/heroines*" and thrills them gratification

Incorporates innovation new social, cultural and aspirational value beyond economic value

Home print
by own design

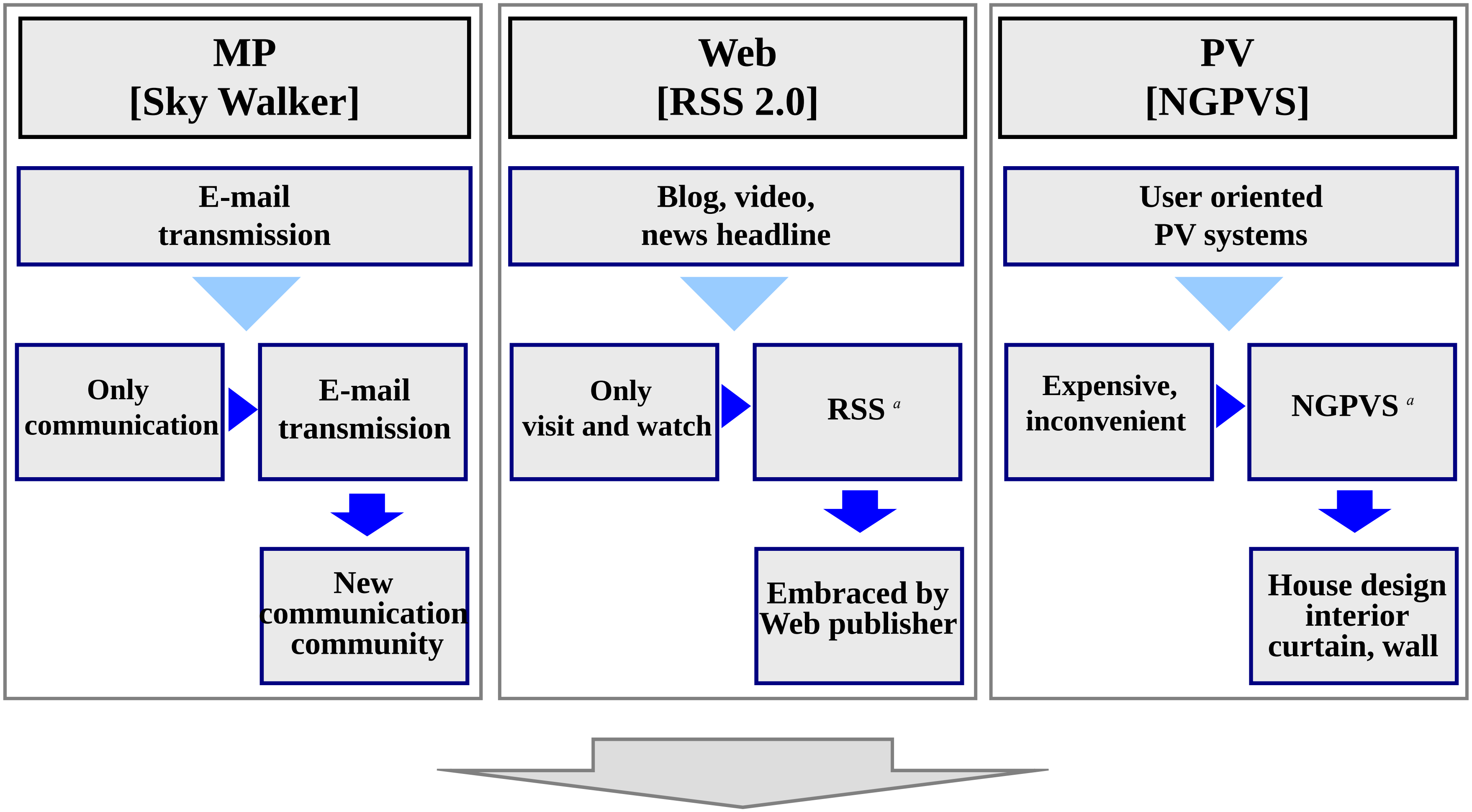
Explore new world
Internet
with as preferred

multimedia services
IPTV
interactivity

Blog
as hero/heroines

Clean energy
by own interior design

Fig. 22. New Functionality Development Frontier Leading to Supra-functionality.



New FD frontier which instills in users an "exciting story on their own initiatives as heroes/heroines" thrills them with gratification beyond economic value

[a] **RSS**: Really Simple Syndication; and NGPVS: New Generation Photovoltaic System.

(7) Strategy for Substitution

Table 6 Concept of Imitator Substitutes for Innovator

Innovator	Imitator
Leader	Follower
Supplier	Customer
Producer	Consumer
Fear to new products	Gratification of consumption

Sustainable FD

⇕

q (imitator) substitutes for *p* (innovator) ⇔ **Assimilation of spillover technology**

⇕

Knowledge transfer

⇕

- ⇔ Customer substitutes for supplier
- ⇔ Open innovation
- ⇔ Coopetiotion (Cooperation and competition)
- ⇔ Co-evolutionary domestication

⇔ **Hybrid management of technology**

4. Effects of Learning

4.1 Learning by Doing

4.2 Theory of Learning by Doing

4.3 Learning Curve

4.4 Market Learning

4.5 Hybrid Management of Technology

4.6 Necessity for Effective Learning

4. Effects of Learning

4.1 Learning by Doing

(1) Chronology to Endogenous Technological Improvement

Solow (1956)	$Y = F(L, K, T)$ $= ATL^{\alpha}K^{1-\alpha}$ $= Ae^{\lambda t}L^{\alpha}K^{1-\alpha}$	Solow residuals → Technological progress
Denison (1962)	$\dot{Y} - \dot{X} = \sum v_j \dot{p}_j - \sum w_i \dot{q}_i,$ $w_i = \frac{q_i Y_i}{\sum q_i Y_i}, \quad v_j = \frac{p_j X_j}{\sum p_j X_j}$	TFP
Solow/Johansen (1960)	$Y = F(L, K(T))$	Technology embody into capital
SMAC (1961) Solow, Minhas, Arrow, Chenery	$f = \gamma[\delta k^{-\rho} + (1-\delta)]^{-\mu/\rho}$ $f = Y/L, \; k = K/L$	CES (Constant elasticity of substitution)
Kaldor (1962)	$\Delta f / f = g(\Delta k / k)$	Technological progress function
Arrow (1962)	$L = \lambda(K) = bK^{-n}$ $Y = aK[1 - (1 - \frac{L}{cK^{1-n}})^{1/1-n}], \quad c = b/1-n$	Learning by doing

Technical change was assumed to change exogenously

↓

Why firms innovate?

↓

Endogenous growth theory

Innovation and technical change are determined **endogenously**

Kenneth J. Arrow

Aug. 23, 1921 (age 91)

United States

Stanford University

Macroeconomics

General equilibrium theory

Social choice theory

1972 Novel prize in Economics

Fig. 23. Chronology to the Initial Efforts to Endogenous Technological Improvement.

(2) Learning, Diffusion and Induced Innovation

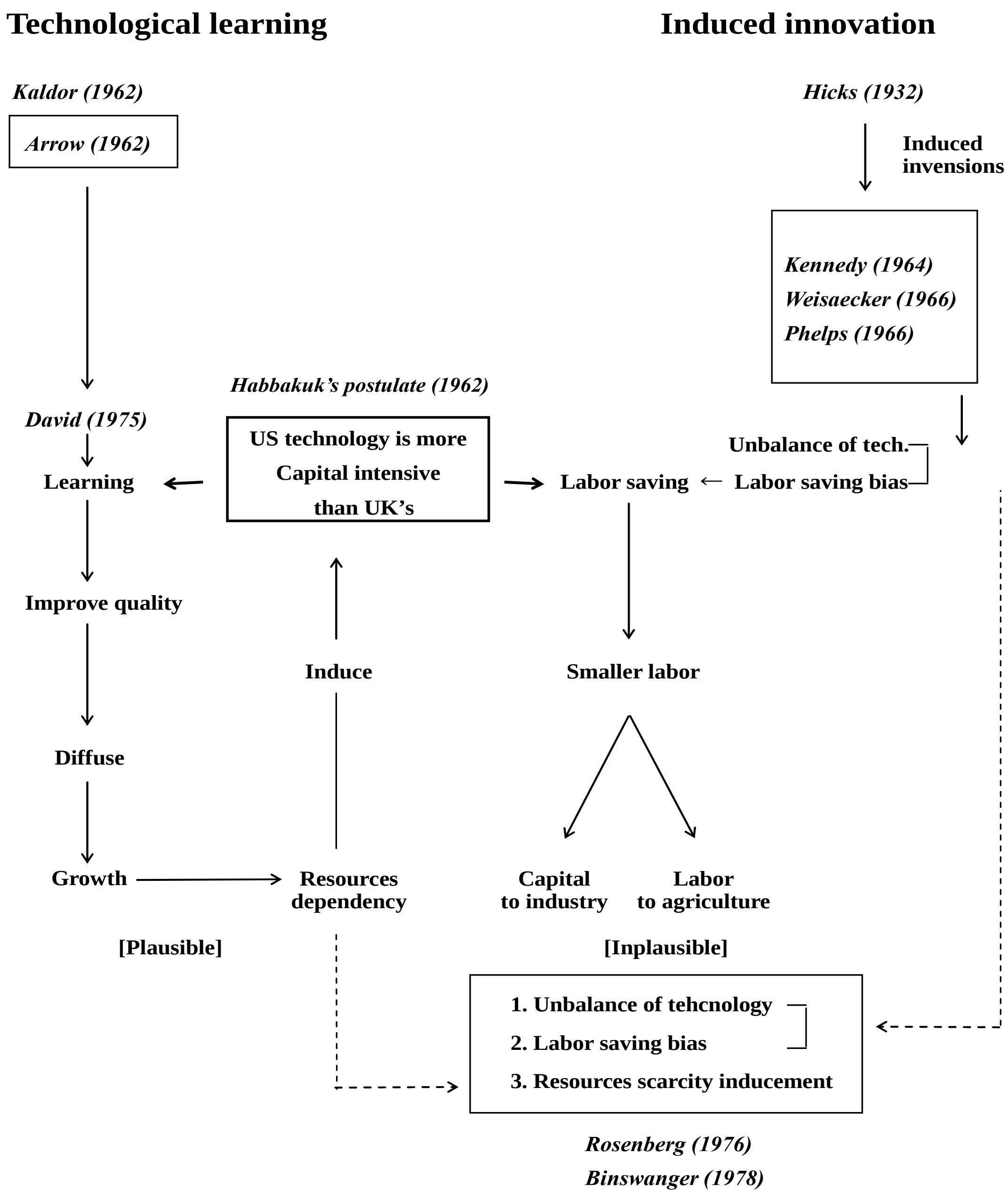


Fig. 24. Technological Learning, Diffusion and Induced Innovation.

(3) Dynamism between Innovation, Diffusion, Learning and Spillover

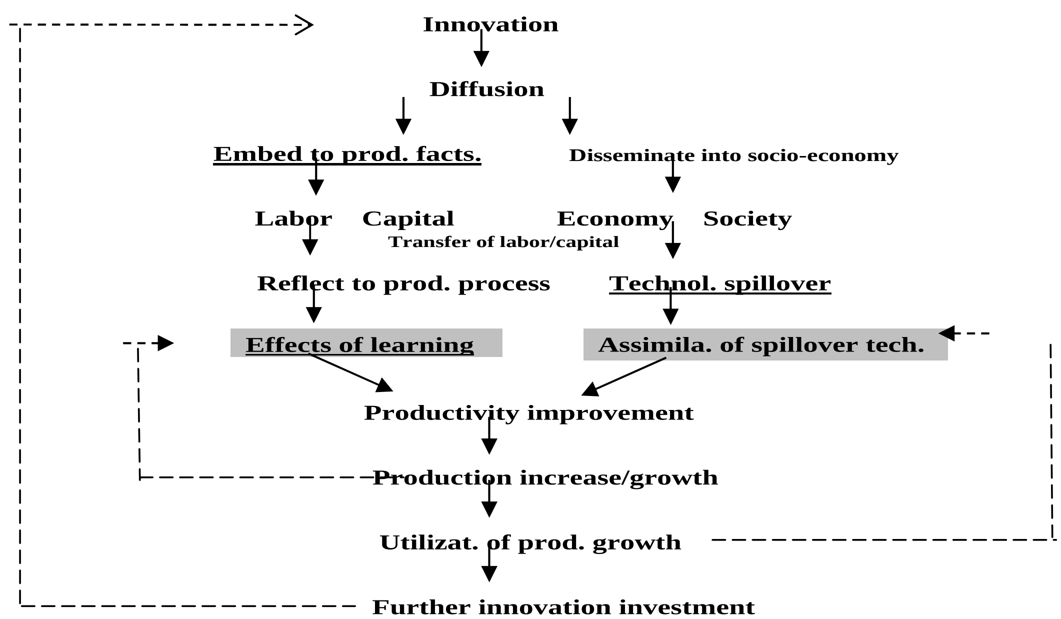


Fig. 25. Innovation, Diffusion, Learning and Spillover Dynamism.

Effects of learning

1962 Kaldor $\triangle(Y/L)/(Y/L) = F(\triangle(K/L)/(K/L))$ *Technical Progress Function*

1962 Arrow $L = \lambda(K) = b\ K^{-a}$ *Learning by doing*

Embed to production factors

1964 Nelson (Capital) *Vintage Model*

1967 Denison (Labor) *Quality of Labor*

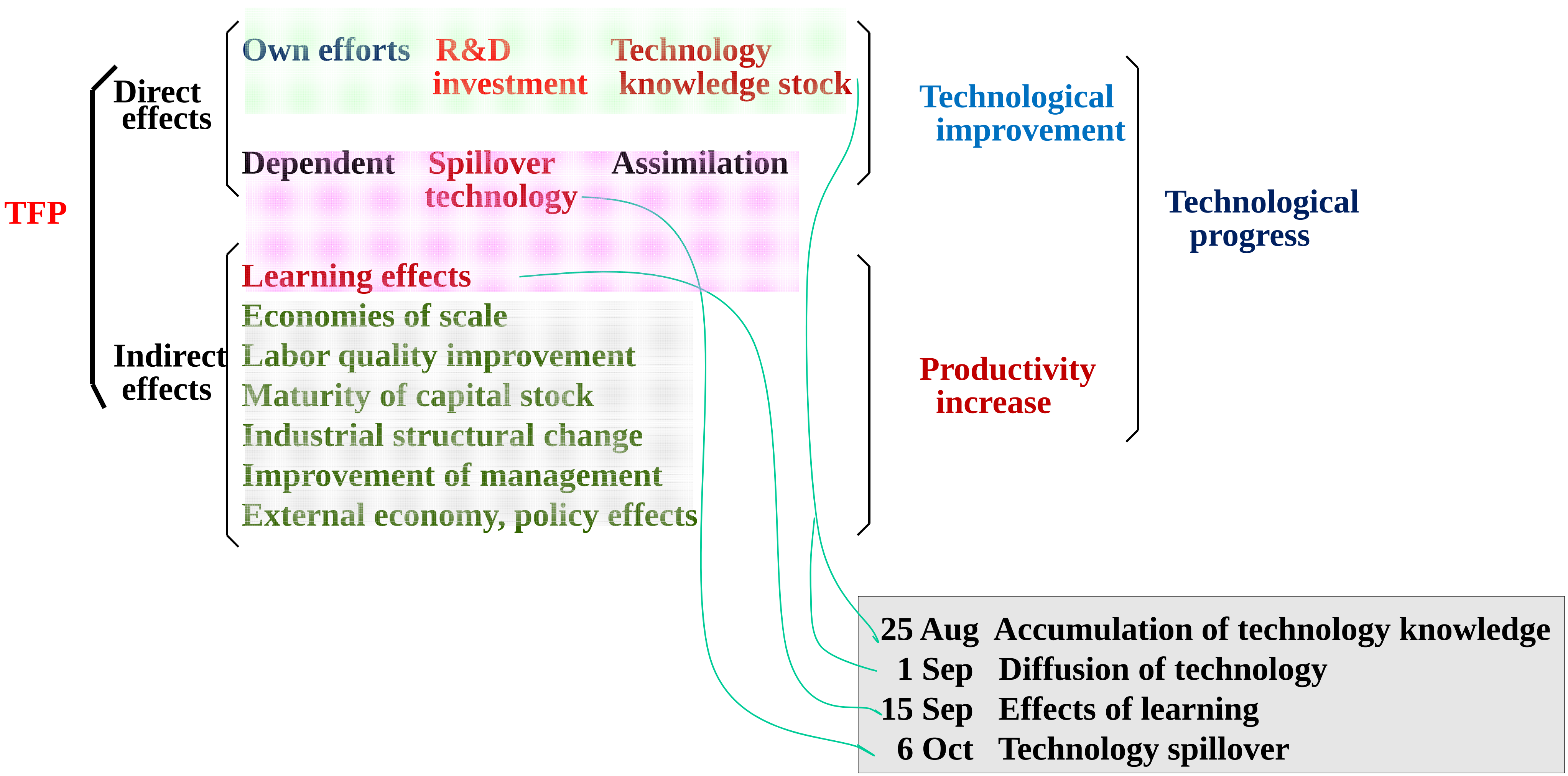
Technology spillover

1979 Griliches *Technology Distance*

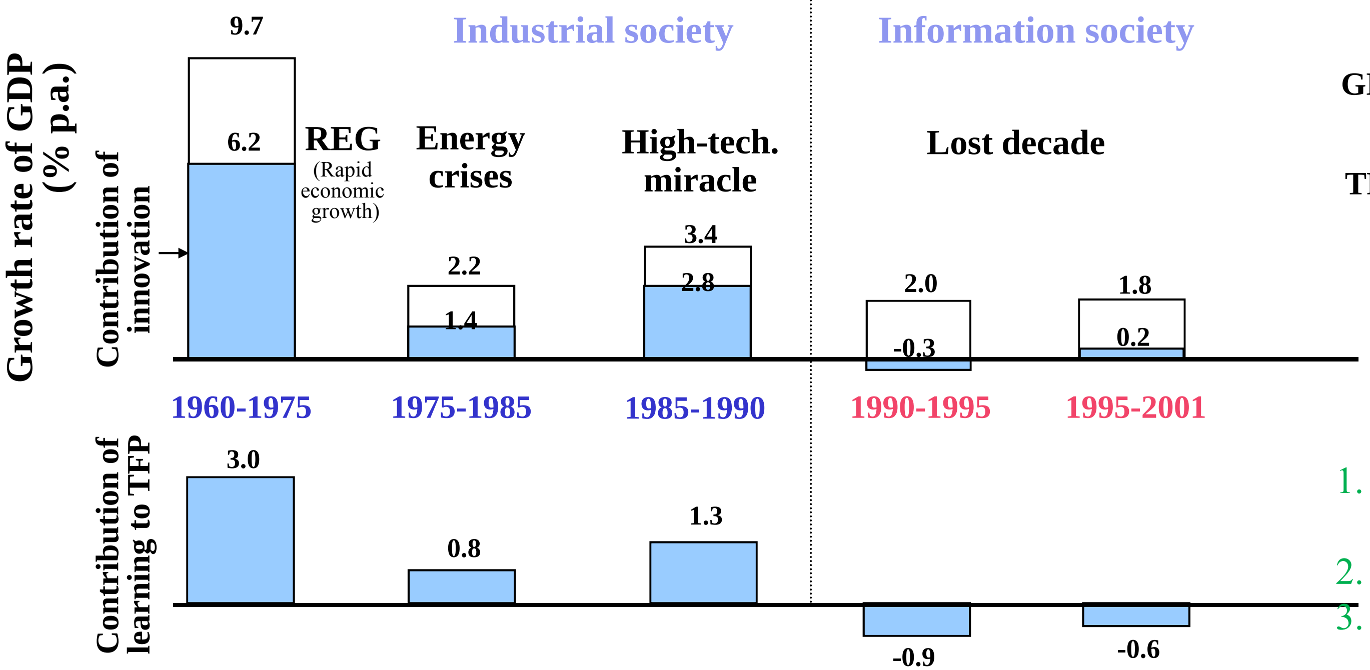
1982 Scherer

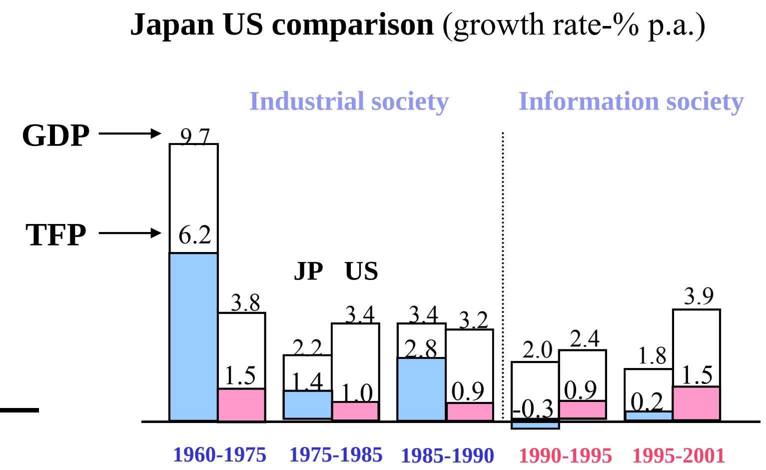
1986 Jaffe *Proximity*

(4) Contribution of Learning to TFP Growth



(5) Japan's Unique X Efficiency Depending on Learning





1. Japan accomplished conspicuous X-efficiency during the period of industrial society.
2. Which contributed to increase MPT.
3. This can be attributed to Japan's intensive learning efforts.

Fig. 26. Trend in Contribution of Learning to TFP and Consequent GDP Growth Rate in Japan (*1960-2001*) – % p.a.

Japan's TFP composition		1960-1973	1975-1985	1985-1990	1990-1995	1995-2001
	GDP (TFP)	9.7 **(6.2)**	2.2 **(1.4)**	3.4 **(2.8)**	2.0 **(-0.3)**	1.8 **(0.2)**
	Direct effect of R&D investment	*1.0*	*0.2*	*0.5*	***0.2***	***0.3***
	Indirect effect of R&D investment	*2.2*	*0.4*	*1.0*	***0.4***	***0.5***
	Learning and spillover effects	***3.0***	***0.8***	***1.3***	***- 0.9***	***- 0.6***

Source: Watanabe (2005).

MPT			
	Japan	**0.6**	**1.1**
	U S	**0.4**	**0.3**

Learning led to high MPT

4.2 Theory of Learning by Doing

(1) Learning Incorporated Production Function

Arrow considered requirement of labor decreases as capital (K) increases with a following function:

$$L = \lambda(K) = bK^{-n} \qquad (35)$$

b: Coefficient > 0, n: Leaning coefficient > 0

Based on this analysis Arrow developed the following production function:

$$V = aK\left[1 - \left\{1 - \frac{L}{cK^{\frac{1}{1-n}}}\right\}^{\frac{1}{1-n}}\right] \approx aK\left[1 - e^{-\left(\frac{L}{b}\right)^{\pi}}\right] \quad (n \neq 1) \qquad (36)$$

$$= aK\left[1 - e^{-\frac{L}{b}}\right] \quad (n = 1)$$

a: Production capacity corresponding to $K > 0$

$$c = \frac{b}{1-n} > 0$$

$$\pi = 1 + \frac{1}{n}\frac{1}{(1-n)} > 0 \qquad (37)$$

$$K = \left(\frac{L}{b}\right)^{-1/n},$$

$$\frac{L}{cK^{1/1-n}} = \frac{1-n}{b}\frac{L}{\{(\frac{L}{b})^{-1/n}\}^{1/1-n}}$$

$$= (1-n)\left(\frac{L}{b}\right)^{1+\frac{1}{n}\frac{1}{1-n}} \equiv (1-n)\left(\frac{L}{b}\right)^{\pi}$$

$$1 - \frac{L}{cK^{1/1-n}} \approx e^{-(1-n)(\frac{L}{b})^{\pi}}$$

$$V = aK\left[1 - \{e^{-(1-n)(\frac{L}{b})^{\pi}}\}^{\frac{1}{1-n}}\right]$$

$$= aK(1 - e^{-(\frac{L}{b})^{\pi}})$$

(2) Increasing Returns to Scale Behavior

Above production function demonstrates increasing returns to scale.

e.g., in case n=1 (same as the case $n \neq 1$),

$$V = aK(1 - e^{-L/b}) \qquad \ln V \approx \ln a + \ln K - e^{-L/b} \qquad \Delta V/V = \Delta K/K + (\Delta L/b)e^{-L/b} > \Delta K/K \quad (\text{when } \Delta L > 0)$$

While in general production function, $\Delta V/V = \alpha\Delta L/L + \beta\Delta K/K < \alpha\Delta K/K + \beta K/K = (\alpha+\beta)\Delta K/K = \Delta K/K$ (when $\Delta K/K > \Delta L/L$)

In case of $n \neq 1$, $\ln V \approx \ln a + \ln K - e^{-(L/b)^{\pi}}$, $\dfrac{\Delta V}{V} = \dfrac{\Delta K}{K} + (L/b)^{\pi}(\Delta L/L)e^{-(L/b)^{\pi}} > \dfrac{\Delta K}{K}$

Appendix: Mathematical Development of Arrow's Learning Incorporated Production Function

$$V = F(L, K), \quad L = L(K) \qquad 1$$

$$L = L(K) = \int_{K_0}^{K} \lambda(K)dK, \quad \lambda(K): \text{Number of labor} \qquad 2$$

$$V = \int_{K_0}^{K} \gamma(K)dK, \qquad \gamma(K): \text{Production capacity} \qquad 3$$

$$\Lambda(K) \equiv \int \lambda(K)dK \qquad 4$$

$$\Gamma(K) \equiv \int \gamma(K)dK \qquad 5$$

$$L = \Lambda(K) - \Lambda(K_0) \qquad 6$$

$$V = \Gamma(K) - \Gamma(K_0) \qquad 7$$

From 6 $\Lambda(K_0) = \Lambda(K) - L, \quad K_0 = \Lambda^{-1}[\Lambda(K) - L]$ 8

Substitute 8 for 7 $V = \Gamma(K) - \Gamma[\Lambda^{-1}\{\Lambda(K) - L\}]$ 9

Provided that $\gamma(K) \equiv a \quad (a > 0)$ 10

$\lambda(K) \equiv bK^{-n} \quad b > 0, n > 0$ 11

$$\Gamma(K) = \int_{K_0}^{K} \gamma(K) = \int_{K_0}^{K} adK = aK \quad (K_0 = 0) \qquad 12$$

$$\Lambda(K) = \int_{K_0}^{K} \lambda(K) = \int_{K_0}^{K} bK^{-n}dK = \frac{b}{1-n}K^{1-n} \equiv cK^{1-n} \quad c \equiv \frac{b}{1-n} > 0 \quad (n \neq 1) \qquad 13$$

$$= \int_{K_0}^{K} \frac{b}{K}dK = b\ln K \quad (n = 1) \qquad 14$$

From 13 $\Lambda\left[\left(\frac{K}{c}\right)^{\frac{1}{1-n}}\right] = K, \Lambda\left[\left\{\frac{(\Lambda(K)-L)}{c}\right\}^{\frac{1}{1-n}}\right] = \Lambda(K) - L, \quad \Lambda^{-1}\{\Lambda(K)-L\} = \left\{\frac{\Lambda(K)-L}{c}\right\}^{\frac{1}{1-n}} = \left\{\frac{cK^{1-n}-L}{c}\right\}^{\frac{1}{1-n}}$ 15

Substitute 15 for 9 $V = aK - a\left\{\frac{cK^{1-n}-L}{c}\right\}^{\frac{1}{1-n}} = aK - a\left\{\frac{K^{1-n}(cK^{1-n}-L)}{cK^{1-n}}\right\}^{\frac{1}{1-n}} = aK - aK\left[1-\left\{\frac{L}{cK^{1-n}}\right\}\right]^{\frac{1}{1-n}} = aK\left[1-\left\{1-\frac{L}{cK^{1-n}}\right\}^{\frac{1}{1-n}}\right] \quad (n \neq 1)$ 16

When n = 1, from 14, $\Lambda(e^{\frac{K}{b}}) = K, \quad \Lambda(e^{\frac{\Lambda(K)-L}{b}}) = \Lambda(K) - L, \quad \Lambda^{-1}\{\Lambda(K)-L\} = e^{\frac{\Lambda(K)-L}{b}},$ 17

Substitute 17 for 9 $Y = aK - ae^{\frac{\Lambda(K)-L}{b}} = aK - ae^{\frac{\Lambda(K)}{b}}e^{\frac{-L}{b}} = aK - ae^{\frac{b\ln K}{b}}e^{\frac{-L}{b}} = aK(1 - e^{\frac{-L}{b}})$ 18

$$V = F(L, K)$$

Learning effects

$$L = \lambda(K) = bK^{-n} \qquad b, n > 0$$

$$V = aK\left[1 - \left(1 - \frac{L}{cK^{1-n}}\right)^{\frac{1}{1-n}}\right] \quad (n \neq 1) \qquad c = \frac{b}{1-n} > 0$$

$$= aK\left[1 - e^{-\frac{L}{b}}\right] \quad (n = 1)$$

$$\frac{\Delta V}{V} > \frac{\Delta K}{K}$$

Increasing returns to scale

Λ^{-1}: *reverse function*

Substitute $(K/c)^{1/1-n}$ *for* K *in* 13 *then substitute* $\Lambda(K) - L$ *for* K

4.3 Learning Curve

(1) Learning Coefficient

Incorporation of the effects of learning in production function can be examined by learning curve (or experience curve) that illustrates correlation between cumulative production and prices.

Asuume that prices of product P and cumulative production $\boldsymbol{Y^*}$ **(=Σ*Y*)**, learning curve can be depicted by the following equation:

$$\boldsymbol{P = A \cdot Y^{*-\lambda}} \tag{38}$$

where A: scale factor, λ: learning coefficient.

(2) Learning Rate (LR)

Given that $P = P(\boldsymbol{Y^*})$,

$$LR = -[P(2Y^*) - P(Y^*)]/P(Y^*) \tag{39}$$

Price declines by LR % for each doubling of cumulative production

(3) Progress Ratio (PR)

$$PR = P(2Y^*)/P(Y^*) = 2^{-\lambda} = 1 - LR \tag{40}$$

Speed of learning

$$P(2Y^*)/P(Y^*) = A2Y^{*-\lambda}/AY^{*-\lambda} = 2^{-\lambda} = 1-LR$$

(4) Measurement of Learning Effects

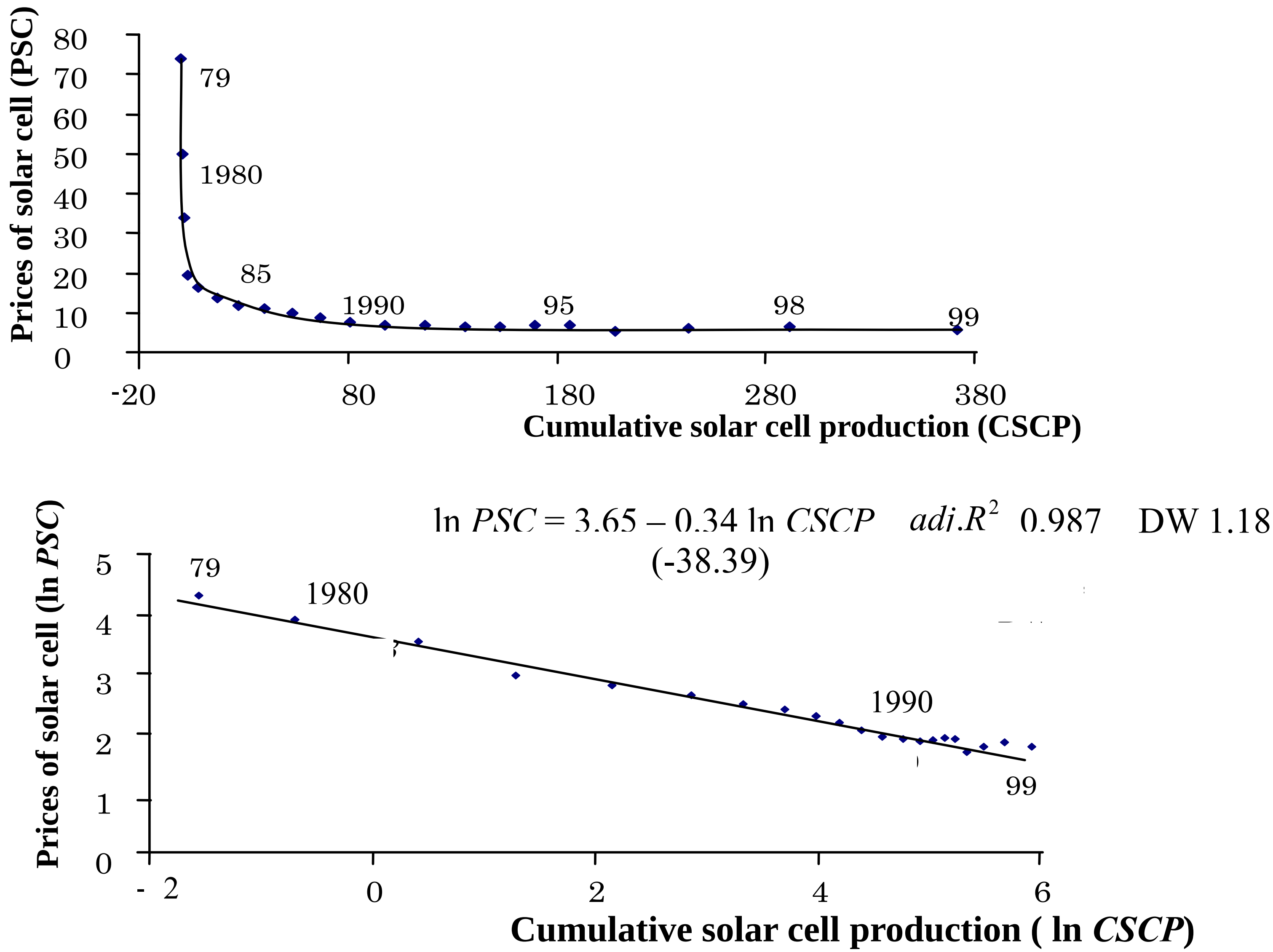


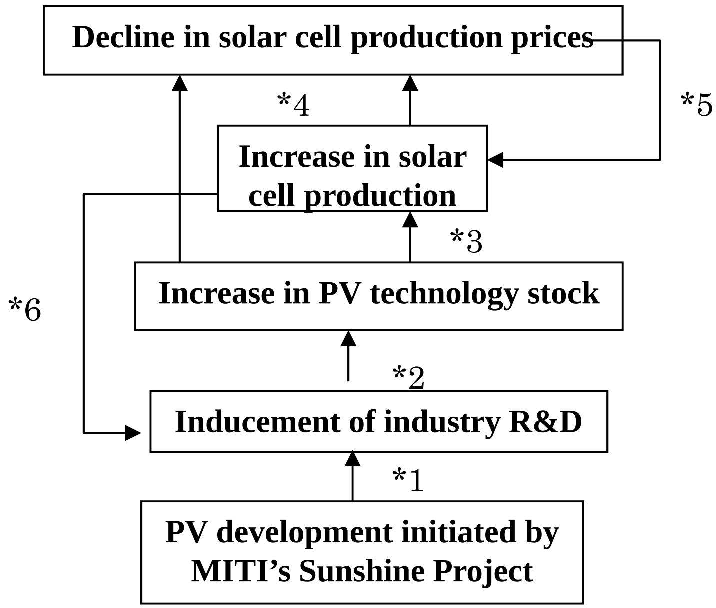
Fig. 27. Learning Effects of PV Development in Japan's Firms *(1979-1999).*

Table 7 Learning Coefficients in Japan's Leading PV Producing Firms *(1976-1990)*

$$PSC = A \cdot CSCP^{\lambda}$$

		λ	t-value	$adj.R^2$	DW	
Whole industry		-0.35	(-22.80)	0.981	1.42	1976－1990
	[	-0.37	(-73.88)	0.997	1.60	1976－1995]
PV firms	A	-0.12	(-28.31)	0.988	2.09	1976－1990
	B	-0.25	(-25.92)	0.988	2.63	1976－1990
	C	-0.29	(-7.47)	0.871	1.49	1976－1990
	D	-0.69	(-18.99)	0.978	2.53	1981－1990
	E	-0.41	(-9.34)	0.911	1.77	1976－1990
	F	-0.31	(-14.46)	0.962	1.52	1976－1990

PSC: Prices of solar cell (fixed prices), CSCP: Cumulative solar cell production.
A-F: leading PV firms including Sanyo, Kyocella, Sharp, Kanegafuchi chemicals, Fuji electrics and Hitachi.



PSC: **Prices of solar cell**

SCP: **Production of solar cell**

TPV: **Technology stock of PV**

PVR: **PV R&D by industry**

SSPV: **R&D budget in the Sunshine Project**

Pey**: Relative energy prices**

	Equation	$adj.R^2$	*DW*
*1	$\log(PVR) = 1.37 + 0.77 \log(SSPV_{-1})$ (29.35)	0.979	1.31
*2	$TPVt = PVR_{t-m} + (1-\rho)TPV_{t-1}$ m = 2.8 年, $\rho = 20.3\%$		
*3	$\log(SCP) = -8.26 + 2.19 \log(TPV) + 5.94 \log(Pey)$ (35.48) (13.60)	0.985	1.75
*4	$\log(PSC) = 11.97 - 0.97 \log(TPV) - 1.04 \log(Pey)$ (-39.51) (-5.59) Effects of technology stock and energy prices	0.988	1.53
	$\log(PSC) = 130.87 - 0.06\,\text{Year} - 0.31 \log(SCP)$ (-9.32) (-18.87) Effects of learning and economies of scale	0.995	1.38
*5	$\log(SCP) = 16.97 - 2.02 \log(PSC_{-1}) + 2.98 \log(Pey_{-1})$ (-58.73) (13.61)	0.995	1.25
*6	$\log(PVR) = 3.59 + 0.43 \log(SCP)$ (25.96)	0.973	1.03

Fig. 28. Virtuous Cycle of Japan's PV Development *(1976-1995).*

4.4 Market Learning

(1) Dynamic Learning Coefficient

Learning function according to diffusion of innovative good *Y*

$$P = A \cdot Y^{-\lambda} \qquad (38')$$

P: fixed prices of PCs; ***A***: scale coefficient; ***Y***: cumulative production; ***λ***: learning coefficient.

Learning coefficients *λ in the market learning* are a series of continual coefficients during production, distribution and usage phases when they are diffused, these coefficients are expressed as function of *t* as:

$$\lambda(t) = \lambda(\lambda_1(t), \lambda_2(t), \lambda_3(t), \cdots, \lambda_n(t)) \approx \sum_{i=0}^{n} a_i t^i \qquad (39)$$

b_i is the *ith* coefficient of column *t*.

These dynamic learning coefficients λ_1, λ_2, … λ_n are learning results regarding as effects of "marketing learning" during a serial process of production, distribution and usage.

$$\ln P = \ln A - \sum_{i=0}^{n} a_i t^i \ln Y + \varepsilon \qquad (38'\text{-}2)$$

ε is disturbance column which is independent from $\lambda(t)$.

$\lambda(t)$ can be computed by taking differentiation of equation (38'-2) by *lnY*.

$$\lambda = \frac{\partial \ln P}{\partial \ln Y} = \sum_{i=0}^{n} a_i t^i \qquad (39)$$

(2) Dynamic Learning Coefficient of PCs: An Empirical Analysis

Dynamic learning coefficient of China's PC λ is measured by the following equation with the usage of fixed prices of PCs:

$$\ln P = \ln A - \lambda(t) \ln PC_T + dD_{81} = \ln A - \sum_{i=0}^{n} a_i t^i \ln PC_T + dD_{81}$$

Table 8 Comparison of Dynamic Learning Coefficient of China's PCs *(1982-2002)*

	ln*A*	a_0	a_1	a_2	a_3	a_4	a_5	*d*	*adj.* R_2	*DW*	*AIC*
n = 3	11.79 (3.37)	0.37 (3.63)	-0.029 (-1.70)	$3.2*10^{-3}$ (2.79)	$-8.7*10^{-5}$ (3.35)			0.30 (3.37)	0.996	1.38	-51.79
n = 4	12.01 (122.99)	0.84 (5.35)	-0.17 (-3.98)	0.020 (4.07)	$-9.3*10^{-4}$ (-3.82)	$1.5*10^{-5}$ (3.47)		0.27 (3.93)	0.997	2.03	-62.76
n = 5	11.89 (85.61)	-0.50 (1.48)	0.033 (0.26)	$-3.3*10^{-3}$ (0.15)	$-9.5*10^{-4}$ (-0.56)	$5.7*10^{-5}$ (0.88)	$1.0*10^{-6}$ (1.12)	0.26 (3.85)	0.997	1.29	-62.65

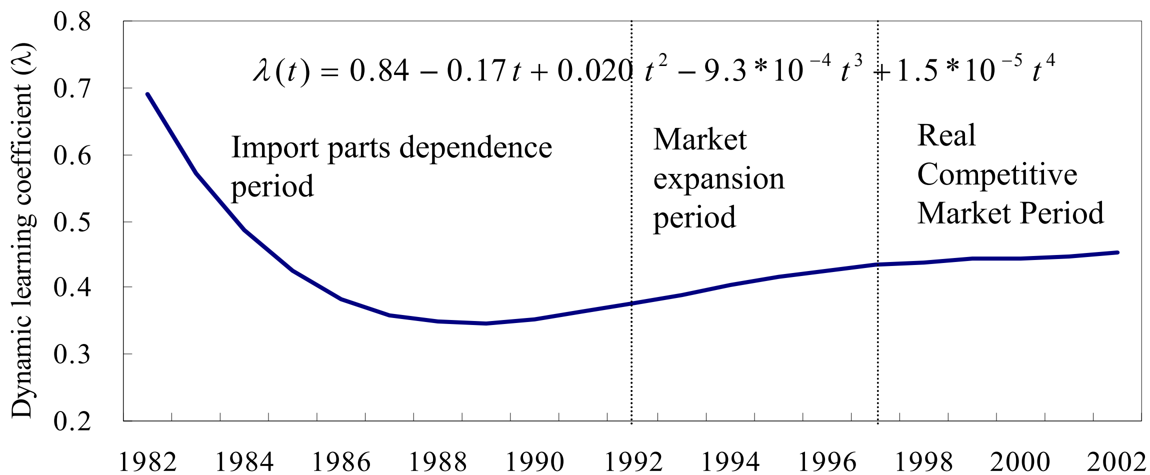


Fig. 29. Trend in Dynamic Learning Coefficient of China's PCs *(1982-2002)*.

Table 9 Comparison of Dynamic Learning Coefficient of Japan's PCs *(1982-2002)*

$$\ln P = \ln A - \lambda(t) \ln PC_T + dD_{82} = \ln A - \sum_{i=0}^{n} a_i t^i \ln PC_T + dD_{82}$$

				a_2	a_3	a_4	d	*adj.* R^2	*DW*	*AIC*
$n = 2$	1.91 (1.04)	0.08 (0.20)	-0.018 (-1.08)	$2.2*10^{-4}$ (0.52)			0.27 (1.04)	0.923	0.56	-1.73
$n = 3$	7.66 (5.90)	-1.40 (-4.53)	0.11 (5.13)	$-8.5*10^{-3}$ (-6.34)	$2.1*10^{-4}$ (6.60)		0.68 (4.74)	0.979	1.38	-28.30
$n = 4$	5.63 (2.35)	-0.84 (-1.33)	0.039 (0.52)	$-6.8*10^{-5}$ (-0.01)	$-2.5*10^{-4}$ (-0.55)	$8.9*10^{-6}$ (1.01)	0.47 (1.88)	0.979	1.29	-27.81

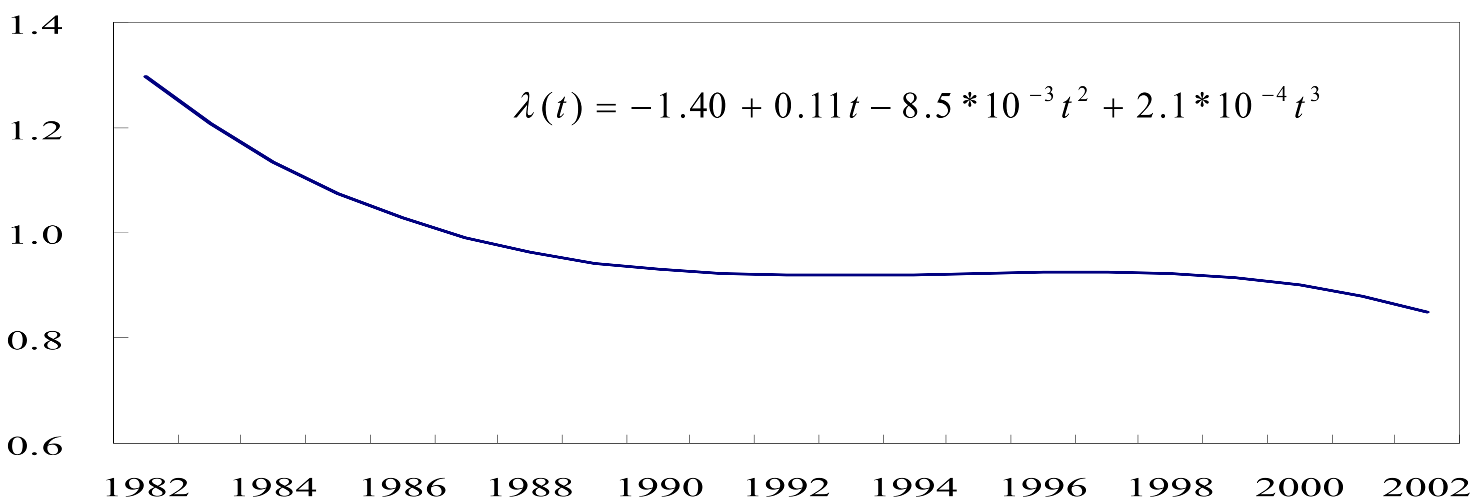


Fig. 30. Trend in Dynamic Learning Coefficient of Japan's PCs *(1982-2002).*

(i) Japan's Dynamic Learning Coefficients of PCs

The value of Japan's coefficient is higher than that of China's, but it decreases continually.

(ii) China's Dynamic Learning Coefficients of PCs

a. The value of coefficient was in the bottom in 1980s, and it increased in 1990s near to the value of Japan's;

b. It increases when the effect of technology spillover began to decrease at the beginning of 1990s;

c. That is, "Technology of China's PCs was accelerated by marketing learning effects after full enjoyment of spillover technology during market expansion period ."

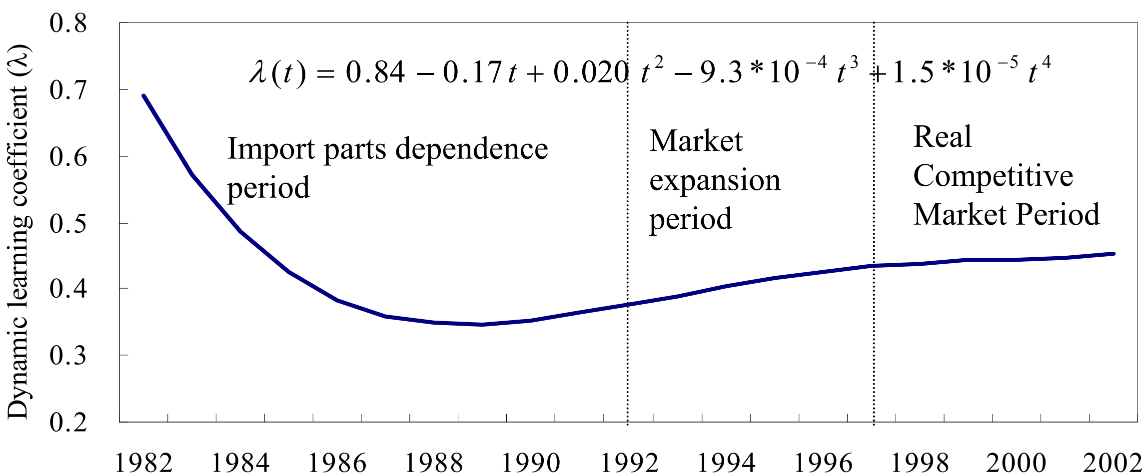


Fig. 31. Trends in Dynamic Learning Coefficient of China's PCs *(1982-2002)*.

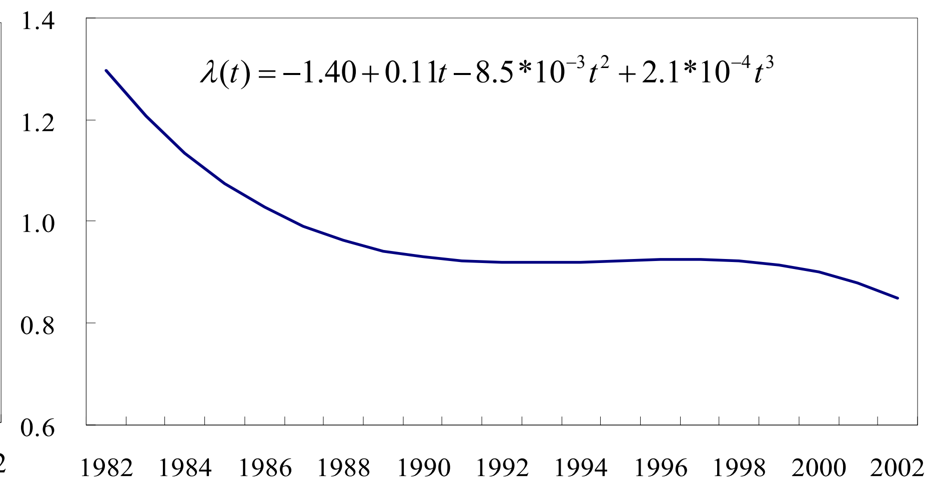


Fig. 32. Trends of Dynamic Learning Coefficient of Japan's PCs *(1982-2002)*.

Interpretation by the Empirical Analysis

(1) PCs prices decreased rapidly when entering into market expansion period;

(2) China's government reduced tariff, abolished the system of import permission, the protection ordinance of computer software was executed, and joint-production was permitted (it was restricted to foreign sale by themselves in domestic market) during 1991, 1992. Foreign producers reduced their prices to expand their sales share in the market.

(3) China's producers reduced prices to opposite foreign producers because of poor functionality. However, it is limited to only depend on the effect of technology spillover, it should expand range of learning including setting up new factories, production and distribution.

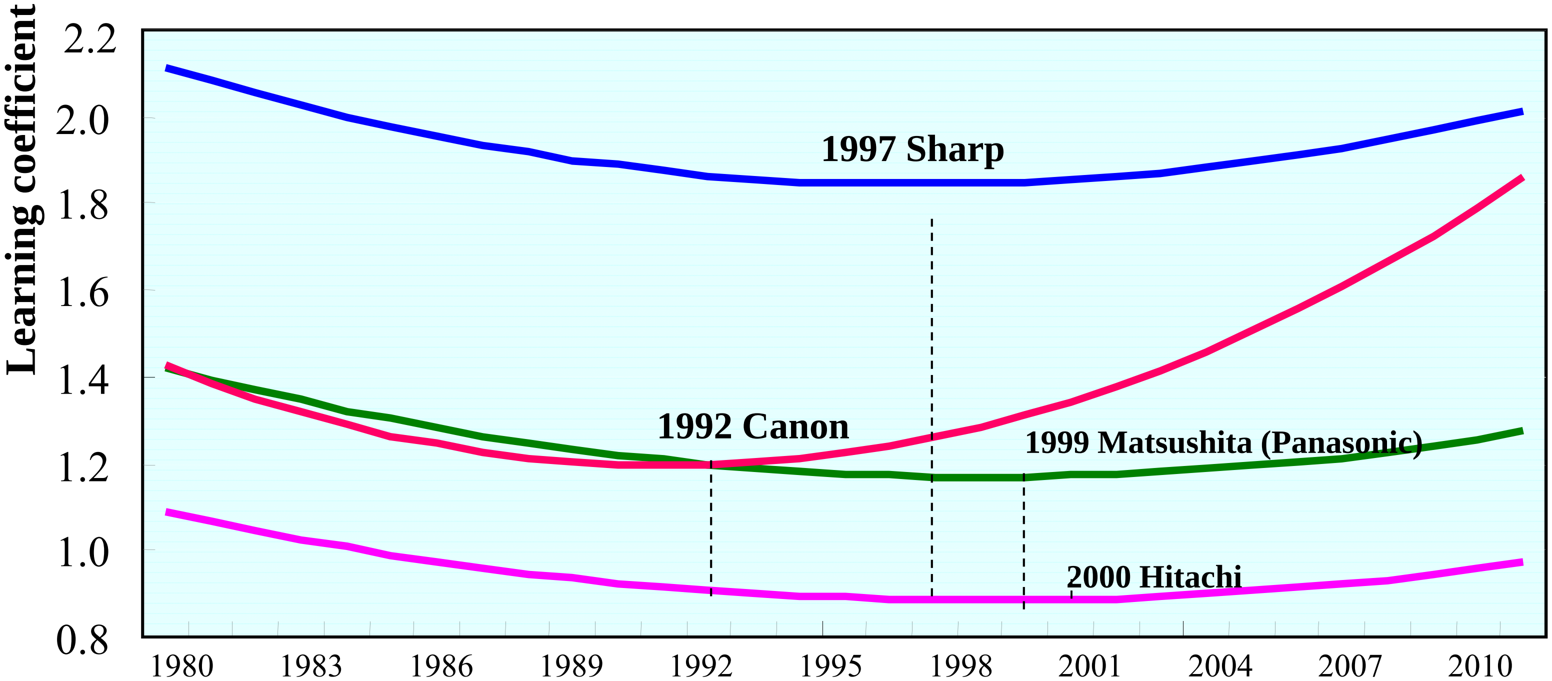
(4) Lenovo's PCs had No.1 share of China's domestic market through the marketing learning in 1996.

4.5 Hybrid Management of Technology: Learning vs NIH

(1) Learning Efforts of Leading High-Technology Firms

1. While learning coefficient has declined in Japan's leading firms due to puffing-up of the success in the1980s (Not Invented Here: NIH syndrome), certain high technology firms have maintained intensive learning.

2. Canon can be one of the typical example which learned system LSI, SCM and cell production system from external market.



	Inflection year	Learning coefficient (2004/1990)
Canon	1992	1.25
Sharp	1997	1.01
Panasonic	1999	0.97
Hitachi	2000	0.94

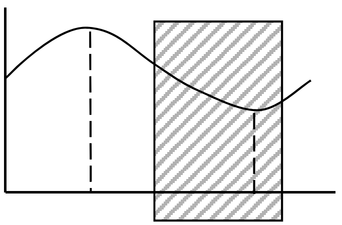


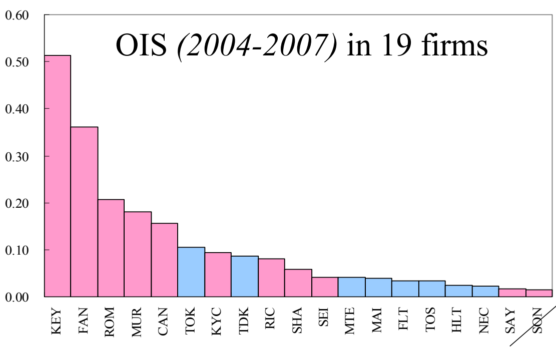
Fig. 33. Learning Coefficients in 4 Electrical Machinery Firms *(1980-2003).*

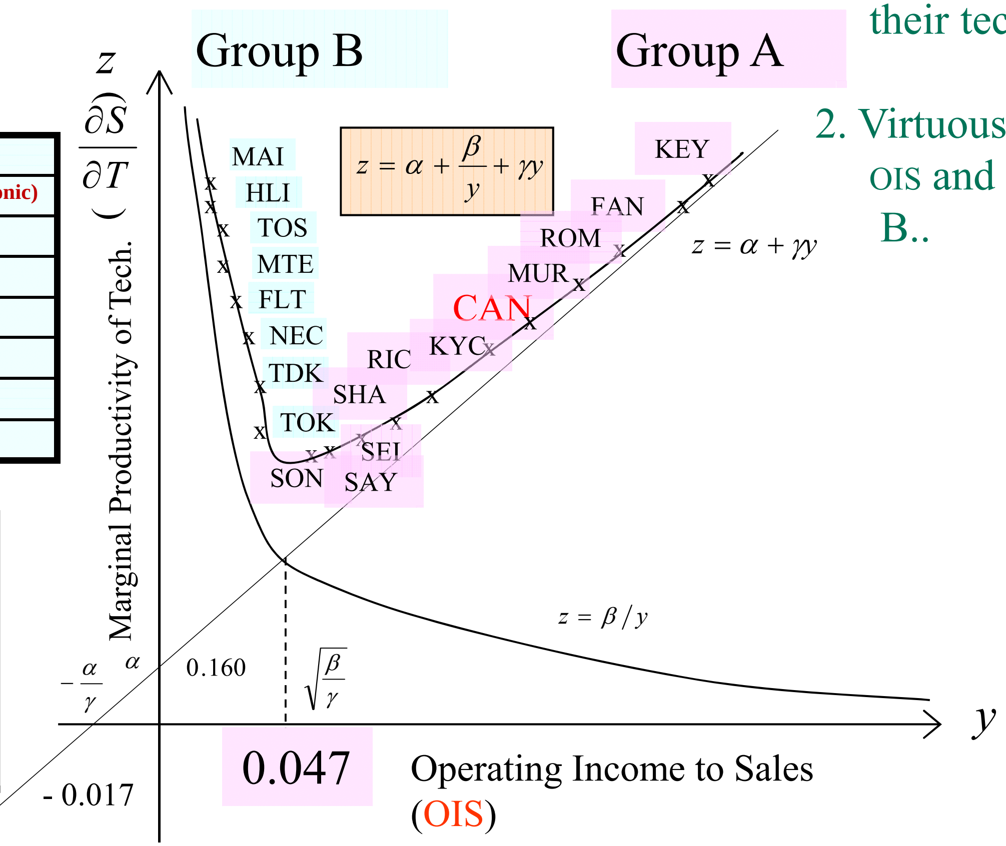
(2) Bi-polarization of Technopreneurial Trajectory

1. Japan's leading electrical machinery firms demonstrate bi-polarization in their technopreneurial trajectories.
2. Virtuous cycle in Group A between OIS and MPT, while vicious in Group B..

Group B

12	**HLT**	**Hitachi**
13	**MAI**	**Matsushita (Panasonic)**
14	NEC	NEC
15	TOS	Toshiba
16	FLT	Fujitsu
17	MTE	Mitsubishi
18	TDK	TDK
19	TOK	Tokyo Electron





Group A

1	**CAN**	**Canon**
2	**SHA**	**Sharp**
3	RIC	Ricoh
4	FAN	Fanuc
5	SEI	Seiko Epson
6	SAY	Sanyo
7	SON	Sony
8	MUR	Murata
9	ROM	Rohm
10	KYC	Kyocera
11	KEY	Keyence

Fig. 34. Technoprenurial Positions of 19 Electrical Machinery Firms *(2001-2004).*

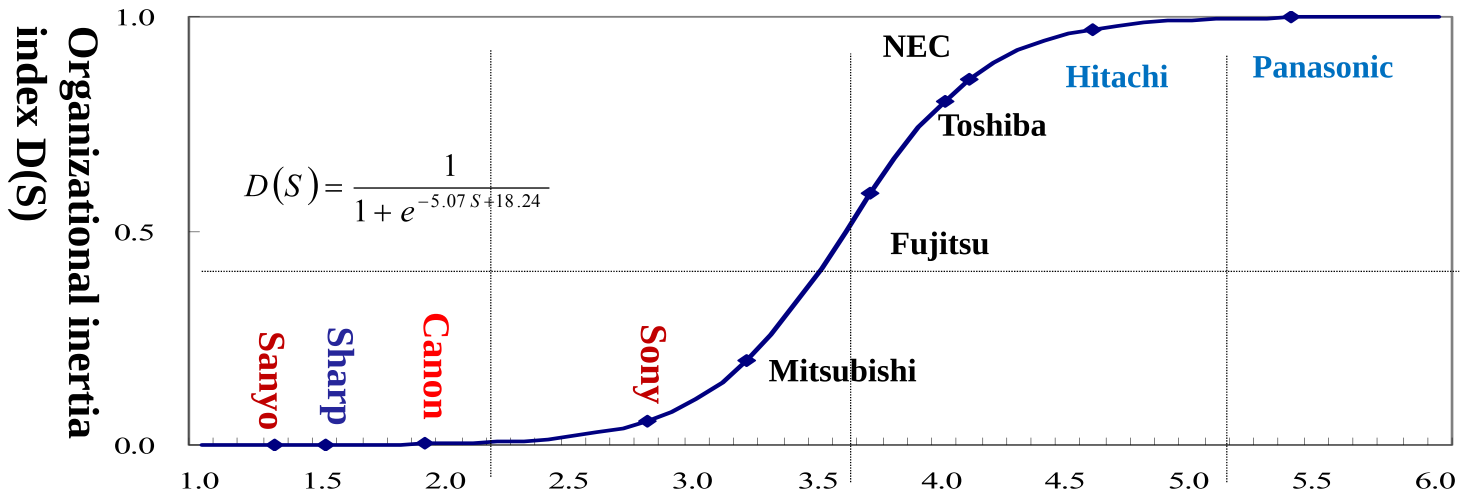
Firms technology progress W depends on the ratios of (i) R&D and operating income X and (ii) operating income and sales Y.

$W = F(X, Y)$ Taylor expansion to the secondary term, $\ln W = a + b \ln X + c \ln Y + d \ln X \cdot \ln Y$ (a, b, c, d: coefficients)

$\ln W, \ln X, \ln Y$ → *growth rate of TFP*, R/OI (R&D expenditure to OI), OI/S (operating income to sales)

$$\frac{\Delta TFP}{TFP} = a + b\frac{R}{OI} + c\frac{OI}{S} + d\frac{R}{OI}\cdot\frac{OI}{S} = a + b\frac{1}{OI/R} + c\frac{OI}{R}\cdot\frac{R}{S} + d\frac{R}{S} \Rightarrow \frac{\partial S}{\partial T} = \alpha + \frac{\beta}{OI/S} + \gamma\frac{OI}{S}$$

Organizational Inertia by Firm Size



Sales *S* (1995 fixed prices: trillion Yen)

Organizational Inertia Index

$$D(S)=\frac{1}{1+e^{\ln\left(\frac{\eta}{1-\eta}\right)\cdot\left(\frac{1}{S_1-S_0\pm\varepsilon}\right)S-\ln\left(\frac{\eta}{1-\eta}\right)\cdot\left(\frac{S_0\pm\varepsilon}{S_1-S_0\pm\varepsilon}\right)}}$$

$$=\frac{1}{1+e^{-5.07\,S+18.24}}$$

1995-1998

S_0: 2.7, S_1: 5.1, ε: 0.9, η: 0.0005

Fig. 35. Organizational Inertia Corresponding to Firm Size in Japan's Leading 10 Electrical Machinery Firms *(1995-1998).*

(i) Differences of the endeavor to technological diversification challenge due to organizational inertia by firm size

$$\ln TDI = \alpha + \beta_1 \ln R/S + \beta_2 D(S) \ln R/S$$

TDI : Technological diversification index, R/S : R&D intensity.

(ii) D(S) can be depicted by a logistic growth function.

(3) Hybrid Management -*Fusing East and West*

(i) Japan is emerging from years of sluggish growth (Group A firms).

(ii) Its firms appear to have produced something.

(iii) Management method that incorporates lessons from US firms (*West*) while preserving the practices that once made Japanese firms famous (*East*).

International Herald Tribune
Thursday, August 31, 2006

Made in corporate Japan: New approach to business

Hybrid management fuses east and west

by Patrick L. Smith

TOKYO: Now that Japan is emerging from years of sluggish growth, its corporations appear to have produced something few executives or analysts expected even a few years ago: a management method that incorporates lessons from American companies while preserving the practices that once made Japanese companies famous.

Even a few years ago, it was widely expected that recession and the mounting pressures of global competition would force corporate Japan to surrender such traditions as loyalty to employees and suppliers, responsibility to stakeholders and the like. Prominent analysts in the Tokyo offices of firms like Goldman Sachs and Merrill Lynch were among the most enthusiastic exponents of this view.

But a funny thing happened on the way to the Japanese recovery. What was almost universally written off as Japan's "lost decade" has left this nation's leading companies stunningly competitive while still holding to the corporate ethos for which they have long been known.

"A lost decade? Nonsense. A painful transition? Yes," said James Abegglen, chairman of the Asia Advisory Service and an expert on Japanese corporate organization. "Companies have done what had to be done to redesign themselves. They've retained basic values while changing what had to be changed."

With Japan now recovering, what is emerging here is a hybrid management strategy that is partly Japanese and partly Western, or a kind of "third way" in the corner office. Executives, management experts and consultants say this is producing a reinvigorated corporate sector that is more focused on primary businesses, better able to maximize human capital, more dedicated to advanced technologies such as robotics and second to none in cost-effectiveness.

The corporate ideal as this hybrid takes hold here is Toyota, Japan's leading auto maker. Company executives, notably the chairman, Hiroshi Okuda, have long been known for their cutting-edge management methods even as

JAPAN, Continued on Page 14

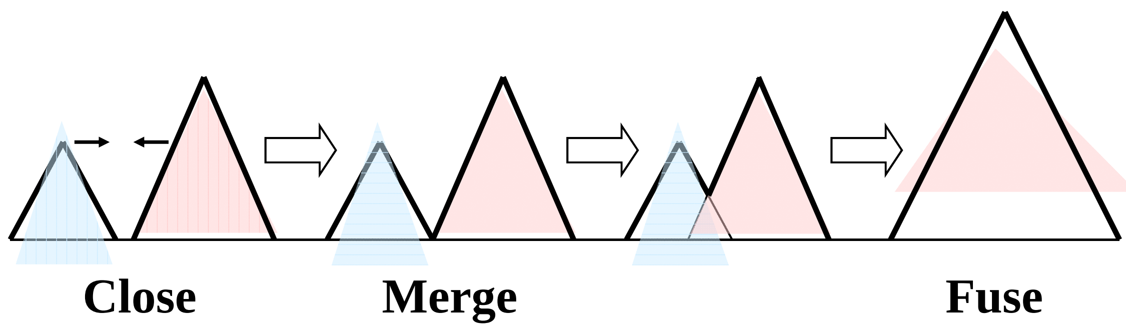


Fig. 43. Scheme of Fusion.

4.6 Necessity for Effective Learning

1. Success in Hybrid Management of Technology can be attributed to learning effects (West) based on indigenous strength (East) thereby "fusing East and West" was realized.

2. Fundamental ability distinguishing between
   (1) To be learned and not to be learned, and
   (2) To be able to learn and not able to learn.

3. For that following abilities are required:
   (1) Curious to know new/exotic experience,
   (2) Willing to be actively involved in the experience,
   (3) Able to distinguish harm/good, and can/cannot,
   (4) Able to reflect on the experience,
   (5) Possessing analytical skills to conceptualize,
   (6) Possessing decision making and problem solving skills,
   (7) Envisioning fusion between *East* and *West*.

Absorptive capacity
Assimilation capacity

Effective utilization of spillover technology