Co-evolutionary Dynamism between Innovation and Institutional Systems

- The Rise and Fall of the Japanese System of Management of Technology

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Abstract— **Japan has constructed a sophisticated co-evolutionary dynamism between innovation and institutional systems by transforming external crises into a springboard for new innovation. This can largely be attributed to the unique features of the nation such as having a strong motivation to overcoming fear based on xenophobia and uncertainty avoidance as well as abundant curiosity, assimilation proficiency, and thoroughness in learning and absorption. Such explicit dynamism was typically demonstrated by technology substitution for energy in the 1970s, leading Japan to achieve a high-technology miracle in the 1980s.**

While this dynamism shifted to the opposite direction in the 1990s due to a systems conflict with the rise of the information society, it became reactivated in the early 2000s by a hybrid management of technology between indigenous strength and learning from global best practice. Although reactivated firms have multi-polarized during the current period of global economic stagnation, Japan's model for transforming a crisis into a springboard for new innovation has drawn global concern and its application to supra-functionality for new consumption behavior is of interest around the world. Since the dramatic increase in oil prices during mid-2008 has signaled the possibility of a paradigm shift to a post-oil society, Japan's notable dynamism, based on an "utmost fear" hypothesis expected to be derived from supra-functionality may lead to a new entrepreneurial strategy toward such a society.

An empirical analysis is attempted to demonstrate this hypothetical view.

Index Terms— Innovation, Institutions, Co-evolution, Hybrid management, Functionality development, Open innovation

1. INTRODUCTION

1.1 Hypothetical Views

With the understanding that co-evolutionary dynamism between innovation and institutional systems is decisive for an innovation driven economy, careful observation of the rise and fall of the Japanese system of management of technology prompts the following hypothetical views:

(i) Based on xenophobia and uncertainty avoidance together with abundant curiosity, assimilation proficiency, and thoroughness in learning and absorption, Japan indigenously incorporates a sophisticated function in transforming external crises into a springboard for new innovation which can largely be attributed to a high level of technology productivity enabled by a virtuous cycle of a growth-oriented trajectory in an industrial society.

(ii) A paradigm shift to an information society based on a functionality development (FD) initiated trajectory reveals the limit of the traditional model and leverages the significance of FD that can be expected within the scope of the integration of the production, diffusion and consumption functions.

(iii) Provided that FD incorporates a declining nature, its sustainability is decisive to firm strategy to which IT's self-propagating development through earlier FD emergence in successive innovation based on the effective utilization of learning from preceding innovation is suggestive.

(iv) Such learning effects suggest the significance of follower substitution for a leader in the diffusion process corresponding to an open innovation stream.

(v) Such a stream highlights the significance of the hybrid management of technology fusing indigenous strength and learning from a digital economy enabled by co-evolutionary domestication.

(vi) Confronting the current global economic stagnation resulting in diminishing consumption, utmost gratification of consumption by means of supra –functionality which instills in customers an "exciting story with their own initiative as heroes/heroines" and thrills them gratification is essential for activating co-evolutionary domestication dynamism.

(vii) Experiencing the dramatic increase in oil prices in mid-2008, this endeavor may lead to reactivation of Japan's indigenous explicit function in transforming "utmost fear" into a springboard for new innovation toward a post-oil society. Japan's explicit co-evolutionary dynamism between innovation and institutional systems can thus be activated.

1.2 Structure

Aiming at demonstrating the foregoing hypothetical views, the following seven dimensional analyses were attempted:

(i) Japan's system in transforming external crises into a springboard for new innovation,

(ii) Limit of substitution model in a production function in a new paradigm of an information society,

(iii) Co-evolutionary domestication for sustainable FD,

(iv) Open innovation for sustainable FD,

(v) Hybrid management of technology,

(vi) Supra-functionality leading to an utmost fear hypothesis, and

(vii) New innovation dynamism toward a post-oil society.

2. JAPAN'S SYSTEM IN TRANSFORMING CRISES INTO A SPRINGBOARD FOR INNOVATION

Japan's Co-Evolution and Development Cycle - Learning and Assimilation

As demonstrated in **Fig. 1**, Japan accomplished conspicuous X-efficiency during the period of an industrial society. The contribution of learning to TFP (Total Factor Productivity) amounted to 50% in this period. This can largely be attributed to Japan's intensive cumulative learning efforts with its unique function as (i) motivated by xenophobia and uncertainty avoidance [29], and (ii) abundant curiosity, assimilation proficiency, thoroughness in learning and absorption [58] <1, 2>. Based on this unique function, Japan's system of MOT achieved co-evolutionary development by learning and assimilating advanced innovation and advancement of its own institutional systems and indigenous innovation, which in turn further accelerated more qualified learning (see Appendix A) leading to high performance (much higher than the US as demonstrated in Figs. 1 and 2) in terms of technological development in an industrial society [74], [75], [77] (see ***Appendix A***).

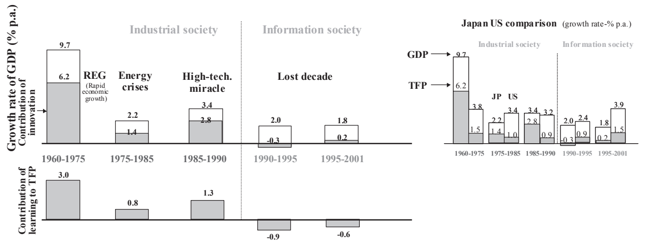


Fig. 1. Trend in Contribution of Learning to TFP and Consequent GDP Growth Rate in Japan *(1960-2001) - % p.a.*.

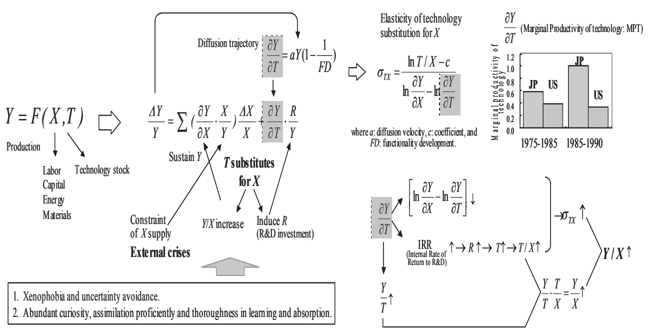


Fig. 2. Japan's Notable Dynamism in Transforming External Crises into a Springboard for New Innovation.

This high performance technological development, together with a strong motivation for overcoming fear based on xenophobia and uncertainty avoidance, constructed a sophisticated system in transforming external crises into a springboard for new innovation. Fig. 2 illustrates this notable dynamism.

Japan's foregoing unique institutional system led to a high level of MPT (Marginal Productivity of Technology) leveraging a conspicuously high level of elasticity of technology substitution for energy *(σ TX)* [76], [80] leading to a shift from energy to technology *(T/E),* and increased technology productivity (*Y/T*) which generated a notable energy productivity as a multiplier effect of these accomplishments (*Y/E = (T/E)(Y/T)*). Enhanced energy productivity relaxed energy constraints and enabled sustainable growth which again induced higher MPT leading to constructing a virtuous cycle between the foregoing improvement.

2.2 Technology Substitution for Energy

This explicit dynamism was typically demonstrated by technology substitution for energy in the 1970s that led Japan to achieve the world's highest level of energy efficiency improvement as demonstrated in Figs. 3 and 4 [79] (***Appendix B***) <3>.

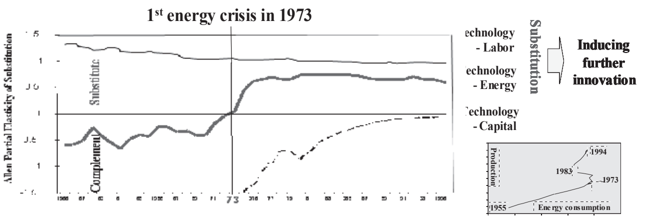


Fig. 3. Trends in Technology Substitution for Production Factors in the Japanese Manufacturing Industry *(1955-1997) - Allen Partial Elasticity of Substitution.*

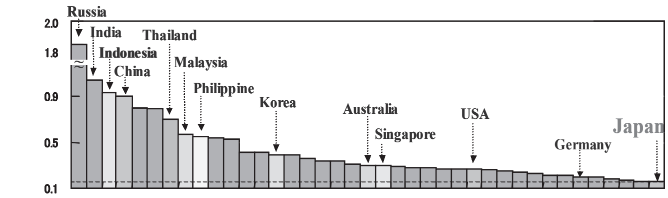


Fig. 4. Energy Consumption per GDP in 40 Countries *(2004).*

Noteworthy is that such conspicuous energy efficiency can be attributed to similar substitution efforts in the 1960s, technology substitution for labor and cross sector technology spillover as demonstrated in Fig. 5 [82] that suggests a coopetition (cooperation and competition) strategy in the 1990s [9].

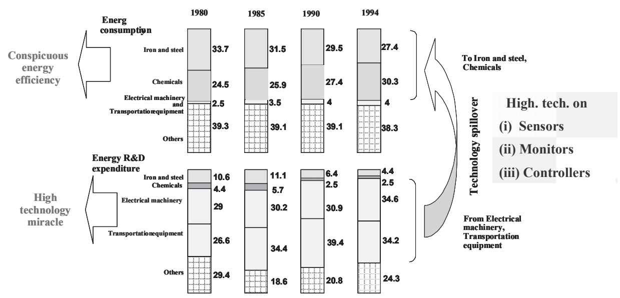


Fig. 5. Technology Spillover from Electrical Machinery and Transportation Equipment to Iron and Steel and Chemical in Japan *(1980-1994).*

2.3 Limit of Substitution Model

However, due to feature differences between MT and IT [86], Japan's notable dynamism moved in the opposite direction in an information society of the 1990s as demonstrated in Fig. 6.

This reveals the limit of substitution model in a production function and leverages the significance of production, diffusion and consumption integration.

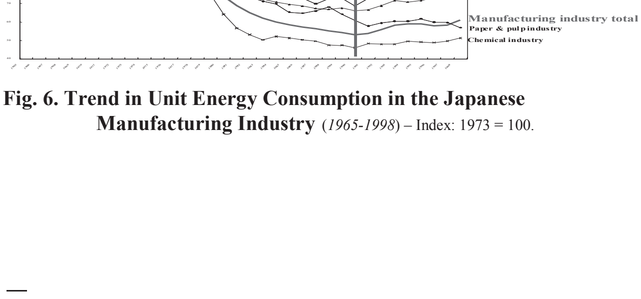


Fig. 6. Trend in Unit Energy Consumption in the Japanese Manufacturing Industry (*1965-1998*) – Index: 1973 = 100.

3. LIMIT OF SUBSTITUTION MODEL IN A PRODUCTION FUNCTION

3.1 Functionality Development in Innovation

Table 1 compares features of manufacturing technology (MT) and IT with respect to an industrial society and an information society, respectively. While the former leads with a growth oriented trajectory, the latter initiates functionality development (FD) with an initiated trajectory [86].

Table 1 Comparison of Features between Manufacturing Technology and IT

	1980s	1990s
Paradigm	Industrial society	Information society
Core technology	**Manufacturing technology (MT)**	**IT**
1. Key features formation process	Provided by suppliers	Formed through the interacting with institutions
2. Fundamental nature	As given at the development stage	Formed in a self-propagating way during the course of diffusion
3. Development trajectory	**Growth oriented trajectory**	**Functionality development initiated trajectory**

Fig. 7 demonstrates diffusion trajectories in Japan's fixed and mobile phones (MP). MP as a crystal of IT, demonstrates self-propagating development with enhancement of FD [10], [11].

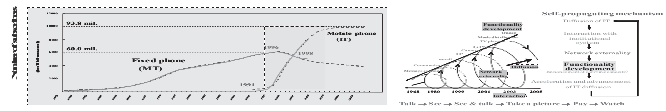


Fig. 7. Diffusion Trajectories in Japan's Fixed and Mobile Phones.

FD plays a decisive role in an information society and it can be depicted by the following diffusion trajectory [95].

(i) Diffusion trajectory can be depicted by an epidemic function.

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

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

(ii) FD can be defined as follows:

Y continues to diffuse as far as it incorporates

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

(iii) FD can be measured by the following way:

Y terminates to diffuse when it reaches N

(i) $Y \to N$ $\quad \frac{dY}{dt} = 0$ **(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**

(iv) Firm competitive strategy should focus on sustaining FD.

Efforts to prolong higher level of FD | **Sustainable FD** | **Self-propagating FD**

3.2 FD for Firm Sustainable Growth

Fig. 8 compares growth options and identifies that FD could be the only option for sustainable growth in an information society.

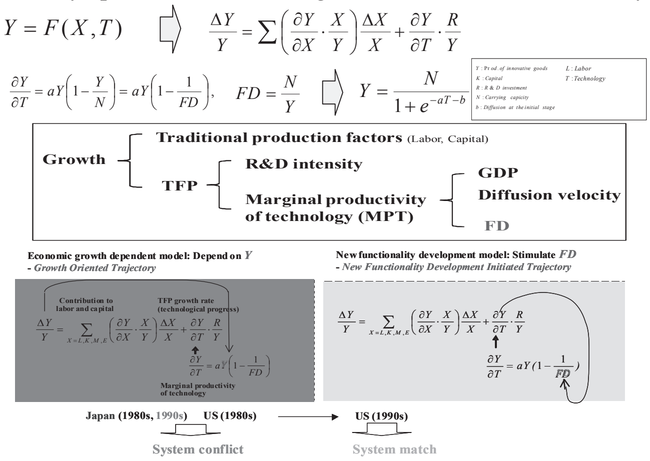


Fig. 8. Contrast of Growth Option.

Fig. 9 compares development paths in Japan and the US. Japan's systems conflict with an information society led to institutional inelasticity, resulting in a dramatic decrease in FD. The decrease in FD then led to reduced MPT which resulted in a TFF decrease [89] (see ***Appendix C***) <4>.

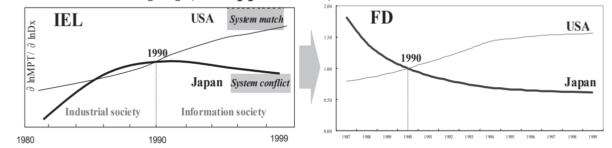


Fig. 9-1. Institutional Elasticity of Manufacturing Technology - Elasticity of the Shift to an Information Society to Marginal Productivity of Technology (1980-1999) - Index: 1990 = 100.

Fig. 9-2. Functionality Development (1987-1999) - Index: 1990 = 1.

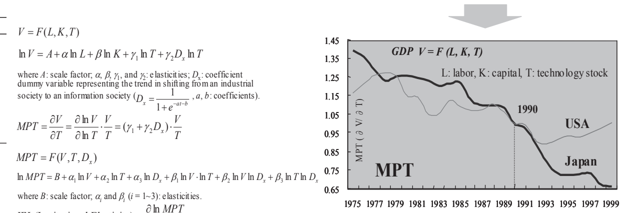


Fig. 9-3. Marginal Productivity of Manufacturing Technology (1975-1999) - Index: 1990 = 1.

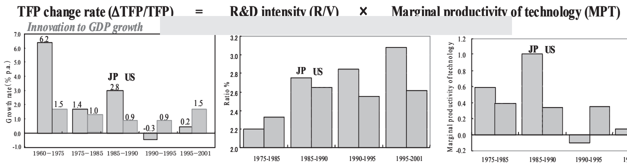


Fig. 9-4-1. TFP Growth Rate (1960-2001). **Fig. 9-4-2. R&D Intensity** (1975-2001). **Fig. 9-4-3. Marginal Productivity of Technology** (1960-2001).

3.3 Integration of Production, Diffusion and Utility Functions

As the paradigm shifts to an information society, the place where innovation occurs shifts from production sites to diffusion and consumption processes leading to a great significance of production, diffusion and consumption integration. Fig. 10 demonstrates the significance of this integration for sustainable growth in an information society. FD enhances utility which induces consumption leading to increased GDP (Y). Increased Y induces R&D investment leading to a technology stock (T) increase. Increased T enhances the carrying capacity (N) of diffusion trajectory leading to an FD increase. Increased FD increases MPT which induces a higher elasticity of T substitution for X (other production factors). Higher elasticity induces an X productivity increase as $Y/X = Y/T \times T/X$ contributing to sustainable growth <5>.

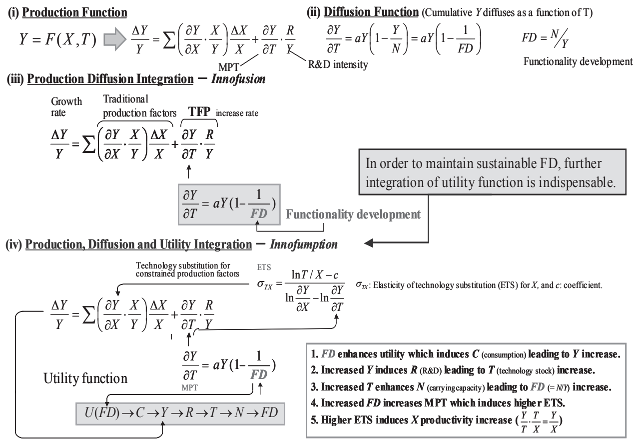


Fig. 10. Integration of Production, Diffusion and Utilization Functions.

While such co-evolution in an integrated system is decisive for firm competitiveness in an information society, the mechanism enabling such dynamism remains a black box <6>.

4. CO-EVOLUTIONARY DOMESTICATION FOR SUSTAINABLE FUNCTIONALITY DEVELOPMENT

4.1 Emergence of FD in a Diffusion Trajectory

Aiming at elucidating the foregoing black box, a key to sustainable FD in mobile phone (MP) diffusion was elucidated as its development is typical of Japan's institutions, similar to the way that elephant tortoises have developed in the unique environment of the Galapagos islands. Fig. 11 depicts the timing of FD emergence and the level at that timing in the diffusion trajectory of innovation that is identified as $3+\sqrt{3}$ by Mahajha et al. [38], [49], [60].

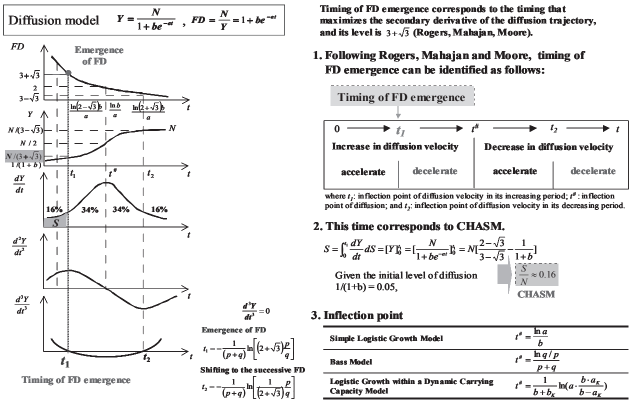


Fig. 11. Level and Timing of Inflection in Diffusion Trajectory.

The monthly diffusion trajectory of Japan's mobile phones (MP) over the last decade can be traced by a bi-logistic growth model. This suggests that Japan's MP diffusion in the last decade was initiated by two waves Y_1 and Y_2. Figs. 12, 13 and Table 2 demonstrate the decomposed trajectories.

$$Y = Y_1 + Y_2 = \frac{N_1}{1+b_1e^{-a_1t}} + \frac{N_2}{1+b_2e^{-a_2t}}$$

$Y(t)$: 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).

IP: Internet Protocol Service

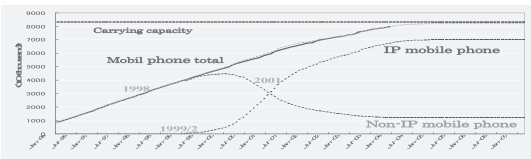


Fig. 12. Diffusion Trends in Japanese Mobile Phones *(Jan. 1996-Dec. 2006)*.

Table 2 Estimation of Japan's Mobile Phones Diffusion by the Bi-logistic Growth Model *(Jan. 1996-Dec. 2006)*

	N_1	a_1	b_1	N_2	a_2	b_2	*adj. R²*
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	

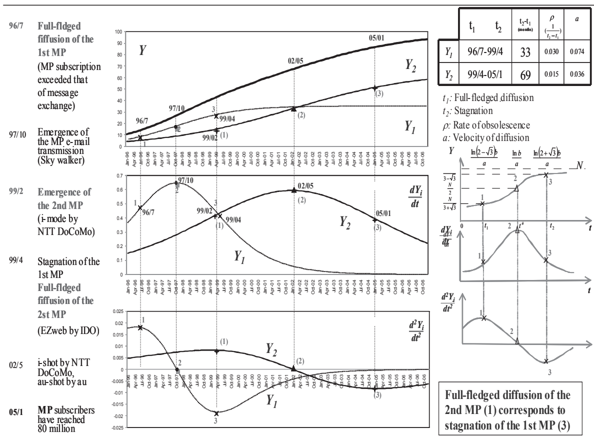


Fig. 13. Diffusion Dynamism of Japan's Mobile Phones *(Jan.. 1996 – Dec. 2006)*.

4.2 Earlier Emergence of FD Based on Learning

Corresponding to full-fledged diffusion of the 1st MP (96/7), FD emerged. Its level was $3+\sqrt{3}$. The 2nd MP FD emerged at 99/2 with a level of 5. This can be attributed to the earlier emergence of FD (2months earlier than full-fledged diffusion of the 2nd MP (99/4)) based on the effects of cumulative learning of the preceding innovation as illustrated in Fig. 14. Thus, sustainable FD was realized and the FD function can be depicted thereon <7>.

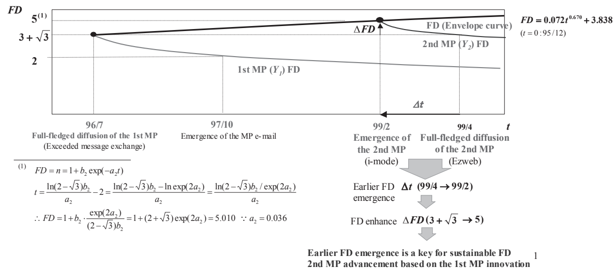


Fig. 14. Functionality Development Trajectory of the Successive Innovation in Japan's Mobile Phones.

Based on this function, the MP price function can be identified and governing factors were estimated as tabulated in Table 3.

$$P = A\cdot FD^{\alpha}\cdot N^{\beta}\cdot e^{\gamma t+\delta D} \qquad \ln P = \ln A + \alpha \ln FD + \beta \ln N + \gamma t + \delta D$$

$$\underset{(-6.58)}{\ln P = -718.181} + \underset{(6.65)}{589.339} \ln FD - \underset{(-6.73)}{39.199} \ln N - \underset{(-6.72)}{0.606}\, t + \underset{(12.55)}{0.031} D_1$$

$adj.\ R^2 = 0.998$, $DW = 1.53$

P: Prices of mobile phone handsets (Bank of Japan),
A: Scale factor,
FD: Functionality development,
N: Number of subscribers (TCA: Telecommunication Carriers Association)
t: Monthly trend
D: Dummy variables depicting the events of mobile phones development.
$\alpha, \beta, \gamma, \delta$: elasticity.

Table 3 Factors Contributing to Change in Prices of Japan's Mobile Phones Handset *(Jan.1996-Dec.2006)*

	P	*FD*	*N*	*time*	*residuals*
00/1-02/5	-0.12	12.90	-6.07	-7.26	0.32
02/5-05/1	-0.14	10.37	-3.26	-7.26	0.02
05/1-06/12	-0.09	10.30	-1.74	-7.26	-1.39

4.3 Co-evolutionary Domestication

Fig. 15 demonstrates the driving forces of MP development which suggests that (i) FD increases prices, (ii) learning corresponding to subscribers increase and economics of scale decrease prices, and (iii) dynamism between these factors plays the role of an engine in MP development.

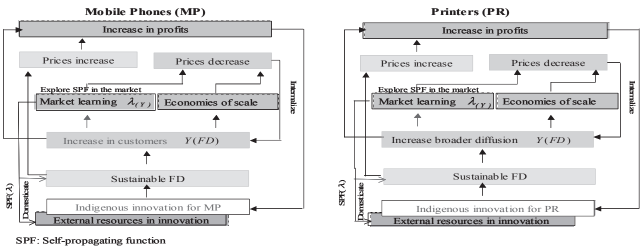


Fig. 15. Contrast of Co-evolutionary Domestication between MP and Printers.

Noteworthy is that an FD increase induces subscribers to increase, which supports market learning and restores the effects of learning as innovation resources for succeeding MP innovation in a co-evolutionary way. This dynamism can be called co-evolutionary domestication [98] as it enables MP co-evolutionary development in production, diffusion and consumption integration [97]. Coopetition (cooperation and competition) dynamism [9] initiated by the development of Canon printers development demonstrates a similar dynamism as contrasted in Fig. 15 ***(see Appendix D and E).***

5. OPEN INNOVATION FOR SUSTAINABLE FUNCTIONALITY DEVELOPMENT

5.1 Innovator Imitator Dynamics in a Diffusion Trajectory

Inspired by the preceding findings on the earlier emergence of FD by means of effective utilization of learning of preceding innovation, by utilizing the Bass model, innovator and imitator dynamism accelerating earlier FD emergence was analyzed as illustrated in Fig. 16.

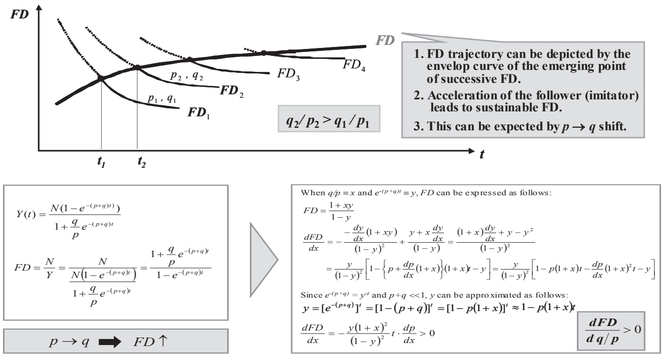


Fig. 16. Scheme of Functionality Development of the Successive Innovation in a Bass Model.

By utilizing a newly developed Bi-Bass model, innovator (p) and imitator (q) interaction in the transition from Web 1.0 to Web 2.0 was analyzed as demonstrated in Table 4 and Fig. 17. It could be demonstrated that FD increases as the ratio of q/p increases corresponding to the shift from innovator to imitator.

Table 4 Estimation of Japan's Internet co.jp Domains by Bi-Bass Model (*May 1993 – June 2006*)

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

Parameter	Estimate	t-value	*adj. R^2*	*AIC*
N_1	2.42×10^5	145.87	0.999	17.08
N_2	2.49×10^5	75.66		
p_1	1.38×10^{-5}	8.35	$q_1/p_1=0.78\times10^4$	
q_1	1.08×10^{-1}	58.33		
p_2	0.25×10^{-5}	2.60	$q_2/p_2=2.20\times10^4$	
q_2	0.55×10^{-1}	22.74		

Shift from p to q: $q_1/p_1 < q_2/p_2$ → Innovator (leader) → Imitator (follower); Transition from Web 1.0 to Web 2.0

Transition to Web 2.0 (Inflection time): Y_1 $t_1^{\#}=\frac{\ln q_1/p_1}{p_1+q_1}$ 82.9 (2000/3) → Y_2 $t_2^{\#}=\frac{\ln q_2/p_2}{p_2+q_2}$ 182.9 (2008/7)

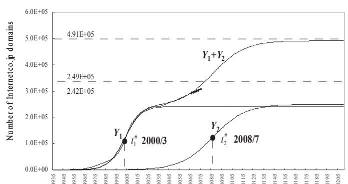


Fig. 17. Estimation of Japan's Internet co.jp Domains by Bi-Bass Model (May 1993- Dec. 2010)[a]

[a] May 1993 - Jun. 2006: actual, and Jul. 2006–Dec. 2010: estimate.

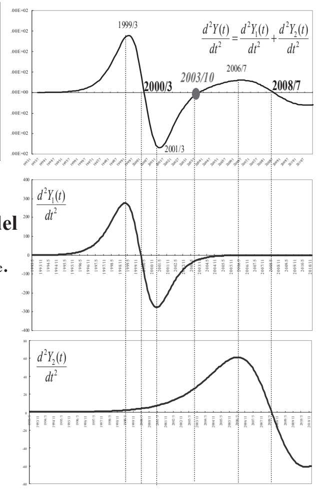


Fig. 18. Trend in Trend in Inflection Points in Japan's Internet co.jp Domains (*May 1993 – Dec. 2020*).

Based on Fig. 11, Fig. 18 analyzed the transition from Web 1.0 to Web 2.0 and demonstrated that this transition emerged in 2003/10.

5.2 Emergence of FD in a Diffusion Trajectory

However, similar to i-mode in MP, a substantial transition was initiated by RSS 2.0 in 2003/7, leading to an increasing envelope curve as illustrated in Fig. 19, which demonstrates a substantial FD increase by shifting from Web 1.0 to Web 2.0. Table 4 demonstrates that such an increase was enabled by imitator substitutes for innovator as the *q/p* increased 3 times.

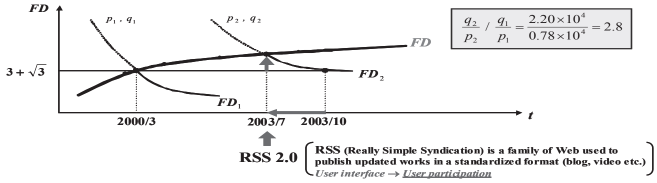


Fig. 19. Earlier Emergence of Functionality Development in Web 2.0.

Aiming at identifying the impact of this substitution on an FD increase, utilizing the timing of FD emergence (t_1) as analyzed in Table 11, and inducing the impacts of a *q/p* increase on the acceleration of t_1 emergence leading to an FD increase was analyzed as demonstrated in Fig. 20 (***Appendix L***).

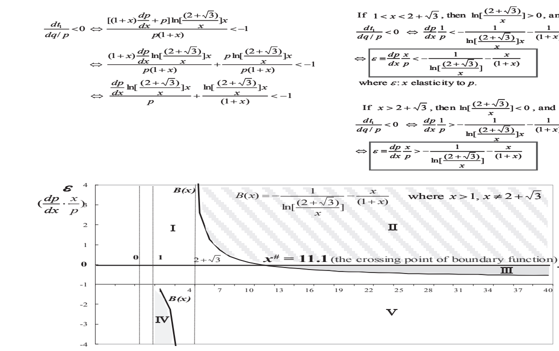


Fig. 20. Areas Satisfying Earlier FD Emergence.

5.3 Follower Substitution for a Leader

Based on the foregoing finding, an empirical analysis on the impact of a q/p increase on FD emergence was then conducted based on printers, software, MP, LCD and the Web as demonstrated in Table 5 and Fig. 21 [93] (see ***Appendix H and I***).

Table 5 Diffusion Parameters in Major Innovative Goods

		N	*p*	*q*	*adj.* R^2
Printer	**LLBP** (*1975-1994*)	1581 (19.33)	5.43×10^{-3} (15.13)	5.8×10^{-2} (9.94)	0.999
	LBP/BJ (*1987-2005*)	97205 (166.57)	1.47×10^{-3} (2.27)	2.9×10^{-2} (37.96)	0.999
SW	**Software** (*1990-2006*)	999.9 (97.11)	0.73×10^{-3} (13.30)	3.6×10^{-2} (3.37)	0.995
MP (*1990-2006*)	**MP 1**	38216 (149.45)	0.70×10^{-1} (5358.9)	0.5×10^{1} (2616.7)	0.999
	MP 2	65741 (170.24)	0.37×10^{-1} (1270.1)	0.15×10^{2} (438.3)	0.999
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
	LCD 2	2.4×10^{3} (656.1)	0.4×10^{-4} (1654.3)	0.8×10^{-1} (1654.3)	
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
	Web 2.0	2.49×10^{5} (75.66)	0.25×10^{-5} (2.60)	0.55×10^{-1} (22.74)	

[a] LLBP: Large-scale Laser Beam Printer; LBP: Laser Beam Printer; BJ: Bubble Jet Printer; SW: Japan's software outsourcing to China; LCD: Liquid Crystal Display; MP: Mobile phone; and Web: Internet dependency based on the number of co.jp domains.

Figures in parentheses indicate *t*-value. All demonstrates statically significant at the 5% level.

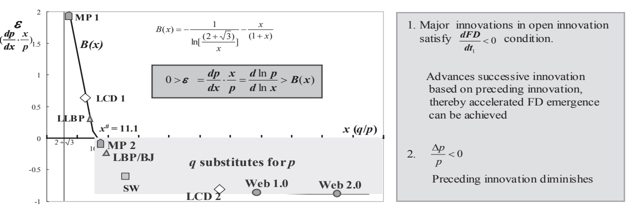


Fig. 21. Sustainable Functionality Development Condition.

All demonstrated that imitator (follower) substitutes for innovator (leader) contribute to greater FD leading to increased firm competitiveness increase in corresponding to an open innovation stream.

6. HYBRID MANAGEMENT OF TECHNOLOGY

6.1 Canon's Success in Hybrid Management

Canon has developed a similar sustainable FD strategy as demonstrated for MP and the Web depending on a technological diversification strategy which maximizes the effect of intra-firm technology spillover such as camera to copying machines, print -ers and digital cameras as demonstrated in Fig. 22 [87], [88], [94] <8>.

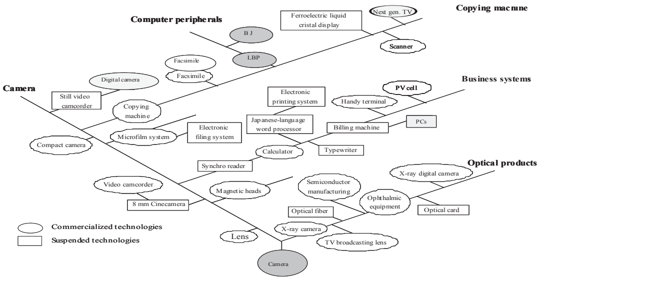


Fig. 22. Canon's Technological Diversification Paths.

Canon has thus constructed a co-evolutionary trajectory between printers and PCs called coopetition, cooperation with a competitor, as demonstrated in Fig. 23 [9], [95].

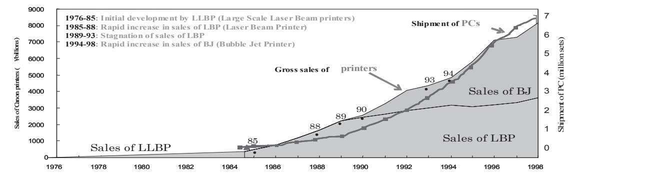


Fig. 23. Co-evolutionary Trajectory between Canon Printers and PCs *(1976-1998)*.

6.2 Functionality Development by Fusing

Consequently, Canon has thus constructed sophisticated hybrid management that enabled smart fusing between its strength and learning from external competitors thereby sustainable FD was enabled [95]. Basic scheme of this management can be depicted as follows (see ***Appendix F***):

Sustainable functionality development condition

$$\frac{d}{dT}FD > 0 \;\Rightarrow\; \frac{d\ln\kappa}{d\ln T} > 1 \quad \begin{cases} \dfrac{d\ln\kappa}{d\ln T} < 1 & P = A_t T^{\kappa} & \text{Can not satisfy} \\ \dfrac{d\ln\kappa_2}{d\ln T'} > 1 & P = AT^{\kappa_1}PC^{\gamma} = A'T'^{\kappa_2},\; T = B\cdot PC^{\phi} & \text{Can be satisfied by Two factors learning, Inducement by PC} \end{cases}$$

where $\kappa = \dfrac{\partial \ln P}{\partial \ln T}$: elasticity of technology to relative prices; T: technology stock; and P: relative price.

Sustainable FD requirement can be satisfied only by two factors learning and effective technology inducement by the advancement of PC as demonstrated in Fig. 24 and Table 6.

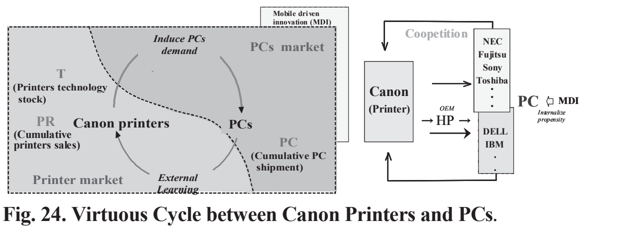


Fig. 24. Virtuous Cycle between Canon Printers and PCs.

Table 6 Coopetition between Canon Printers and PCs *(1986-1998)*

Relative prices of printers technology; Printers technology stock; Cumulative PC shipment; D: 1986, 2000-05=1, other years=0.

$$\ln P = 3.34 + 0.08 \ln T + 0.40 \ln PC - 0.25 D \qquad adj.R^2\ 0.997$$
$$(165.75)\quad (67.66)\quad (67.66)\quad (-8.14) \qquad DW\ 1.60$$

Internal learning — External learning

$$\ln P_V = 1.04 - 0.33 \ln PR - 0.18 \ln PC \qquad adj.R2\ 0.999$$
$$(1.74)\quad (-5.01)\quad (-5.14) \qquad DW\ 2.55$$

Price of printers; Cumulative printers sales; Cumulative PC shipment

6.3 Co-evolutionary Domestication from the Market

Canon's coopetition strategy enables it effective utilization of its indigenous strength in assimilating external technology not only directory from its rivals but also indirectly through market.

MP driven innovation can be attributed to both Japan's indigenous institutional systems and effects of fusing its indigenous strength in MT and the cumulative learning from digital technology as demonstrated in Table 7 [11]. Broad firms involved in this development as tabulated in Table 8 [10], [97].

Table 7 Core Technologies in Mobile Innovation Spillover

1. Semi conductor	2. Electronics	3. Sensor	4. Materials
5. Battery	6. Wireless Communication	7. IC card	8. Liquid Crystal
9. Optics	10. Acoustic	11. Micro Devices	12. High Density
13. Application	14. Plat form	15. Security	16. Compression

Table 8 Impacts of Mobile Driven Innovation on Electric Machinery Firms *(2000-2005)*

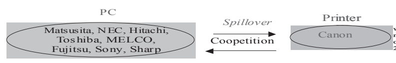
		Mobile firms (20)		Non-mobile firms (19)
Large (7)	A	Matsushita, NEC, Hitachi, Toshiba, MELCO, Fujitsu, Sony		
Medium (32)	B	Sharp, Sanyo, Rohm, TDK, NIDEC, Casio, Murata, Other 6 firms	C	Canon
			D	Ricoh, Fanuc, Keyence, Pioneer, Daikin, Other 13 firms

R&D intensity; Spillover effects

$$OIS = a + b\ln R/S + c\sum_{j=1}^{38} R_j \Big/ R + dD$$

	Constant	ln R/S	∑ R/R
A	0.089	**0.034**	0.15E-03
B	0.660	**0.194**	0.15E-03
C	0.097	0.030	**5.00E-03**
D	0.097	0.030	0.15E-03

$$OIS = 0.097 + 0.563 D_{mb} + 0.287 D_{kf} - 0.571 D_{gi} + 0.039 D_t$$
$$(1.89)\ (5.18)\quad (10.87)\quad (-2.44)\quad (3.36)$$
$$+ 0.030 \ln R/S + 0.164 D_{mb} \ln R/S - 0.160 D_{gi} \ln R/S$$
$$(1.76)\quad (4.76)\quad (-1.94)$$
$$+ 0.153\times 10^{-4}\sum R/R + 4.850\times 10^{-3} D_{ca}\sum R/R$$
$$(6.20)\quad (2.40)$$
$$adj.\ R^2 = 0.782$$



where D_{mb}: Mobile firms = 1, non-mobile firms = 0; D_{gi}: Large firms = 1, medium firms = 0; D_t: 2003-2005 = 1, 2000-2002 = 0; D_{ca}: Canon = 1, other firms = 0; D_{kf}: Fanuc, Keyence = 1 (Non-mobile but high OIS: over 25%), other firms = 0.

Table 8 compares impacts of MP driven innovation on 39 electric machinery firms profit suggesting that: (i) mobile firms *(A,B)* demonstrate higher dependency on R/S for their OIS, (ii) medium firms depend higher spillover effects through learning. (iii) while Canon is non-mobile firms, it utilizes highest spillover effects through intensive learning and coopetition with mobile firms majority of them are PC producers and partner of coopetition.

Thus, Canon has constructed a comprehensive co-evolutionary domestication dynamism as demonstrated in Fig. 25 consists of

(i) Market stimulation by providing attractive innovation,
(ii) Inducement of self-propagating FD in the market,
(iii) Leveraging vendors innovation in response to market demand,
(iv) Domestication by learning and inducement through coopetition, and
(v) Intra-firm technology spillover..

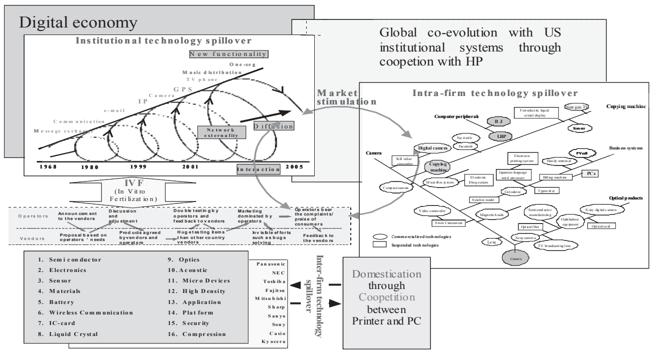


Fig. 25. Scheme of Canon's Co-evolutionary Domestication.

Noteworthy is that this dynamism has been constructed in a stepwise way starting from (i) individual technology, (ii) intra technology spillover, (iii) domestication of rival firms (coopetition), to (iv) domestication of market innovation.

Canon's fusing option can be compared to Google's business model, while Hitachi's model can be compared to that of Microsoft <9, 10>.

7. -FUNCTIONALITY LEADING TO THE "UTMOST FEAR HYPOTHESIS"

7.1 Dynamism Leading to Supra-Functionality

As reviewed in the preceding Section, Japan's global high-technology firms as Canon constructed sophisticated hybrid management system by making effective utilization of external resources and fusing it with indigenous strength. Consequently, these firms demonstrated conspicuously high level of R&D profitability as demonstrated in Fig. 26 <11, 12>.

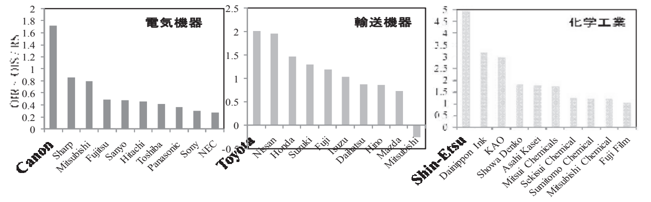


Fig. 26. Operating Income to R&D in 10 Leading Firms in 3 High-technology Sectors in Japan *(2001-2007)*.

[a] OIS = OI / S (Operating income to sales); RS = R / S (R&D intensity).

Supported by these global high-technology firms, Japan's economy was succeeded in reactivation in the early 2000s. However, confronting the current global-wide economic stagnation, these firms resulted in decreasing their profits again from the late 2008. This can largely be attributed to diminishing consumption in the hybrid management partners and subsequent stagnation of their innovation.

Important lesson learned from the current global-wide stagnation is the termination of traditional consumption dependent economy that anticipated the recovery of consumption simply by business upturn.

With the understanding that reactivation of Japan's economy is indispensable to sustaining world economy and that maintaining Japan's hybrid management will play a key role for this, institutional way of activation of consumption is examined as this could lead to reactivating innovation of hybrid management partners essential for Japan's hybrid management of technology.

Prompted by habit persistence hypothesis (Modigliani) [47] that people never forget its utmost gratification of consumption ever experienced in its life, and, therefore, people's consump tion behavior is affected by its utmost gratification, supra-FD which may remind people supra-functionality ever experienced was examined. Supra-functionality encompasses social, cult- ural, aspirational, and emotional needs beyond economic value (McDonagh) [42]. Fig. 27 illustrates the dynamics of utmost FD for gratification of consumption leading to supra-functionality <13>.

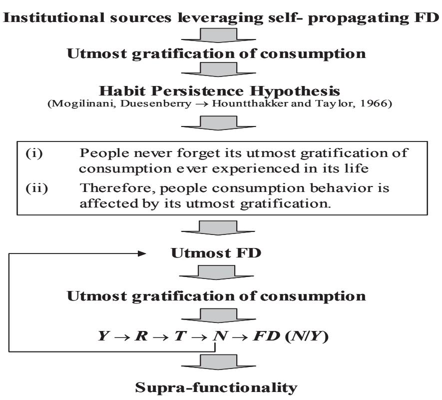


Fig. 27. Utmost FD for Gratification of Consumption Leading to Supra-Functionality.

7.2 Optimal FD Dynamics

Based on the optimal theory, optimal FD trajectory leading to utmost gratification of consumption by satisfying (i) *investment intensity maximizing utility*, (ii) *cost minimum*, and (iii) *FD maximum* conditions was identified as illustrated in Fig. 28 (see ***Appendix G***).

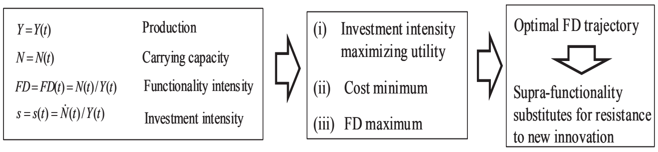


Fig. 28. Analytical Framework for Optimal FD Trajectory.

An empirical analysis taking Japan's MP development over the last decade was attempted as demonstrated in Fig. 29.

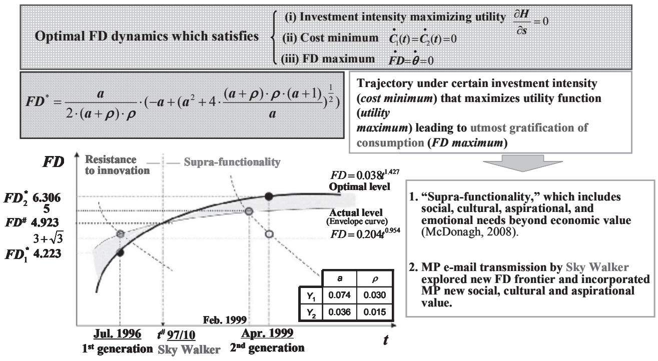


Fig. 29. Comparison of Optimal and Actual Levels of FD in Japan's MP Development Trajectory *(1996-2006)*.

The Figure demonstrates that while the optimal trajectory was lower than actual level (Fig. 14), it exceeded this level in 1997/10 corresponding to MP e-mail transmission by Sky Walker (***Appen -dix J***) suggesting supra-functionality substituted for resistance to innovation (Bauer) [6] and also a possibility of follower (optimal level) substitutes for a leader (actual level) in open innovation. By exploring new FD frontier through e-mail transmission which instills customers "exciting story with their own initiative as heroes/ heroines" and thrills them gratification, Sky Walker has incorporated MP new social, cultural and aspirational value.

7.3 Inducement of the "Utmost Fear Hypothesis"

While the dramatic increase in oil prices during mid-2008 has signaled the possibility of a paradigm shift to a post-oil society, utmost fear hypothesis can be induced from the foregoing supra-functionality dynamism as illustrated in Fig. 30.

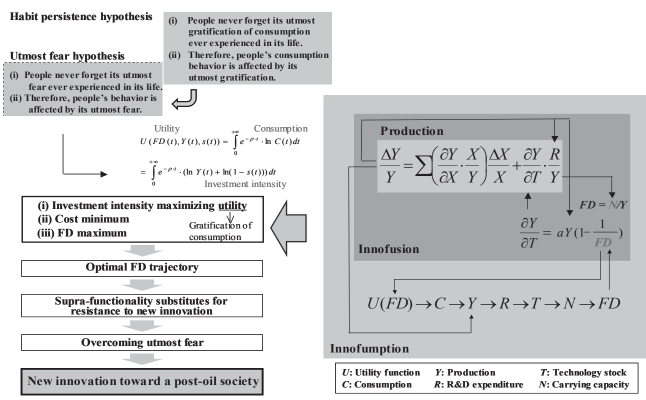


Fig. 30. Leverage of Utmost Fear Ever Experienced in Shifting Resistance to Supra-Functionality.

8. INNOVATION DYNAMISM TOWARD A POST-OIL SOCIETY

8.1 PV Development against Utmost Fear

Supra-functionality dynamism derived from habit persistence hypothesis suggests utmost fear hypothesis. Since Japan's innovation endeavor is very sensitive to such fear as reviewed in Section 2, and given increasing concern on Japan's model for transforming a crisis into a springboard for new innovation particularly in the current environment of simultaneous global economic stagnation, identification of innovation dynamism toward a post-oil society based on this approach is Japan's significant contribution to the global community (see Appendix K).

An empirical analysis taking PV (photo-voltaic solar cell) development as technology driven energy to which Japan maintains institutional advantage was attempted as illustrated in Fig. 31 <14>.

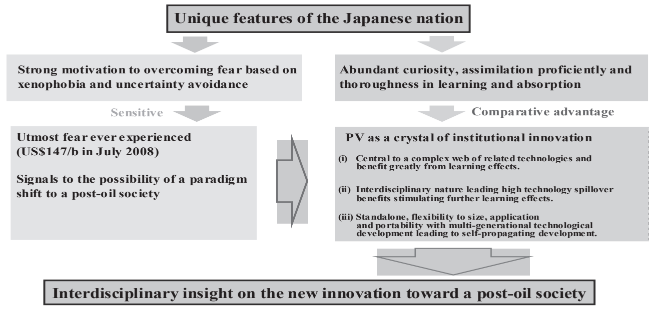


Fig. 31. Utmost Fear Hypothesis in Japan's PV Development.

Similar to the analysis on MP in Section 7, PV development trajectory over the last 3 decades by utilizing bi-logistic growth model was first attempted as illustrated in Fig. 32 and Table 9.

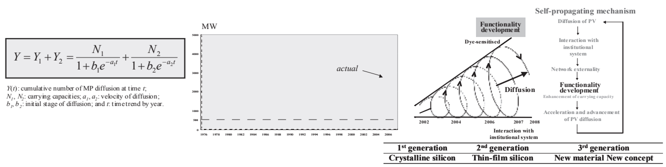


Fig. 32. Japan's PV Development Trajectory by Bi-Logistic Growth Model *(1976-2007)*.

Table 9 Estimation of Japan's PV Diffusion by the Bi-logistic Growth Model (*1976-2007*): MW

	N_1	a_1	b_1	N_2	a_2	b_2	adj. R^2
Parameter	0.2×10^3	4.58×10^{-1}	29.0×10^2	10.0×10^3	3.68×10^{-1}	4.59×10^2	0.999
t-value	34.95	15.13	3.90	113.51	41.34	3.59	

8.2 Optimal FD Trajectory Corresponding to Utmost Fear

Similar to the preceding optimal FD development analysis, optimal FD trajectory was compared with that of actual trajectory based on the foregoing analysis by means of bi-logistic growth model as demonstrated in Fig. 33 <15, 16>.

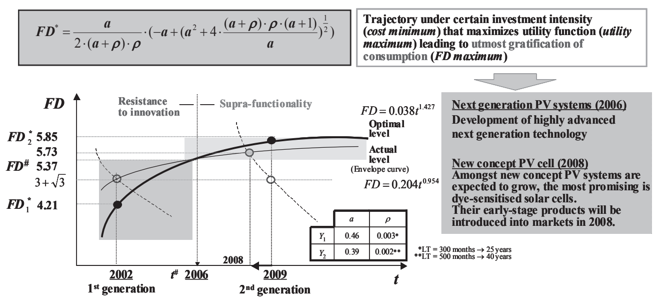


Fig. 33. Comparison of Optimal and Actual Levels of FD in Japan's PV Development Trajectory *(1976-2007)*.

[a] FD#: Utmost FD level; $3+\sqrt{3}$: Level of FD at its emergence (Rogers, Mahajan, Moore).

Japan's PV demonstrates supra-functionality substituted for resistance in 2006 and also a possibility of follower (optimal level) substituted for leader (actual level) in open innovation at this timing. Based on preceding innovation, new FD frontier was incorporated in PV in 2006 instilling users "exciting story," similar to Sky-walker in MP. Fig. 34 demonstrates a conspicu -ous increase in PV development endeavor in Japan since then.

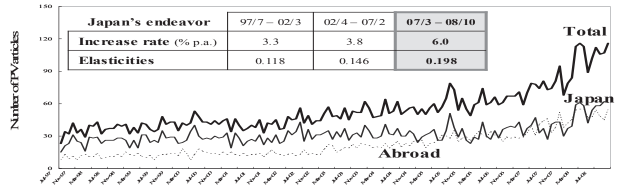


Fig. 34. Trends in Number of PV Endeavors (*Jul. 1997-Oct. 2008*)[a].

[a] Number of projects endeavoring to PV development introduced by PV News.

Source: PV News (PV Energy System Inc., monthly issue).

Table 10 also supports this finding by demonstrating dramatic increase in elasticity of oil prices to PV endeavor as 0.118 *(97/4-02/3)*, 0.146 *(02/4-07/2)* and 0.198 *(07/3-08/10)* in Japan. Furthermore, cumulative PV development increased 5 times higher between 2005 and 2008 (Fig. 32, see ***Appendix K***).

Table 10 Impacts of Oil Prices Increase in Inducing PV Development Endeavors in Japan and Abroad (*Jul. 1997-Oct. 2008*)**:** 3 months moving average

	adj. R^2	*DW*
$\ln N_{Japan} = 2.839 + 0.118D_1 \ln P + 0.146D_2 \ln P + 0.198D_3 \ln P + 0.168D_4$ (39.96) (5.14) (7.81) (12.37) (13.47)	0.881	1.47
$\ln N_{abroad} = 1.010 + 0.467D_1 \ln P + 0.533D_2 \ln P + 0.600D_3 \ln P + 0.183D_4$ (13.36) (19.11) (26.90) (35.32) (13.77)	0.975	1.10
$\ln N_{total} = 2.821 + 0.260D_1 \ln P + 0.302D_2 \ln P + 0.361D_3 \ln P + 0.123D_4$ (62.28) (7.79) (25.49) (33.51) (15.57)	0.977	1.39

where N_{Japan}, N_{abroad}, and N_{total}: number of projects endeavoring to PV development in Japan, abroad, and World total, respectively introduced by PV News; P: international oil prices (US$/bbl at current prices) by WTI (West Texas Intermediate); and D_i (i = 1~4): dummy variables with following classifications:

Dummy variables	Aug. 1997-Mar. 2002	Apr. 2002-Feb. 2002	Mar. 2007-Sep. 2009
D_1	1	0	0
D_2	0	1	0
D_3	0	0	1

8.3 Significance of the "Utmost Fear Hypothesis"

However, higher level of elasticity incorporates fragile structure with respect to consistent endeavor regardless the change in oil prices. Thus, utmost fear hypothesis is essential. Table 11 demonstrates this significance by comparing the direct impact of the oil prices and that of utmost fear (highest level of oil prices) on Japan's PV development.

Table 11 Comparison of the Inducing Impacts of Oil Prices Increase on the Advancement of Japan's PV (*1986-2015*)

		adj. R^2	*DW*	*AIC*	*F*
Direct impact	$\ln Y_{23} = -7.712 + 4.911\,D_1 \ln P + 4.786\,D_2 \ln P + 5.061\,D_3 \ln P + 1.881\,D_4$ (-2.23) (4.30) (5.72) (6.43) (4.14)	0.898	0.75	15.05	64.49
	$\ln Y_{24} = -7.979 + 5.014\,D_1 \ln P + 4.853\,D_2 \ln P + 5.222\,D_3 \ln P + 1.797\,D_4$ (-2.19) (4.17) (5.51) (6.31) (3.76)	0.895	0.70	18.15	62.74
	$\ln Y_{25} = -8.246 + 5.117\,D_1 \ln P + 4.921\,D_2 \ln P + 5.384\,D_3 \ln P + 1.714\,D_4$ (-2.15) (4.04) (5.34) (6.18) (3.40)	0.892	0.66	21.23	61.04
Comprehensive impacts with utmost fear	$\ln Y_{23} = 17.273 - 3.624D_1 \ln(P_{max1} - P) - 1.495D_2 \ln P - 1.476D_3 \ln(P_{max2} - P) + 2.628D_4$ (14.60) (-9.24) (-5.28) (-3.79) (7.54)	0.952	1.69	-7.70	144.73
	$\ln \boldsymbol{Y}_{24} = 18.071 - 3.893\boldsymbol{D}_1 \ln(\boldsymbol{P}_{max1} - \boldsymbol{P}) - 1.683\boldsymbol{D}_2 \ln \boldsymbol{P} - 1.620\boldsymbol{D}_3 \ln(\boldsymbol{P}_{max2} - \boldsymbol{P}) + 2.615\boldsymbol{D}_4$ (14.73) (-9.57) (-5.74) (-4.01) (7.24)	0.952	1.75	-5.53	145.65
	$\ln Y_{25} = 18.868 - 4.163D_1 \ln(P_{max1} - P) - 1.872D_2 \ln P - 1.763D_3 \ln(P_{max2} - P) + 2.601D_4$ (14.70) (-9.79) (-6.10) (-4.18) (6.88)	0.952	1.78	-2.82	143.74

[a] Y_{2i} (i = 1~5): cumulative stock of PV diffusion in phase 2 with extended estimation with annual increase rate of 20% (Y_{21}), 30% (Y_{22}), 50% (Y_{23}), 60% (Y_{24}) and 70% (Y_{25}), respectively;
P: international oil prices (US$/bbl at current prices) by WTI (West Texas Intermediate) with extended estimation of 5US$/b p.a. increase from 2009; and D_i (i = 1~3): dummy variables with following classifications:

Dummy variables	1986-2003*	2004-2008	2009-2015
D_1	1	0	0
D_2	0	1	0
D_3	0	0	1

P_{max1}: 40US$/b (prices in 1980); P_{max2}: 105US$/b (prices in 2008)
D_4: 1994-2003 = 1, 2006-2012 = 1 and other years =0 (comprehensive case).
D_4: 1994-2004 = 1, 2009-2012 = 1 and other years =0 (direct impact case).
*Breakpoint: 2003-2004 and P> 40US$/b from 2008.

Utmost fear demonstrates statistically significance than direct impact and also proves extremely lower elasticity of oil prices to PV development demonstrating explicit ratchet function for consistent PV development independent from oil prices decrease.

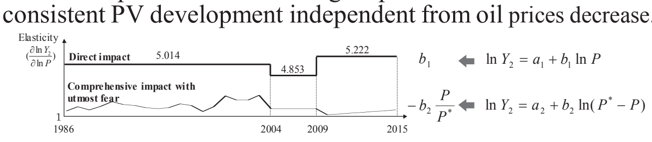


Fig. 35. Elasticity of Oil Prices to PV Development in Comprehensive Impacts with Utmost Fear (*1986-2015*).

This suggests that given Japan's explicit function in transforming fear into a springboard to new innovation, institutional mechanism incorporating new concept of utmost fear into the engine of new innovation toward a post-oil society is essential.

9. CONCLUSION

Aiming at elucidating, conceptualizing and operationalizing Japan's explicit co-evolutionary dynamism between innovation and institutional systems, SIMOT has undertaken three approaches: (i) Systems analysis on the interacting mechanism between the market and technology, (ii) Identification of Japan's system of innovation cycle, and (iii) Historical suggestions regarding the institutions co-evolving with innovation.

This paper has shared the first approach and attempted a systems analysis of the co-evolutionary dynamism using an empirical analysis of the rise and fall of the Japanese system of management of technology. Noteworthy findings include:

(i) Japan's notable function in transforming external crises into a springboard for new innovation was enabled by a high level of technology productivity in an industrial society. This can largely be attributed to a co-evolutionary dynamism between the unique features of the nation such a having strong motivation of overcoming fear as well as abundant curiosity, assimilation proficiency, thoroughness in learning, and prioritized innovation.

(ii) However, this sophisticated dynamism moved in the opposite direction in the 1990s due to a systems conflict with an information society where a FD initiated trajectory is essential, resulting in a dramatic decrease in the productivity of technology and a subsequent stagnation of innovation.

(iii) Japan's mobile phone development trajectory demonstrated a self-propagating development through earlier FD emergence in successive innovation based on the effective utilization of learning from preceding innovation, thereby providing a constructive suggestion for sustainable FD.

(iv) Similar self-propagating FD was demonstrated more explicitly by the transitional trajectory from Web 1.0 to Web 2.0, which suggested to firms the significance of follower substitution for a leader in a diffusion process corresponding to an open innovation stream.

(v) This stream suggested the significance of a hybrid management of technology fusing indigenous strength and learning from a digital economy enabled by co-evolutionary domestication, and contributed to reactivating Japan's indigenous co-evolution.

(vi) While reactivated firms have multi-polarized during the current period of global economic stagnation, the utmost gratification of consumption by means of supra -functionality which instills customers with an "exciting story" thrilling them with gratification could maintain co-evolutionary domestication dynamism and prompts an utmost fear hypothesis.

(vii) Since the dramatic increase in oil prices during mid-2008 has signaled the possibility of a paradigm shift to a post-oil society, Japan's notable dynamism based on an utmost fear hypothesis may lead to a new entrepreneurial strategy toward such a society.

[NOTE]

1. Enkawa analyzed that *sophisticated quality management of Japanese companies was based on high uncertainty avoidance and their strengths had been enhanced at every crisis through down-to-the-earth efforts and Japanese corporations had made themselves into crisis-resilient composition.*

2. Senoo and Nomura analyzed that *under the increasing global competitiveness, HQ's isomorphism and local differentiation orientation caused an institutional dilemma while intensive learning changed it into co-evolution.*

3. Muraki pointed out that *contrary to outstandingly high energy efficiency is in the industry sector, it is low in the residential and transport sectors due to an institutional slack.*

4. Iijima analyzed that *Japan's IT investment level was not inferior to that in the US, but IT utilization level was desperately low, attributable to insufficient process-orientation leading to indispensable circumstances in process visualization and changes of company soil through organizational reformation.*

5. Tsao analyzed that *the roots of SCM can be traced back to the integrated system of production, distribution and consumption that met a severe criticism by the US as structural impediments in the late 1980s and SCM has developed from the integrated decision making across different divisions to the one across different organizations. Consequently, in order to raise competitiveness further, micro and macro methods should be combined and firms' capability to evolve according to environmental changes needs to be enhanced.*

6. Higa analyzed by taking a case of successful venture and indicated that *in order for Japan-style e-commerce to be rooted, dynamism of interactions between value and trust need to work well.*

7. Kimoto *analyzed that in order to capture the essence of technological developments, it is insufficient only to account for the mere accumulation of individual improvements. He pointed out that in nstead, the historical trajectory can be understood by studying relationship in technologies and relationship between technologies and social institutions. Post-war technological developments were not necessarily rational, being under the heavy constraint of the social institution.*

8. Tanaka and Saiki analyzed that *lack in cooperation between divisions led to the large amount of dormant patents, indicating a huge loss of intellectual resources. They pointed out that based on the good cooperation between IP division and others, Japanese corporations need to raise a ratio of basic patents to an optimal level according to industrial characteristics.*

9. Chung analyzed the retail internationalization in Taiwan was analyzed through both the micro-aspect and the macro aspect to show the path where business know-how is transferred to China after merger with its domestic strength.

10. Ito identified that *while Japanese patients tend to view doctor's error reporting actions and interactions with patients after a medical accidents relatively more harshly, in the healthcare risk management, where accumulated efforts mitigate such criticism, Japanese institution again draws attention.*

11. Hachiya analyzed that *from the viewpoints of finance and investment, the changes of governance structure of Japanese firms were examined in the comparison of abnormal returns between the companies where monitoring by stockholders works well and the ones where it does not, indicating global corporations maintain institutional complementarity although it may be indirect.*

12. Nagata analyzed that *institutional effects on the relationship between firms' financial activities and the market were also observed based on the earnings management activities at IPO to indicate the characteristics clearly contrasted with the US market.*

13. Umemuro postulated that *in the future product market, affective (being capable to evoke affects in people's mind or being capable to deliberate affects to be invoked in people's mind) technological products and services are decisively important, the key for consumption in the post global recession era. He also suggested that the concept can be expanded to the management, high-quality-orientation and the societal values.*

14. Yamazaki pointed out that *regarding the arguments on the correlations between science-technology and military-economic activities, the history of science policies of the Cold War America and post babble economy Japan were explored and a mathematical model for analyzing economic impact of basic research was introduced.*

15. Miyazaki analyzed that *a hierarchical structure of an institution dictates analyses on a "sector" level. Japanese institution was found to be a bottleneck for diffusion of the wind power, whereas nanotechnology sector suggests the strength that the institution inherently possesses.*

16. Mizuno pointed out that *numerical models connect both, being effective to clarification of the phenomena depending on institutions.*

APPENDIX

A. *Trends in Growth Rate of GDP, TFP and Effect of Learning in Japan*

Table A1 Trends in Growth Rate of GDP, TFP and Effects of Learning in Japan *(1960-2001) % p.a.*

		1960 - 1975	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)
Japan's TFP composition	***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

TFP and its components are estimated by the following equation:

$$\frac{\Delta TFP}{TFP} = \dot{TFP} = \underbrace{\kappa^{-1}\eta \cdot \frac{\partial V}{\partial T} \cdot \frac{T}{V} \cdot \dot{T}}_{\text{Direct effect of R\&D investment}} + \underbrace{(1-\kappa^{-1}\eta)\eta^2(\psi-1)\kappa^{-1}\frac{\partial V}{\partial T} \cdot \frac{T}{V} \cdot \dot{T}}_{\text{Indirect effect}}$$

$$\underbrace{+(1-\kappa^{-1}\eta)\dot{F}_d - (1-\kappa^{-1}\eta)\psi\eta\sum_i s_i \dot{p}_i}_{\text{Learning/spillover effect}}$$

where V: GDP; F_d: final demand; T: technology stock; P: factor's price; s_i: $(PiXi)/(PV)$; X_i: factor i's quantity; η : production elasticity to cost; e: elasticity to production: $\psi = e/(1-e(1-\eta))$: κ : profit ratio ($= PV/C$); and C: total cost.

Source: Watanabe (2005).

B. *Technology Substitution for Constrained Production Factors in Japan's Manufacturing Industry*

By utilizing following translog cost function, technology substitution/complement for/with Energy, Labor and Capital.

(i) Production $Y = F(X_i)$

Xi: L (labor); K (capital); M (material); E (energy): T (technology tock)

(ii) Cost $GC = C(Y, P_i)$

Pi: P_l (lab. price); P_k (cap. price); P_m (mat. price); P_e (energy price);

P_t (technology service price)

$$\ln C = \ln AY + \sum_i \alpha_i \ln P_i + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln P_i \cdot \ln P_j$$

$$\sum_i \alpha_i = 1, \quad \sum_i \beta_{ij} = \sum_j \beta_{ji} = 0 \qquad \beta_{ij} = \beta_{ji}$$

A: scale factor; α_i, β_{ij} : elasticities $(i, j = L, X, M, E, T)$

$$M_i = \frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i}{C} \cdot \frac{\partial C}{\partial P_i} = \frac{P_i}{C} \cdot X_i = \frac{P_i X_i}{C} = \frac{GX_i C}{C} \quad \text{(cost share)}$$

GX_iC: gross X_i cost

(iii) Elasticity of Substitution between production factors i and j

$$\sigma_{ij} = \frac{C \cdot \left(\frac{\partial^2 C}{\partial P_i \partial P_j}\right)}{\frac{\partial C}{\partial P_i} \cdot \frac{\partial C}{\partial P_j}} = \frac{\beta_{ij} + M_i M_j}{M_i M_j} \quad (i \neq j)$$

$\sigma_{ij} > 0.1$	Substitution
$0.1 \geqq \sigma_{ij} \geqq -0.1$	Neutral
$-0.1 > \sigma_{ij}$	Complement

Table A2 Estimate of Translog Cost Function in Japan's Manufacturing Industry *(1956-1992)*

	α_i	β_{li}	β_{ki}	β_{mi}	β_{ei}
$M_l =$	0.1608	$+0.0232 \ln(P_l/Pt)$	$+0.0092 \ln(Pk/Pt)$	$-0.0263 \ln(Pm/Pt)$	$-0.0062 \ln(Pe/Pt)$
	(91.89)	(13.82)	(5.40)	(−10.60)	(−5.80)
$Mk =$	0.1440	$+0.0092 \ln(P_l/Pt)$	$+0.0663 \ln(Pk/Pt)$	$-0.0636 \ln(Pm/Pt)$	$-0.0089 \ln(Pe/Pt)$
	(74.13)	*(5.40)*	*(13.77)*	(−12.21)	(−3.16)
$Mm =$	0.6350	$-0.0263 \ln(P_l/Pt)$	$-0.0636 \ln(Pk/Pt)$	$+0.1042 \ln(Pm/Pt)$	$-0.0031 \ln(Pe/Pt)$
	(265.55)	(−10.60)	*(-12.21)*	(15.58)	(−1.01)
$Me =$	0.0386	$-0.0062 \ln(P_l/Pt)$	$-0.0089 \ln(Pk/Pt)$	$-0.0031 \ln(Pm/Pt)$	$+0.0184 \ln(Pe/Pt)$
	(32.65)	(−5.80)	(−3.16)	(−1.01)	(10.17)

C. *System Conflict in an Information society and Subsequent Functionality Development Decline*

Production function

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

$$\ln V = A + \alpha \ln L + \beta \ln K + \gamma_1 \ln T + \gamma_2 D_x \ln T$$

where A: scale factor; α, β, γ_1 and γ_2 : elasticities; D_x: coefficient dummy variable representing the trend in shifting from an industrial society to an information society ($D_x = 1/(1+e^{-at-b})$) , a, b: coefficients).

Marginal oroductivity of technology

$$MPT = \frac{\partial V}{\partial T} = \frac{\partial \ln V}{\partial \ln T} \cdot \frac{V}{T} = (\gamma_1 + \gamma_2 \cdot D_x) \cdot \frac{V}{T}$$

$$MPT = F\ (V,\ T,\ D_x)$$

$$\ln MPT = B + \alpha_1 \ln V + \alpha_2 \ln T + \alpha_3 \ln D_x + \beta_1 \ln V \cdot \ln T + \beta_2 \ln V \cdot \ln D_x + \beta_3 \ln T \cdot \ln D_x$$

where B: scale factor; α_i and β_i (i = 1~3): elasticities

$$IEL\ (Institutional\ \ Elasticity) = \frac{\partial \ln MPT}{\partial \ln D_x}$$

$$MPT = aV\left(1 - \frac{1}{FD}\right), \quad FD = \frac{1}{1 - \left(MPT/aV\right)}$$

In case of high-technology firms,

$V = F(L,\ K,\ T) = F(L(T),\ K(T),) \approx F(T),\ T_t \equiv pt + q$

Epidemic function depicts

$$\frac{dV}{dt} = aV\left(1 - \frac{V}{N}\right) = aV\left(1 - \frac{1}{FD}\right), FD \equiv \frac{N}{V} \quad \text{where N: carrying capacity}$$

$$\frac{dV}{dt} = \frac{dT}{dt} \cdot \frac{dV}{dT} = P\frac{dV}{dT} \approx P\frac{\partial V}{\partial T} = aV\left(1 - \frac{1}{FD}\right)$$

$$\therefore\ \frac{\partial V}{\partial T} = MPT = \frac{a}{P}V\left(1 - \frac{1}{FD}\right) = a'V\left(1 - \frac{1}{FD}\right) \quad \text{where } a' \equiv \frac{a}{P}.$$

D. Necessary Condition for Sustainable FD

Given the average growth rate of T_i and T_s, g_i and g_s, and their ratio w,

$$T_i = T_{i0}e^{g_i t},\quad T_s = T_{s0}e^{g_s t} \text{ and } \frac{g_i}{g_s} = w \tag{A1}$$

where T_{i0} and T_{s0}: initial level of T_i and T_s, respectively, and t: time trend.
z can be developed as follows:

$$z = \frac{1}{1+\frac{\Delta T_s/T_s}{\Delta T_i/T_i}}\cdot\frac{T_i}{T_s} = \frac{1}{1+\frac{g_s}{g_i}}\cdot\frac{T_i}{T_s} = \frac{w}{1+w}\cdot\frac{T_{i0}e^{g_i t}}{T_{s0}e^{g_s t}} = \frac{w}{1+w}\cdot\frac{T_{i0}}{T_{s0}}e^{g_s(w-1)t} \tag{A2}$$

$$\frac{dz}{dT_i} = \frac{dz}{dt}\cdot\frac{dt}{dT_i} \tag{A3}$$

From equation (A2)

$$\frac{dz}{dt} = \frac{w}{1+w}\cdot\frac{T_{i0}}{T_{s0}}g_s(w-1)e^{g_s(w-1)t} = \frac{w(w-1)}{1+w}\cdot g_s\cdot\frac{T_{i0}}{T_{s0}}e^{g_s(w-1)t} \tag{A4}$$

$\frac{dz}{dt} > 0$ when

$$\frac{w(w-1)}{1+w}\cdot g_s > 0 \tag{A5}$$

Since $\frac{dT_i}{dt} = T_{i0}g_ie^{g_it}$, $\frac{dt}{dT_i} > 0$ when $g_i > 0$

From equations (A3) and (A4),

$$\frac{dz}{dT_i} > 0 \quad \text{(necessary condition for sustainable } FD\text{)} \tag{A6}$$

when

$$\frac{w(w-1)}{1+w}\cdot g_s > 0 \text{ and } g_i > 0 \tag{A7}$$

Necessary condition for sustainable FD can be identified as inequalities (7) and given that $gi > 0$ and $g_s > 0$ and , it can be identified as follows:

$$\frac{w(w-1)}{1+w} > 0 \tag{A8}$$

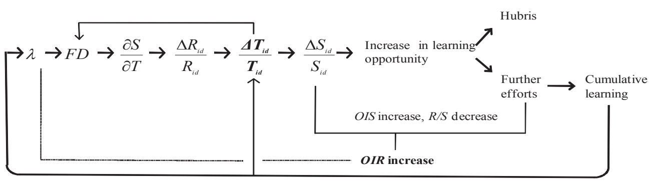
Since

$w = \frac{g_i}{g_s} > 0$, then $w-1 > 0$ therefore, $g_i > g_s$

This implies

$$\frac{\Delta T_i}{T_i} > \frac{\Delta T_s}{T_s} > 0 \tag{A9}$$

E. Learning and Domestication for Sustainable FD



F. Requirement of Sustainable FD for Coopetition

Functionality development (FD) *can be depleted as follows* $\rightarrow dFD/dT > 0$ *is the question*

$$FD = \frac{2}{1-\frac{1}{a\Delta T}\frac{\Delta P}{P}} = \frac{2}{1-\frac{1}{aT}\frac{\Delta P/P}{\Delta T/T}} = \frac{2}{1-\frac{1}{aT}\frac{\partial \ln P}{\partial \ln T}} = \frac{2}{1-\frac{\kappa}{aT}} \tag{A10}$$

where a : diffusion velocity, and κ : elasticity of technology to its relative prices ($= \partial \ln P/\partial \ln T$).

Requirement to Sustainable Functionality Development: A case of Canon's Printers

Requirement to sustainable functionality development (FD) increase ($dFD/dT > 0$) can be obtained:

$$\frac{d}{dT}\left(1-\frac{\kappa}{aT}\right) = -\frac{1}{a}\frac{d}{dT}\frac{\kappa}{T} = -\frac{1}{a}\left(-\frac{\kappa}{T^2}+\frac{1}{T}\cdot\frac{d\kappa}{dT}\right) = -\frac{\kappa}{aT^2}\left(\frac{d\ln\kappa}{d\ln T}-1\right) < 0 \tag{A11}$$

Under the condition when $\kappa\left(=\frac{\partial \ln P}{\partial \ln T}\right) > 0$, this requirement is equivalent to

$$\frac{d\ln\kappa}{d\ln T} > 1 \tag{A12}$$

Since elasticity of technology to its elasticity to price $\left(\frac{d\ln\kappa}{d\ln T}\right)$ is smaller than 1 equation (A12) can be satisfied by incorporating **the effects of external learning by means of two factors learning** as follows:

$$P = AT^{\kappa_1}PC^{\gamma} = A'T'^{\kappa_2} \tag{A13}$$

where PC : cumulative PC shipment;

T': gross technology stock that incorporated the effects of external learning;

κ_1, γ and κ_2 : elasticities; and A, A' : scale factors.

In this condition, equation (A12) requirement is equivalent to equation (A14):

$$\frac{d\ln\kappa_2}{d\ln T'} > 1 \tag{A14}$$

Since **printers technology is induced by the dissemination of PC**, it can be depicted by equation (A15):

$$T = B\cdot PC^{\phi} \tag{A15}$$

where B : scale factor and ϕ: elasticity.

Taking logarithm of equation (A13) and substituting PC in equation (A15) for PC in equation (A10-A13), the following equation is obtained:

$$\ln P = \ln A + \kappa_1\ln T + \gamma\ln PC = \ln A + \kappa_1\ln T + \frac{\gamma}{\phi}(\ln T - \ln B) = (\ln A - \frac{\gamma}{\phi}\ln B) + (\kappa_1+\frac{\gamma}{\phi})\ln T = \ln A' + \kappa_2\ln T' \tag{A16}$$

From equation (A16), the following identifications can be confirmed:

$$\ln A' = (\ln A - \frac{\gamma}{\phi}\ln B) \tag{A17}$$

$$\kappa_2\ln T' = (\kappa_1+\frac{\gamma}{\phi})\ln T \tag{A18}$$

Taking logarithm of equation (A18),

$$\ln\kappa_2 + \ln\ln T' = \ln(\kappa_1+\frac{\gamma}{\phi}) + \ln\ln T \tag{A19}$$

Differentiate equation (A19) with respect to $\ln T'$

$$\frac{d\ln\kappa_2}{d\ln T'} + \frac{1}{\ln T'} = \frac{d\ln(\kappa_1+\frac{\gamma}{\phi})}{d\ln T'} + \frac{1}{\ln T}\frac{d\ln T}{d\ln T'} \quad \left(\frac{d\ln(\kappa_1+\frac{\gamma}{\phi})}{d\ln T'} \text{ is small enough with positive value}\right) \tag{A20}$$

$$\frac{d\ln\kappa_2}{d\ln T'} = \frac{d\ln(\kappa_1+\frac{\gamma}{\phi})}{d\ln T'} + \frac{1}{\ln T}\frac{d\ln T}{d\ln T'} - \frac{1}{\ln T'} > \frac{1}{\ln T}\frac{d\ln T}{d\ln T'} - \frac{1}{\ln T'} > 1 \tag{A21}$$

Thus, equation (A12) requirement can be developed by the following inequality:

$$\frac{d\ln\kappa}{d\ln T} > 1 \qquad \frac{1}{\ln T}\frac{d\ln T}{d\ln T'} > 1 + \frac{1}{\ln T'} \qquad \frac{1}{Y}\cdot\frac{dY}{dX} > 1 + \frac{1}{X} \quad \left(\begin{matrix} X \equiv \ln T' \\ Y \equiv \ln T \end{matrix}\right)$$

Provided that initial state of Y and X as Y_0 and X_0, respectively ($Y_0 = X_0$ given that no external learning at the initial state), the above inequality can be developed as follows:

$$\frac{Y}{X} > e^{X-X_0}$$

From equation (A18),

$$\kappa_2\ln T' = (\kappa_1+\frac{\gamma}{\phi})\ln T \qquad \kappa_2 X = (\kappa_1+\frac{\gamma}{\phi})Y$$

Therefore,

$$\kappa_2 = (\kappa_1+\frac{\gamma}{\phi})\frac{Y}{X} > (\kappa_1+\frac{\gamma}{\phi})e^{X-X_0} \tag{A22}$$

Inequality (A22) depicts the requirement to sustainable functionality development increase under X ($\ln T'$) development.

X can be identified by the following steps:

From equations (A16) and (A17),

$$\kappa_2X_0 = \kappa_2\ln T_0 = \ln P_0 - \ln A' = \ln P_0 - (\ln A - \frac{\gamma}{\phi}\ln B) \tag{A23}$$

$$\kappa_2 = \frac{\ln P_0 - (\ln A - \frac{\gamma}{\phi}\ln B)}{\ln T_0} \tag{A24}$$

From equations (A16), (A22) and (A23,

$$X = \frac{(\kappa_1+\frac{\gamma}{\phi})Y}{\kappa_2} = \frac{\ln P - (\ln A - \frac{\gamma}{\phi}\ln B)}{\kappa_2} = \frac{\ln P - (\ln A - \frac{\gamma}{\phi}\ln B)}{\ln P_0 - (\ln A - \frac{\gamma}{\phi}\ln B)}\ln T_0 \tag{A25}$$

Therefore, $X - X_0 = \frac{\ln P/P_0}{\kappa_2}$

Substituting this balance for X-X_0 in inequality (A22) (**the requirement to sustainable functionality development increase**) ,

$$\kappa_2 > (\kappa_1+\frac{\gamma}{\phi})e^{\frac{\ln P/P_0}{\kappa_2}} \tag{A26}$$

G. Optimal FD Satisfying Utmost Gratification of Consumption

(1) Model Construction

$$Y(t) = C(t) + I(t) = (1-s(t))Y(t) + s(t)Y(t) \Rightarrow \begin{matrix} C(t) = (1-s(t))Y(t) \\ \ln \boldsymbol{C(t)} = \ln \boldsymbol{Y(t)} + \ln(1-\boldsymbol{s(t)}) \end{matrix}$$

where $C(t)$: consumption, $I(t)$: investment, and $s(t)$: investment intensity ($I(t)/Y(t)$).

(i) Main Variables

				price	cost
$t \in [t_0, +\infty)$	Time on the infinite horizon				
$Y = Y(t)$	Production	*First phase variable*	⇨	ψ_2	$C_2 = \psi_2\cdot Y$
$N = N(t)$	Carrying capacity				
$FD = FD(t) = \frac{N(t)}{Y(t)}$	Functionality development (FD)				
$\eta = \eta(t) = \frac{Y(t)}{N(t)} = \frac{1}{FD(t)}$	Production to carrying capacity	*Second phase variable* $\Rightarrow \theta(t) \equiv FD(t) - 1$	⇨	ψ_1	$C_1 = \psi_1\cdot\theta$
$s = s(t) = \frac{\dot{N}(t)}{Y(t)}$	Investment intensity (II)	*Control variable*			

(ii) System's Dynamics

$$\begin{cases} \dot{Y}(t) = a\cdot Y(t)\cdot(1-\eta(t)) \\ \dot{\eta}(t) = a\cdot\eta(t)\cdot\left[1-\eta(t)-\frac{s(t)}{a}\cdot\eta(t)\right] \end{cases}$$

Stationary level of FD

⇩

Stationary condition $\dot{\eta}(0) = 0$

⇨ $(1-\eta_0\cdot(1+\frac{s_0}{a})) = 0$

Here, $Y(t)$ represents GDP at time t.

Constant Levels of Investment Intensity (II)

Constraint $0 < s(t) = s(0) \equiv s_0 \leq A < 1$

Gratification of consumption sustaining stationary level of functionality development

It is necessary for accurate application of the Pontryagin maximum principle.

If this constraint is satisfied, one can prove the existence result for the optimal control problem.

$$s_0 = a\left(\frac{1-\eta_0}{\eta_0}\right) = a\cdot\left(\frac{1-Y_0/N_0}{Y_0/N_0}\right) = a\cdot\frac{(N_0-Y_0)}{Y_0} = a\cdot(FD_0-1)$$

(2) Optimal Control Problem for Functionality Development

$$\begin{cases} \theta(t) \equiv FD(t)-1 \Leftrightarrow FD(t) = \theta(t)+1 \Leftrightarrow \dot{FD}(t) = \dot{\theta}(t) \qquad \eta(t) = \frac{1}{FD(t)} = \frac{1}{\theta(t)+1} \\ \dot{\theta}(t) = \dot{FD}(t) = s(t) - a\cdot(FD(t)-1) = s(t) - a\theta(t) \\ \dot{Y}(t) = a\cdot Y(t)\cdot\left(\frac{\theta(t)}{\theta(t)+1}\right) \end{cases}$$

(3) Utility Function (Integrated Logarithmic Consumption Index)[2)]

Consumption $C(t) = F(FD(t), Y(t), s(t)) = F(\theta(t), Y(t), s(t))$

$$U(\theta(t), Y(t), s(t)) = \int_0^{+\infty} e^{-\rho\cdot t}\cdot\ln C(t)dt = \int_0^{+\infty} e^{-\rho\cdot t}\cdot(\ln Y(t) + \ln(1-s(t)))dt$$

The optimality is understood with respect to the utility function U represented by an integral with a discount coefficient ρ.

Application of the Pontryagin Maximum Principle

Hamiltonian function (Hamiltonian problem which measures the current flow of **utility** from all sources)

$$H(\theta, Y, \psi_1, \psi_2, s) = \ln Y + \ln(1-s) + \psi_1\cdot(s - a\cdot\theta) + \psi_2\cdot a\cdot Y\cdot\frac{\theta}{\theta+1}$$

Investment intensity that maximizes Hamiltonian function

$$\frac{\partial H}{\partial s} = -\frac{1}{1-s} + \psi_1 = 0 \Rightarrow s = 1 - \frac{1}{\psi_1} = \frac{\psi_1 - 1}{\psi_1}$$

(Investment intensity that maximizes utility)

2) $Y(t) = C(t) + I(t) = (1-s(t))Y(t) + s(t)Y(t)$ ⇨ $C(t) = (1-s(t))Y(t)$ ⇨ $\ln \boldsymbol{C(t)} = \ln \boldsymbol{Y(t)} + \ln(1-\boldsymbol{s(t)})$

where $C(t)$: consumption, $I(t)$: investment, and $s(t)$: investment intensity ($I(t)/Y(t)$).

Logarithmic form of utility function is used in the optimal consumption problems (Krasovskii, 2006).

(4) Hamiltonian System

Hamiltonian system with maximized s

$$H(\theta, Y, \psi_1, \psi_2) = \ln Y - \ln\psi_1 + \psi_1\cdot(1-\frac{1}{\psi_1} - a\cdot\theta) + \psi_2\cdot a\cdot Y\cdot\frac{\theta}{\theta+1}$$

(i) Price function (adjoint variable)

$$\dot{\psi}_1 = \rho\cdot\psi_1(t) - \frac{\partial H[\theta(t), Y(t), s(t), \psi_1(t), \psi_2(t)]}{\partial\theta} = \rho\cdot\psi_1(t) + a\cdot\psi_1(t) - a\cdot\frac{\psi_2(t)\cdot Y(t)}{(\theta(t)+1)^2}$$

$$\dot{\psi}_2 = \rho\cdot\psi_2(t) - \frac{\partial H[\theta(t), Y(t), s(t), \psi_1(t), \psi_2(t)]}{\partial Y} = \rho\cdot\psi_2(t) - a\cdot\frac{\psi_2(t)\cdot\theta(t)}{(\theta(t)+1)} - \frac{1}{Y(t)}$$

(ii) Cost function

$$\dot{Cost}(t) = \dot{C}_1(t) + \dot{C}_2(t) = \dot{\psi}_1(t)\cdot\theta(t) + \psi_1(t)\cdot\dot{\theta}(t) + \dot{\psi}_2(t)\cdot Y(t) + \psi_2(t)\cdot\dot{Y}(t)$$

$$\dot{C}_1(t) = \dot{\psi}_1(t)\cdot\theta(t) + \psi_1(t)\cdot\dot{\theta}(t)$$

$$\dot{C}_2(t) = \dot{\psi}_2(t)\cdot Y(t) + \psi_2(t)\cdot\dot{Y}(t)$$

(iii) Optimal control [→ (2)] [3)]

$$\dot{\theta}(t) = s(t) - a\cdot\theta(t) = 1 - \frac{1}{\psi_1} - a\cdot\theta(t) = 1 - \frac{\theta}{C_1} - a\cdot\theta$$

$$\dot{Y}(t) = a\cdot Y(t)\cdot\frac{\theta(t)}{\theta(t)+1}$$

(iv) Cost minimum

$$\dot{C}_1(t) = \rho\cdot C_1(t) - \frac{a\cdot\theta(t)\cdot C_2(t)}{(\theta(t)+1)^2} + \frac{C_1(t)}{\theta(t)} - 1$$

$$\dot{C}_2(t) = \rho\cdot C_2(t) - 1$$

Cost minimum condition
$\Rightarrow \dot{C}_1(t) = \dot{C}_2(t) = 0 \Rightarrow C_2 = \frac{1}{\rho}$

Solution of Stationary Equation of the Hamiltonian System $C_1 = \frac{\theta}{(1-a\cdot\theta)}$ ⇨ $\frac{(a+\rho)\cdot\rho}{a}\cdot C_1 = \frac{\theta}{(\theta+1)^2}$ ⇨ $\frac{(a+\rho)\cdot\rho}{a} = \frac{1-a\cdot\theta}{(\theta+1)^2}$

Solution of Stationary Equation for FD $\frac{(a+\rho)\cdot\rho}{a} = \frac{1-a\cdot\theta}{(\theta+1)^2}$ ⇨ $\frac{(a+\rho)\cdot\rho}{a} = \frac{(1-a\cdot(FD-1))}{FD^2}$ ⇨ $\frac{(a+\rho)\rho}{a}\cdot FD^2 + a\cdot FD - (1+a) = 0$

3) **FD maximum** ⇨ $\dot{FD} = \dot{\theta} = 0$ ⇨ $\theta = \frac{C_1}{a\cdot C_1 + 1}$ ⇨ $\rho\cdot C_1 - \frac{1}{\rho}\cdot\frac{a\cdot\theta}{(\theta+1)^2} + \frac{C_1}{\theta} - 1$ ⇨ $(a+\rho)\cdot\rho\cdot C_1 = \frac{a\cdot C_1}{a\cdot C_1+1}\cdot\frac{(a\cdot C_1+1)^2}{((a+1)\cdot C_1+1)^2}$

Normal form adjoint equation ⇨ $\dot{\psi}_1(t) = \rho\psi_1(t) - \frac{\partial H}{\partial\theta}$, $\dot{\psi}_1(t) = \rho\psi_1(t) - \frac{\partial H}{\partial\theta}$ $(\psi(t) = e^{\rho t}\psi^*(t) \Rightarrow \dot{\psi}(t) = \rho\psi - \frac{\partial H}{\partial X};\ X = Y, \theta)$

ψ^*: steady state price of X satisfying the above condition.

H. Diffusion Parameters in Major Innovative Goods

		N	p	q	adj. R^2	$x = q/p$	$\varepsilon = \frac{d \ln p}{d \ln x}$	
Printer	**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)	0.70×10^{-1} (5358.9)	0.5×10^{1} (2616.7)	0.999	5.0	17.6	**Sky Walker** (*1997/10*)
	MP 2	65741 (170.24)	0.37×10^{-1} (1270.1)	0.15×10^{2} (438.3)	0.999	15.6	-0.10	
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] 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.
Figures in parentheses indicate t-value. All demonstrates statically significant at the 5% level.

I. Sustainable FD by Major Innovation

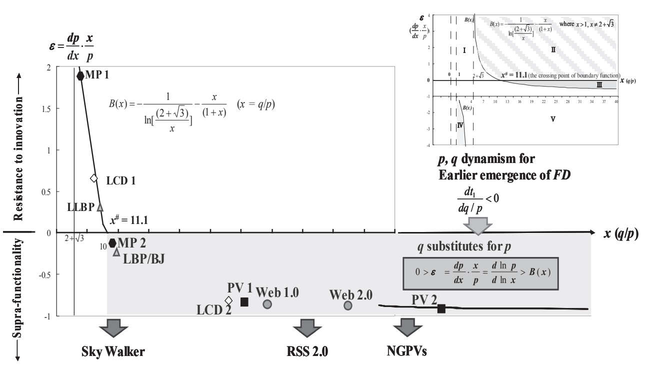
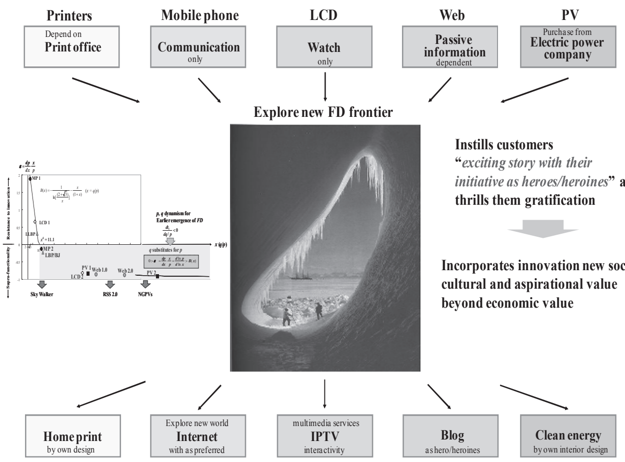


Fig. A1. Sustainable Functionality Development Condition.

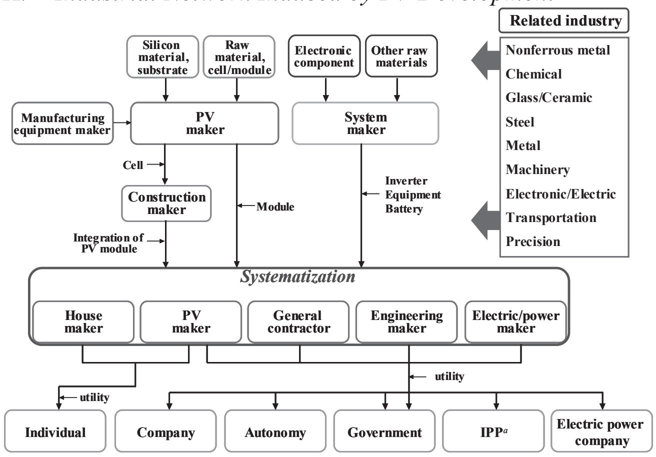
1. While latest high-technology products as LBP/BJ, MP 2, LCD 2, Web 1.0, Web 2.0, PV 1 and PV 2 satisfy conditions for sustainable functionality development, LLBP (1976), MP 1 (1996) and LCD 1 () do not satisfy these conditions resulting in being substituted by LBP, BJ, MP 2 and LCD 2.

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

J. New FD Frontier



K. Industrial Network Induced by PV Development



L. Areas Satisfying Earlier Functionality Development Emergence

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

where p: innovator; q: imitator; and N: carrying capacity

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

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

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

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

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

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

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

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

If $1 < x < 2+\sqrt{3}$, then , and so

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

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

where z: x elasticity to p.

If $x > 2+\sqrt{3}$, then , and we get

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

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

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