Utmost Fear Hypothesis Explores Green Technology Driven Energy for Sustainable Growth

Chihiro Watanabe[1, a]

[1]Professor, Department of Industrial Management, Tokyo Seitoku University,
Professor Emeritus, Tokyo Institute of Technology
Visiting Professor, National University of Singapore
Visiting Professor, University of Jyvaskyla, Finland
Guest Scholar, International Institute for Applied Systems Analysis (IIASA)

Jae-Ho Shin[2,b]

[2]R&D Associate Research Fellow, Korea Institute of S&T Evaluation and Planning (KISTEP)

[a]watanabe.c.pqr@gmail.com, [b]jhshin@kistep.re.kr

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 system conflict with the rise of the information society, recent increase in oil prices has signaled the possibility of a paradigm shift to a post-oil society. In addition, global economic stagnation resulted from excessive consumption has been inducing "*new normal*" customers supra-functionality beyond economic value.

These trends inevitably lead a way to exploring high efficient PV system incorporating supra functionality beyond economic value. March 11 catastrophe accelerates this trajectory.

By means of an empirical analysis utilizing optimal trajectory analysis and taking Japan's PV development as technology driven energy to which Japan maintains institutional advantage, the foregoing hypothetical views are demonstrated thereby new entrepreneurial strategy toward exploring high efficient PV system incorporating supra-functionality beyond economic value is suggested.

Keywords: *Post-oil society, Open innovation, PV, Utmost fear, Supra-functionality, Co-evolution, Institutional innovation, Entrepreneurial strategy*.

1. Introduction

Japan 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 to have 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 [1, 2].

Such explicit dynamism was typically demonstrated by technology substitution for energy in the 1970s [3]. This accomplishment can largely be attributed to similar substitution efforts in the 1960s which resulted in technology substitution for labor leading to world top-level labor saving and automation technologies.

Supported by institutional systems for innovation, technology substitution for scarce resources functioned well in Japan typically in technology substituted for energy started from 1973 as demonstrated in **Fig. 1** [4, 5].

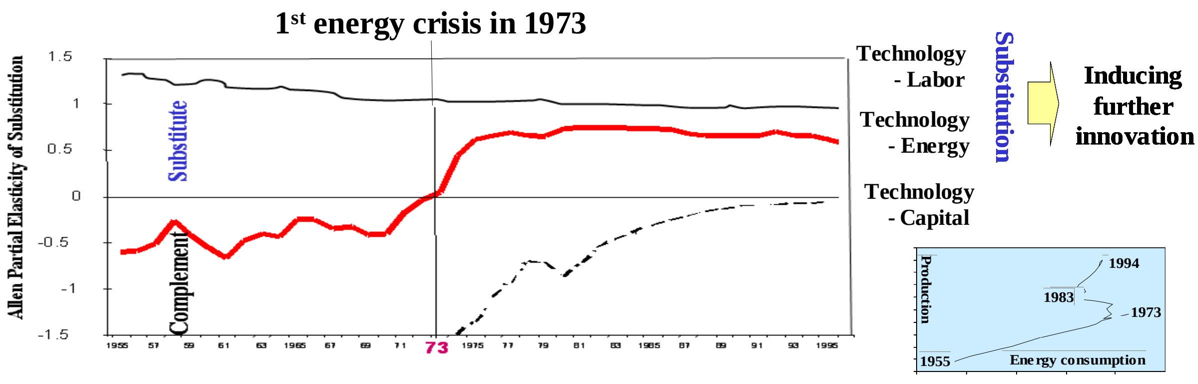

Fig. 1. Trends in Technology Substitution for Production Factors in the Japanese Manufacturing Industry (*1955-1997*) - *Allen Partial Elasticity of Substitution.*

Source: [3].

These cumulative technology substitution efforts subsequently enabled Japan to achieve a high-technology miracle in the 1980s.

Consequently, Japan demonstrates the world's highest energy efficiency as illustrated in **Fig. 2**. Furthermore, technology substitution for scarce resources led Japan demonstrates world top level of manufacturing technology.

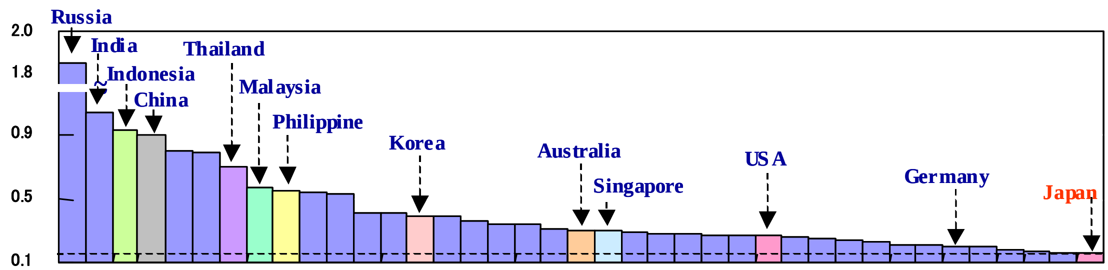

Figure 2. Energy Consumption per GDP in 40 Countries *(2004)*.

Source: [5].

Japan's unique institutional systems enabled conspicuous energy efficiency improvement in energy dependent industry in Japan as demonstrated in **Fig. 3**.

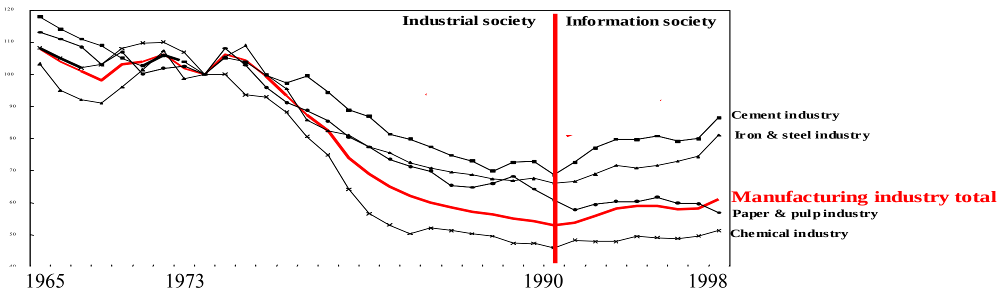

Fig. 3. Trend in Unit Energy Consumption in the Japanese Manufacturing Industry *(1965-1998) – Index: 1973 = 100.*

Thus, Japan constructed a sophisticated co-evolutionary dynamism between innovation and institutional systems by transforming external crises to a springboard for new innovation as illustrated in **Fig. 4**.

This transformation ability can largely be attributed to Japan's unique features of the nation to have (i) a strong motivation to overcoming fear based on xenophobia and uncertainty avoidance, (ii) while abundant curiosity, assimilation proficiency, and thoroughness in learning and absorption [1, 2].

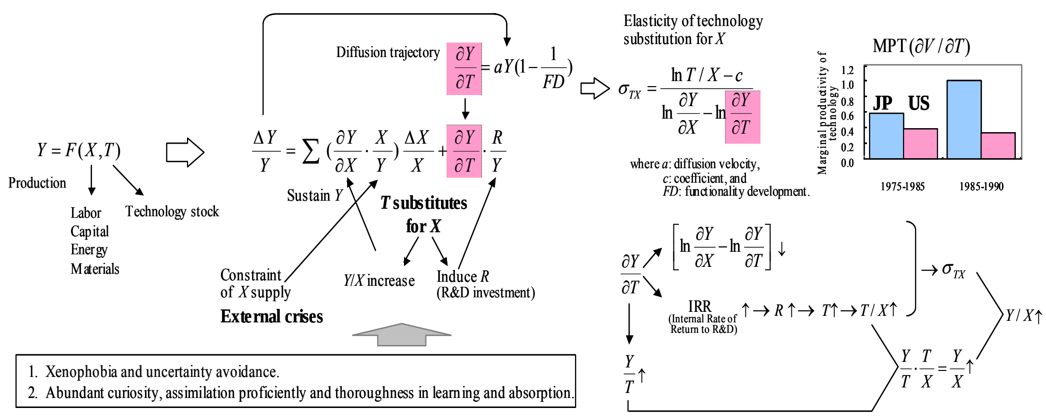

Fig. 4. Japan's Notable Dynamism in Transforming External Crises to a Springboard for New Innovation.

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

While the dramatic increase in oil prices in mid-2008 has signaled the possibility of a paradigm shift to a post-oil society, and not a few works demonstrated entrepreneurial strategies toward such a society (e.g., [6]), none has identified the possible impacts of the sequel that such utmost fear ever experienced might provide even after overcoming the fear.

By applying Japan's notable dynamism, this paper attempted to identify a possible inducement that utmost fear may transform crises into a springboard for new innovation.

In line with the increasing significance of production, diffusion and consumption integration, and subsequent significance of the gratification of consumption for constructing a sustainable development dynamism, by applying a habit persistence hypothesis [7] in which utmost gratification of consumption plays a decisive role in consumption behavior, an utmost fear hypothesis was developed. Given the unique features of the Japanese nation to have a strong motivation to overcoming xenophobia and uncertainty avoidance, Japan's innovation endeavor is very sensitive to such an utmost fear.

An empirical analysis based on the experience of a dramatic increase in oil prices was then conducted assuming photovoltaic solar cell (PV) development which is anticipated to play a leading role as technology-driven energy substituting for fossil energy [8].

Despite a locational disadvantage as a mid-latitude country, Japan has taken a leading role in world PV development. Exceeding the level of the US in 1999, Japan maintained the world leading position in PV development before transferring this position to Germany in 2007 and then to China. Three main factors have been critical to the successful development of PV technology in Japan [8]. First, like semiconductors, PV technology is central to a complex web of related technologies and can therefore benefit greatly from learning effects. Second, because of the interdisciplinary nature of PV development, technology spillover benefits are high, in turn further stimulating learning effects. Third, because of standalone, flexibility with respect to size, application and portability as well as multi-generational technological development, PV technology incorporates self-propagating development in its functionality similar to mobile phone [9]. All corresponds to Japan's explicit learning and assimilation ability based on abundant curiosity, assimilation proficiency, and thoroughness in learning and absorption. Consequently, PV can be considered a crystal of institutional innovation suits to Japan's institutional systems [10].

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On the basis of an empirical analysis on the development trajectory in Japan's PV development over the last 3 decades and also simulation analysis for the next two decades based on the experience of a dramatic increase in oil prices as US$147/b in July 2008, by utilizing the Bi-logistic growth model and Bass model, it was demonstrated that utmost fear plays a role similar to utmost gratification in consumption in leveraging a shift from resistance of innovation to supra-functionality development which incorporates social, cultural, aspirational, and emotional needs beyond economic value [11] aiming at establishing a non-oil dependent resilient society.

In the current environment of simultaneous global economic stagnation, and given increasing concern regarding Japan's model for transforming a crisis to a springboard for new innovation, the foregoing analysis provides an important suggestion to firms with respect to their entrepreneurial strategy under open innovation in a post-oil society. March 11 catastrophe accelerates this demand.

Section 2 reviews utmost fear hypothesis leveraging a new innovation. Section 3 analyzes Japan's PV development trajectory. An empirical analysis aiming at demonstrating the utmost fear hypothesis is introduced in Section 4. Section 5 briefly summarizes the new findings, policy implications and the focus of the future works.

2. Utmost Fear Hypothesis Leveraging a New Innovation

As reviewed in the preceding section, endogenous source of self-propagating functionality development (FD) can be expected by habit persistence hypothesis in that utmost gratitude of consumption plays a decisive role. Utmost fear like the recent dramatic increase in oil prices may play a similar role and leverages a shift from resistance of innovation [12] to supra-functionality [11]. Aiming at demonstrating this hypothetical view, an empirical analysis taking Japan's PV development in corresponds to the trend in oil prices was conducted.

Fig. 5 illustrates the scheme of utmost fear hypothesis in Japan's PV development characterized by its unique feature of the nation sensitive to utmost fear ever experienced while incorporating explicit comparative advantage in PV development.

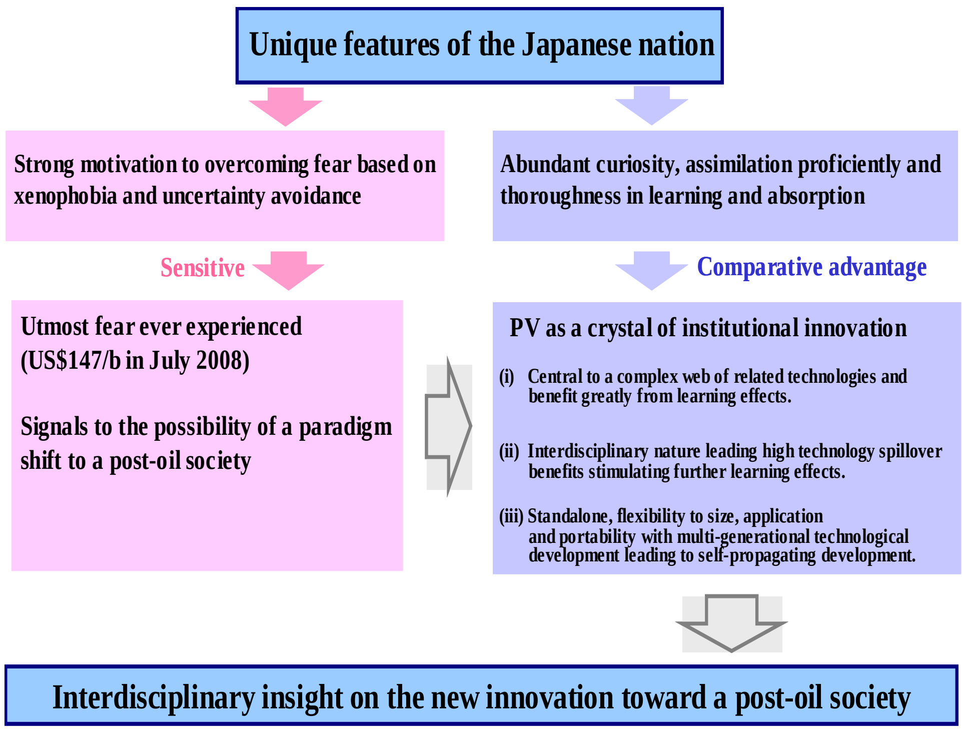

Fig. 5. Utmost Fear Hypothesis in Japan's PV Development.

3. PV Development Trajectory

Fig. 6 demonstrates the industrial networks induced by PV development and Japan's PV research as well as maker has ensured that Japan has become the leading PV nation world-wide, especially well fitted system.

The scarcity of natural conventional energy resources in Japan needs to accelerate the advancement of implementation of new energy such as PV.

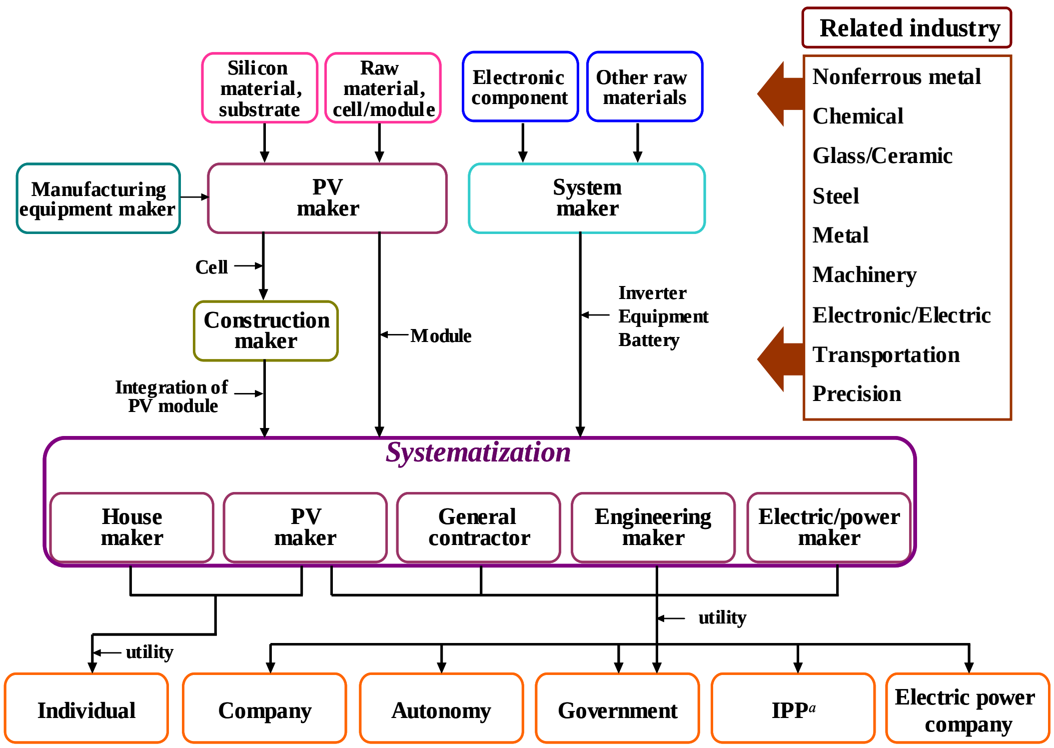

Fig. 6. Industrial Network Induced by PV Development.

[a] IPP: Independent Power Producer.
Source: Authors' elaboration based on [13].

Therefore, the Japanese government promotes implementation of technological development of equipment and installation of facilities. **Fig. 7** demonstrates Japan's PV development trajectory over the last 3 decades. Based on this Figure, development of innovative technology leading to new concept of PV can be observed.

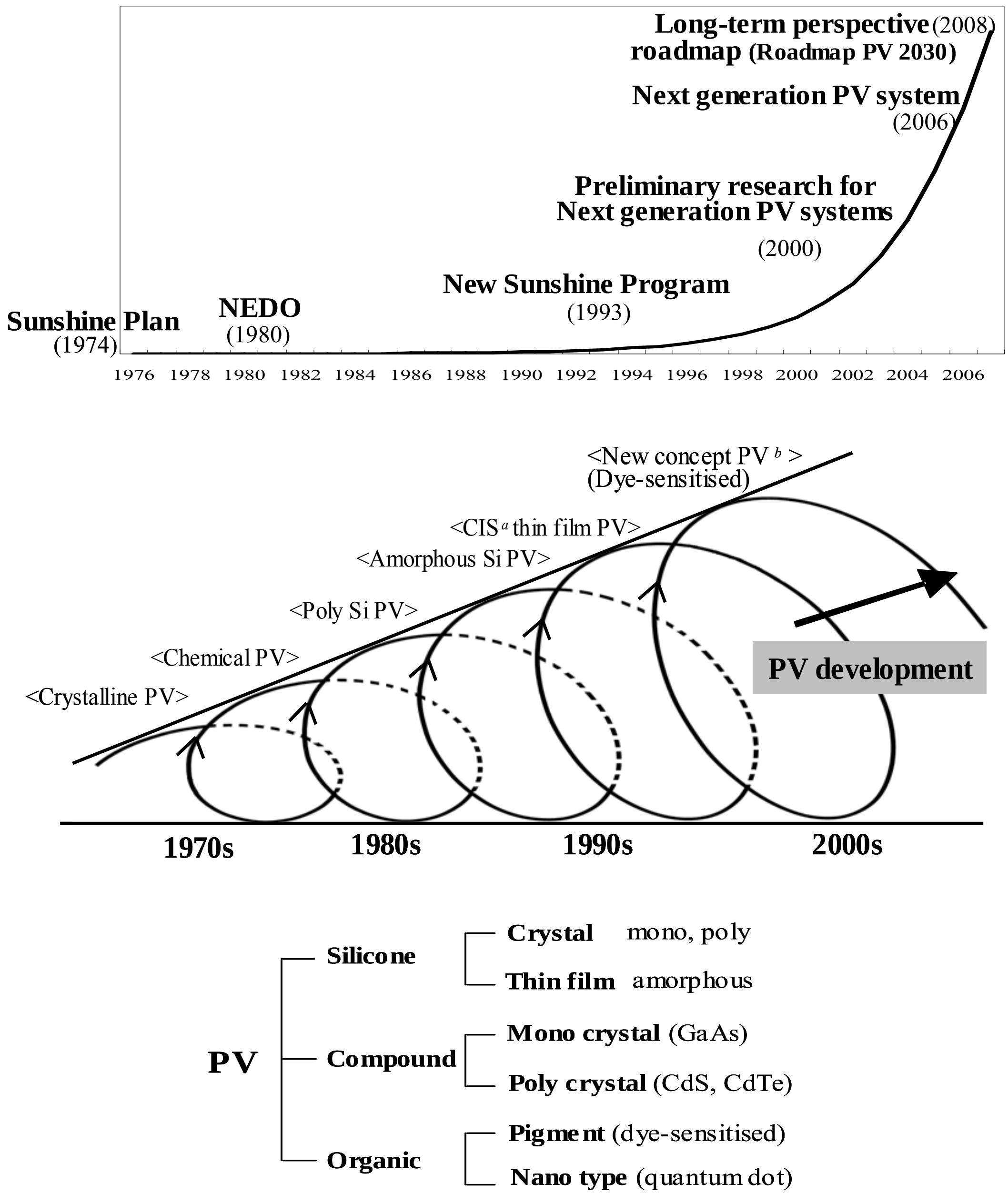

Figure 7. Japan's PV Development Trajectory (1974-2008).

[a] CIS: Copper-Indium-Diselenide compound PV.

Source: Authors' elaboration based on [14].

Table 1 and **Fig. 8** review trends in PV development in the world over the period 1976-2007.

The Table and Figure demonstrate Japan's intensive endeavor in PV development as prospecting technology driven renewable energy [4, 15, 16, 17]. Japan exceeded its PV development level that of the US in 1999 and took the world leading position in this development in the world. However, Germany accelerated PV development from 2007 and since then the world leading position shifted from Japan to Europe and then to China.

Table 1 Trends in PV Development in the World *(1976-2007)*: MW

Year	Japan	USA	Europe	Others	Total
1976	0.01	0.32	0	0	0.33
1977	0.03	0.42	0	0	0.45
1978	0.06	0.84	0	0	0.90
1979	0.1	1.2	0	0	1.3
1980	0.3	2.5	0.3	0	3.1
1981	1.0	3.5	0.8	0	5.3
1982	2.1	5.2	1.4	0.1	8.8
1983	5.0	8.2	3.3	0.3	16.8
1984	8.9	8.0	3.6	0.8	21.3
1985	10.1	7.7	3.4	1.4	22.6
1986	12.8	7.1	4.0	2.3	26.2
1987	13.2	8.7	4.5	2.8	29.2
1988	12.8	11.1	6.7	3.0	33.6
1989	14.2	14.1	7.9	4.0	40.2
1990	16.8	14.8	10.2	4.7	46.5
1991	19.8	17.1	13.4	5.0	55.3
1992	18.8	18.1	16.4	4.6	57.9
1993	16.7	22.4	16.6	4.4	60.1
1994	16.5	25.6	21.7	5.6	69.4
1995	17.4	34.8	21.1	6.4	79.7
1996	21.2	38.9	18.8	9.8	88.7
1997	35.0	51.0	30.4	9.4	125.8
1998	49.0	53.7	33.5	18.7	154.9
1999	80.0	60.8	40.0	20.5	201.3
2000	128.6	75.0	60.7	23.4	287.7
2001	171.2	100.3	86.4	32.6	390.5
2002	251.1	120.6	135.1	55.1	561.9
2003	363.9	103.0	193.4	83.8	744.1
2004	602.0	139.0	314.0	140.0	1195.0
2005	832.6	154.0	470.0	302.0	1758.6
2006	927.5	201.6	678.3	714.0	2521.4
2007	920.0	266.1	1062.8	1484.0	3732.9

Source: [18].

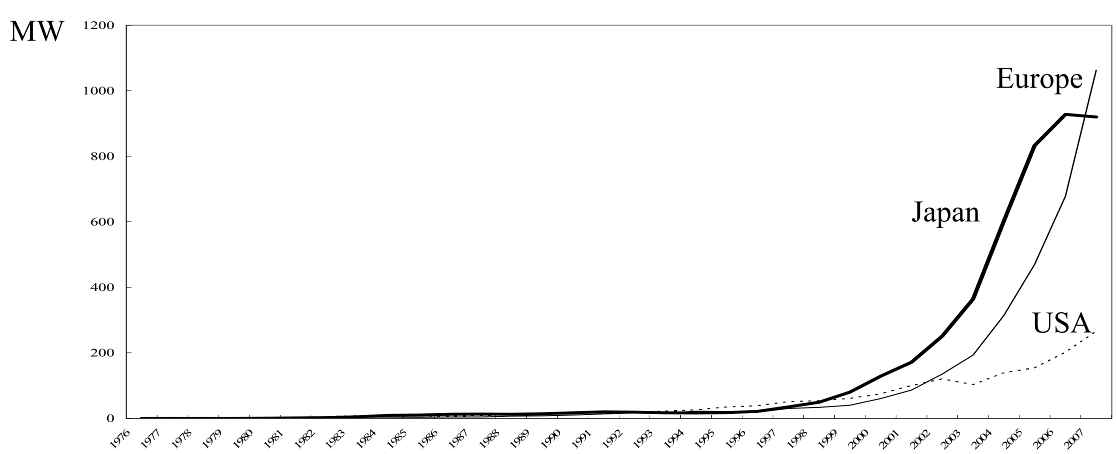

Fig. 8. Trends in PV Development in Japan, the USA and Europe

On the basis of these trends in the world PV development, **Table 2** and **Fig. 9** demonstrate trends in cumulative PV development in the world over the period 1976-2007.

Table 2 Trends in Cumulative PV Development in the World *(1976-2007)*: MW

Year	Japan	USA	Europe	Others	Total
1976	0.01	0.32	0	0	0.33
1977	0.04	0.74	0	0	0.78
1978	0.10	1.58	0	0	1.68
1979	0.2	2.8	0	0	3.0
1980	0.5	5.3	0.3	0	6.1
1981	1.5	8.8	1.1	0	11.4
1982	3.6	14.0	2.5	0.1	20.2
1983	8.6	22.2	5.8	0.4	37.0
1984	17.5	30.2	9.4	1.2	58.3
1985	27.6	37.9	12.8	2.6	80.9
1986	40.4	45.0	16.8	4.9	107.1
1987	53.6	53.7	21.3	7.7	136.3
1988	66.4	64.8	28.0	10.7	169.9
1989	80.6	78.9	35.9	14.7	210.1
1990	97.4	93.7	46.1	19.4	256.6
1991	117.2	110.8	59.5	24.4	311.9
1992	136.0	128.9	75.9	29.0	369.8
1993	152.7	151.3	92.5	33.4	429.9
1994	169.2	177.0	114.2	39.0	499.4
1995	186.6	211.7	135.3	45.4	579.0
1996	207.8	250.6	154.1	55.2	667.7
1997	242.8	301.6	184.5	64.6	793.5
1998	291.8	355.3	218.0	83.3	948.4
1999	371.8	416.1	258.0	103.8	1149.7
2000	500.4	491.0	318.7	127.2	1437.3
2001	671.6	591.4	405.0	159.8	1827.8
2002	922.7	712.0	540.1	214.9	2389.7
2003	1286.6	815.0	733.4	298.7	3133.7
2004	1888.6	954.0	1047.4	438.7	4328.7
2005	2721.2	1108.0	1517.4	740.7	6087.3
2006	3648.7	1309.6	2195.7	1454.7	8608.7
2007	4568.7	1575.7	3258.5	2938.7	12341.6

Original source: [18].

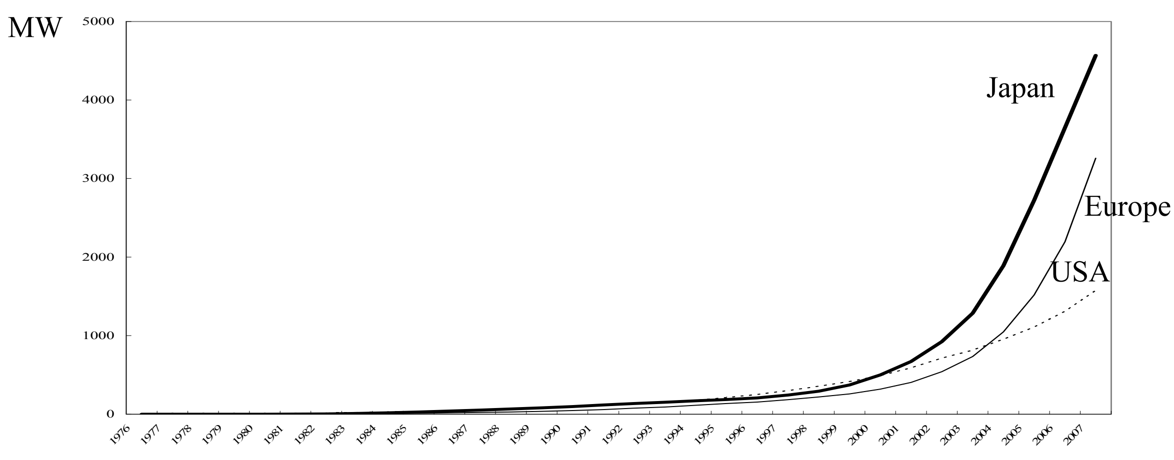

Figure 9. Trends in Cumulative PV Development in Japan, the USA and Europe *(1976-2007)*: MW.

The Table and Figure demonstrate Japan's leading position in cumulative PV development since exceeding that of the US in 2000.

On the basis of the trend in this cumulative PV development in Japan, by utilizing the Bi-logistic growth model, **Table 3** analyzes the composition of Japan's PV development trajectory over the period 1976-2007. Fig. 10 demonstrates this trajectory by decomposing phases 1 (Y_1) and 2 (Y_2) trajectories depending primarily on crystalline silicon based technology and on thin-film silicon technology, respectively.

Table 3 Estimation of Japan's PV Diffusion by the Bi-logistic Growth Model *(1976-2007)*: MW

$$\text{Model: } Y(t) = Y_1(t) + Y_2(t) = \frac{N_1}{1 + b_1 \cdot e^{-a_1 t}} + \frac{N_2}{1 + b_2 \cdot e^{-a_2 t}}$$

Parameter	Estimate	t-value	*adj.* R^2
N_1	0.5×10^3	34.62	0.999
N_2	10.0×10^3	713.21	
a_1	4.58×10^{-1}	12.73	
b_1	26.0×10^5	3.60	
a_2	3.98×10^{-1}	41.34	
b_2	4.59×10^5	3.59	

Sub trajectory	Inflection point	Sub trajectory	Rate of obsolescence (monthly)
Y_1	$t_1^{\#} = \frac{\ln b_1}{a_1}$	28.9 (2003)	1/(28.9x12) = 0.003
Y_2	$t_2^{\#} = \frac{\ln b_2}{a_2}$	34.5 (2009)	1/(34.5x12) = 0.002

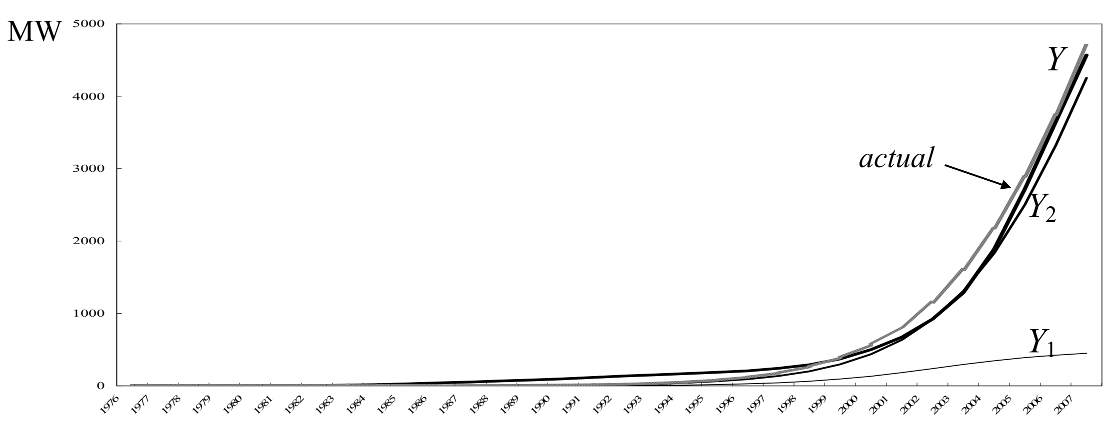

Fig. 10. Trends in Diffusion Trajectory of PV Development in Japan *(1976-2007)*: MW.

Looking at the Table and Figure we note that Y_1 reaches its carrying capacity with 500 MW level. Y_1 changed from increase diffusion velocity to its decrease at inflection point in 2003 with 250 MW level. While Y_2 reaches its carrying capacity with 10,000 MW, Y_2 changes from increase diffusion velocity to its decrease at inflection point in 2009 with 5,000 MW level.

4. Utmost Fear Hypothesis

4.1 Optimal Functionality Development Dynamics

(1) Functionality Development Trajectory in Japan's PV

Fig. 11 demonstrates estimation of Japan's PV development trajectory over the period 1976-2007 by utilizing the Bi-logistic growth model.

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

$Y(t)$: 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: timetrend by year.

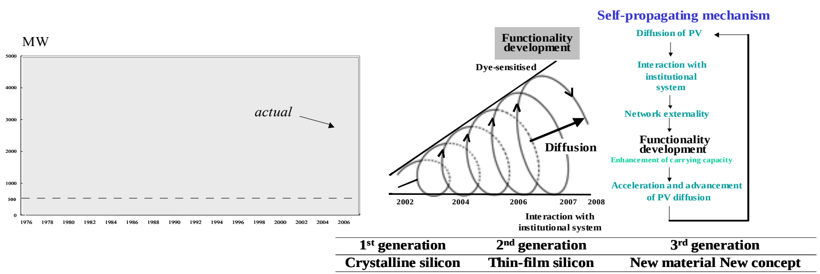

Fig. 11. Estimation of Japan's PV Development Trajectory by the Bi-logistic Growth Model *(1976-2007)*: MW.

(2) Optimal FD

Optimal functionality development trajectory in Japan's PV development was analyzed. **Fig. 12** illustrates scheme of the identification of optimal FD trajectory (see details Appendix).

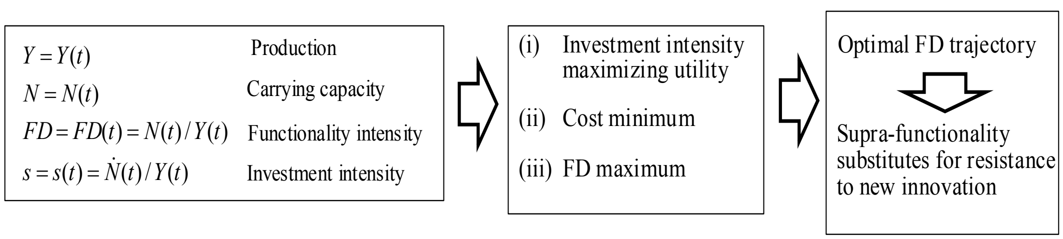

Fig. 12. Scheme of the Identification of Optimal FD Trajectory.

(3) Optimal FD Dynamics Leading to Supra-Functionality

Provided that PV is expected to be crystal of IT similar to mobile phones, and firms make every effort in maintaining sustainable FD in the "Innofumption dynamism," optimal FD trajectory should be endeavored in correspond to maximizing the gratification of consumption. With such understanding, PV development trajectory under certain investment intensity (cost minimum) that maximizes utility function (utility maximum) leading to utmost gratification of consumption (FD maximum) was analyzed based on optimal theory.

Fig. 13 compares trend in actual level of FD in Japan's PV development trajectory over the last decade with that of optimal level of FD estimated by the foregoing optimal dynamics analysis.

Japan's PV development trajectory over the last decade demonstrates this dynamics suggesting a possibility of follower (optimal level) substitutes for leader (actual level) in open innovation. Amongst new concept PV systems are expected to grow, the most promising is dye-sensitised solar cells. Their early-stage products will be introduced into markets in 2008.

In 2006, NEDO (New Energy and Industrial Development Organization) has started public offering of PV field test. Its main purpose is to encourage the improvement of the necessary performance and lower cost for the full-fledged diffusion of PV.

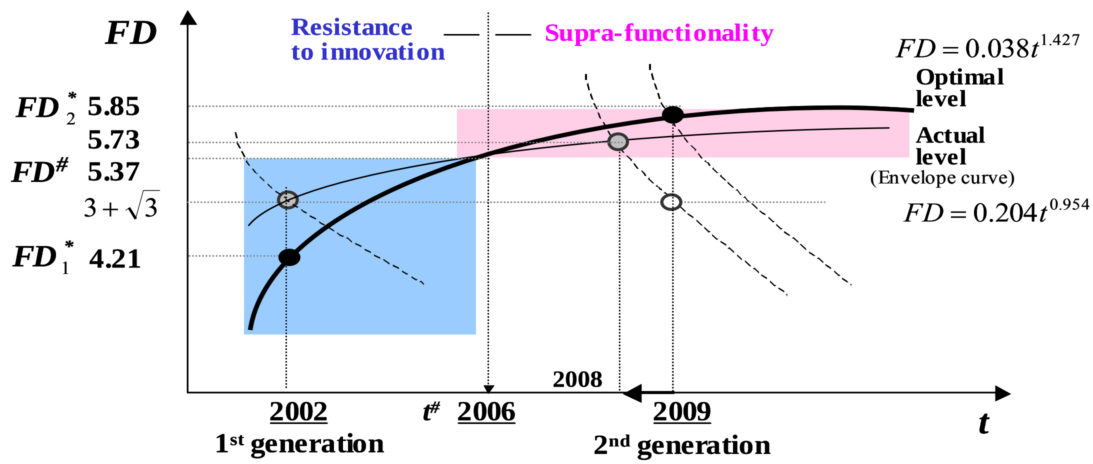

Fig. 13. Comparison of Optimal and Actual Levels of FD in Japan's PV Development Trajectory *(1976-2007)*.

[a] $FD^\#$: Utmost FD level: Level of FD at its emergence (Rogers, Mahajan and Moore).

[b] Trajectory that satisfy investment intensity maximizing utility, cost minimum and FD maximum and depicted by the following equations (see Appendix) [20]:

$$FD^* = \frac{a}{2\cdot(a+\rho)\cdot\rho}\cdot(-a+(a^2+4\cdot\frac{(a+\rho)\cdot\rho\cdot(a+1)}{a})^{1/2})$$

where a and ρ: velocity of diffusion and discount coefficient (rate of obsolescence of technology), respectively.

$Y_1(a,\ \rho) = Y_1(0.46,\ 0.003)$ and $Y_2(a,\ \rho) = Y_2(0.40,\ 0.002)$ (see Table 3).

(4) Dynamism Leading to Supra-functionality

Dynamism leading to supra-functionality of Japan's MP (mobile phone), Web and PV can be demonstrated in Fig. 14. This Figure suggests that new FD frontier which instills in users an "exciting story on their own initiatives as heroes/heroines" thrills them with gratification beyond economic value. Sky Walker has incorporated new social, cultural and aspirational value of MP. Similar to MP, Web and PV also demonstrates that RSS (Really Simple Syndication) and NGPVS (Next Generation PV System) incorporate new FD frontier depicting "exciting story on their own initiatives as heroes/heroines."

Based on this Figure, MP e-mail transmission by Sky Walker suggesting supra-functionality substituted for resistance to new innovation and exploring new FD frontier leads to instill customers through mew communication community. Web also demonstrates supra-functionality through RSS 2.0, which enabling new FD frontier to encourage user participation embraced by Web publisher.

The concept of supra-functionality in PV can be demonstrated in Fig. 15. Based on this Figure, Japan's PV demonstrates supra-functionality substituted for resistance to innovation in 2006. Stimulated by preceding innovation, new FD frontier was incorporated in PV in 2006 instilling users "exciting story," similar to Sky Walker in MP.

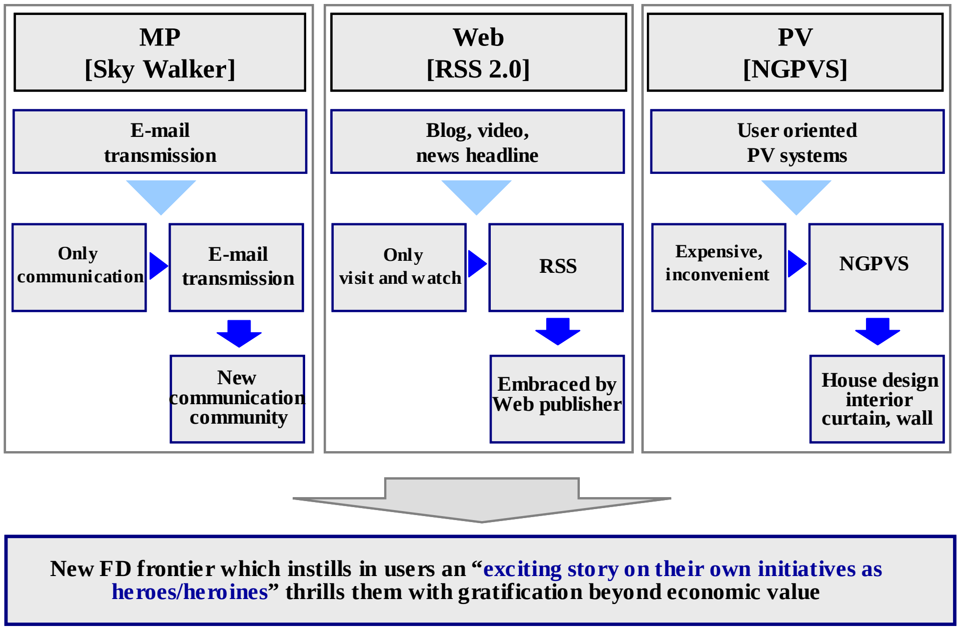

Fig. 14. Dynamism Leading to Supra-functionality of MP, Web and PV in Japan.

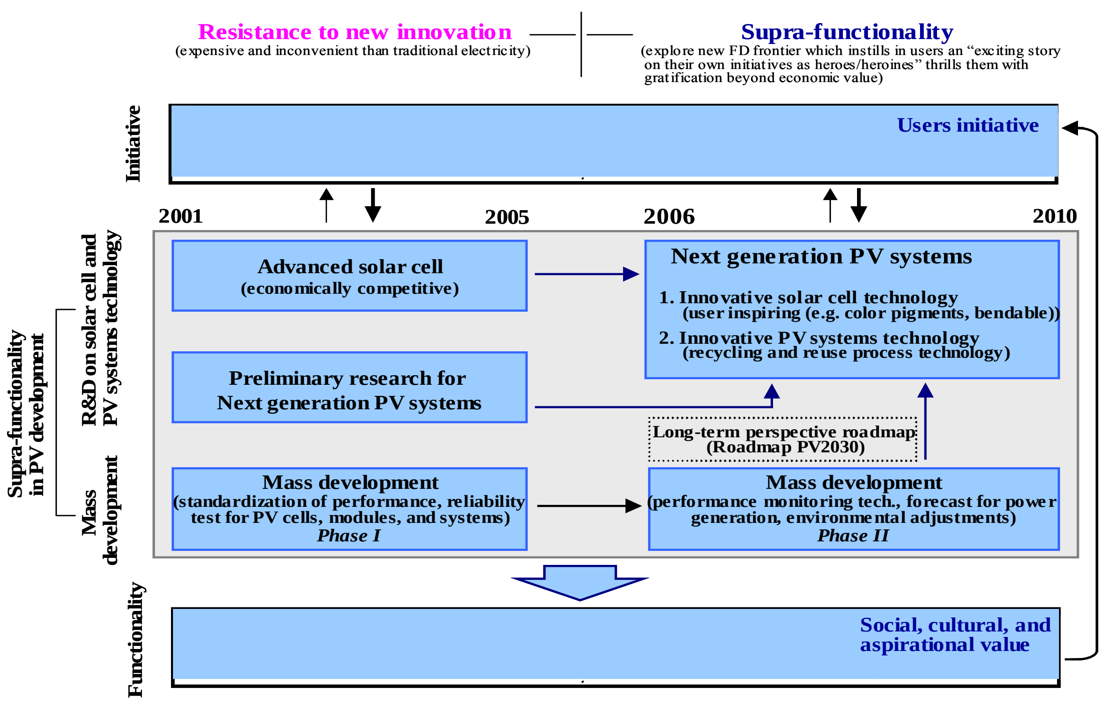

Fig. 15. Supra-functionality in PV Development.

4.2 PV Development Inducement against Utmost Fear

(1) Trends in Oil Prices *(1972-2008)*

International oil prices demonstrated its peak level US$40/b in 1980 as a consequent of the 2nd oil crisis in 1979 as demonstrated in **Fig. 16**. While they changed to declining trend due to glut circumstances in the 1980s and 1990s, they changed to dramatic increase from 2004. They recorded historical highest level as US$137/b in mid-2008 and changed to decline as demonstrated in **Fig. 17**.

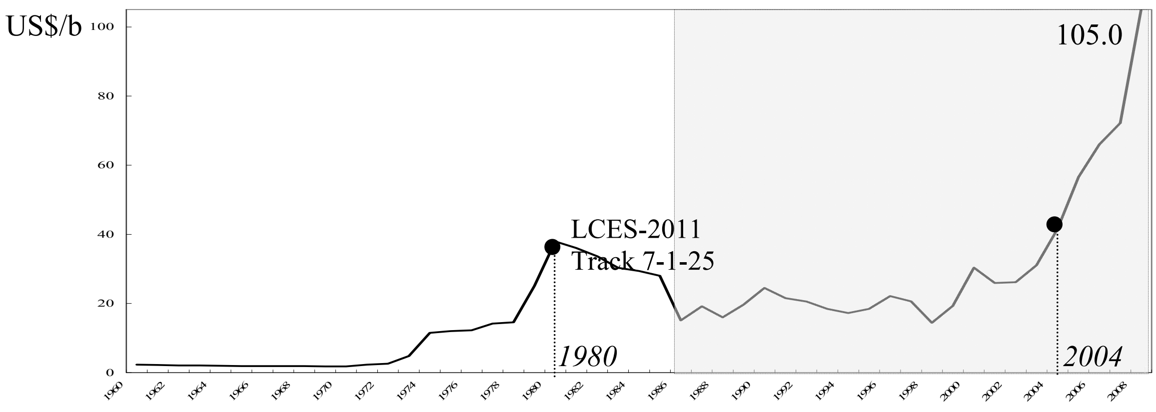

Fig. 16. Trend in Oil Prices *(1960-2008)*: current prices (US$/b).

[a] Prices in 2008 is based on the average of monthly statistics between January and November 2008.
Source: CIF import prices over the period 1960-1975 and International oil prices by WTI (West Texas Intermediate) [19] over the period 1976-2008.

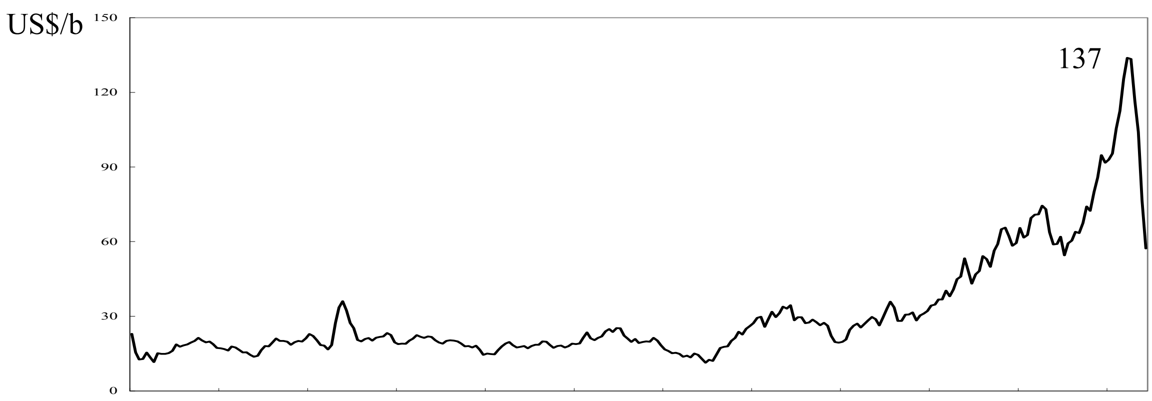

Fig. 17. Trend in Oil Prices *(Jan. 1986-Nov. 2008)*: current prices (US$/b).

Source: International oil prices by WTI (West Texas Intermediate).

(2) Prospects of Oil Prices *(2009-2030)*

While international oil prices changed to decline with the peak in mid-2008, they are anticipated to change to increasing trend again. IEA estimated that they will increase to 200 US$/b in 2030 as illustrated in **Fig. 18** and **Table 4**.

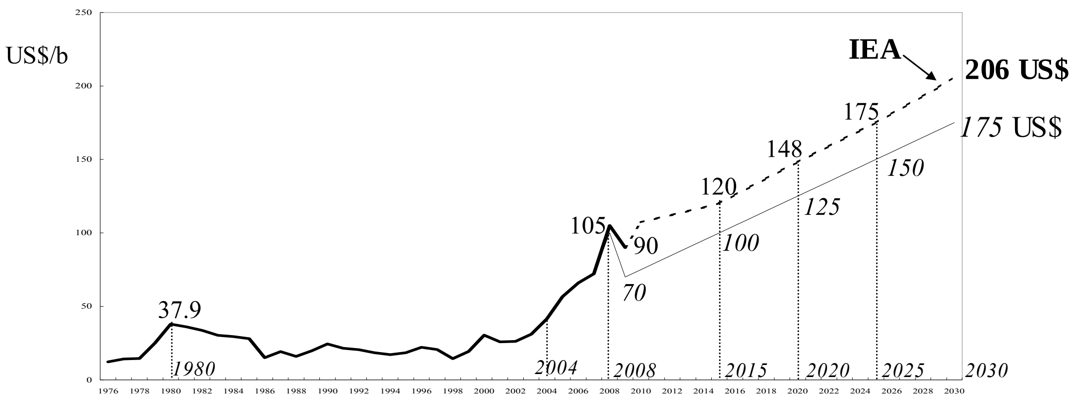

Figure 18. Prospect of International Oil Prices *(1976-2030)*.

Source: Author's estimation scenario based on World Energy Outlook 2008 [4].

Table 4 Prospect of International Crude Oil Prices *(2007-2030)*: US$/b

	2007	2010	2015	2020	2025	2030
Current prices	69.0	107.3	120.3	148.2	175.1	206.4
2007 fixed prices	69.0	100.0	100.0	110.0	116.0	122.0

Source: World Energy Forecast 2008 [5].

(3) Possible PV Development Trajectories *(1976-2030)*

Given the sensitive nature of PV development as an oil-alternative energy sensitive to oil prices, such an increase in oil prices inevitably accelerates PV development as has been broadly demonstrated by dramatic increase in PV development after the dramatic hike in oil prices in mid-2008.

Based on this correlation, **Fig. 19** provides possible scenario of Japan's PV development toward 2030. On the basis of the Bi-logistic growth model over the period 1976-2006, PV development estimate scenario over the period 2008-2030 induced by oil prices increase were estimated with 20%, 30%, 50%, and 60% higher increase than the estimate by the Bi-logistic growth model without taking into account of the utmost fear effect.

Given $\phi \ll 1$,

$$Y_2 = Y_2 e^{\phi t} \approx Y_2 \times (1+\phi)^t \approx Y_2 \times (1+\phi \cdot t)$$

where ϕ_i = scale factor (i = 0.2, 0.3, 0.5 and 0.6).

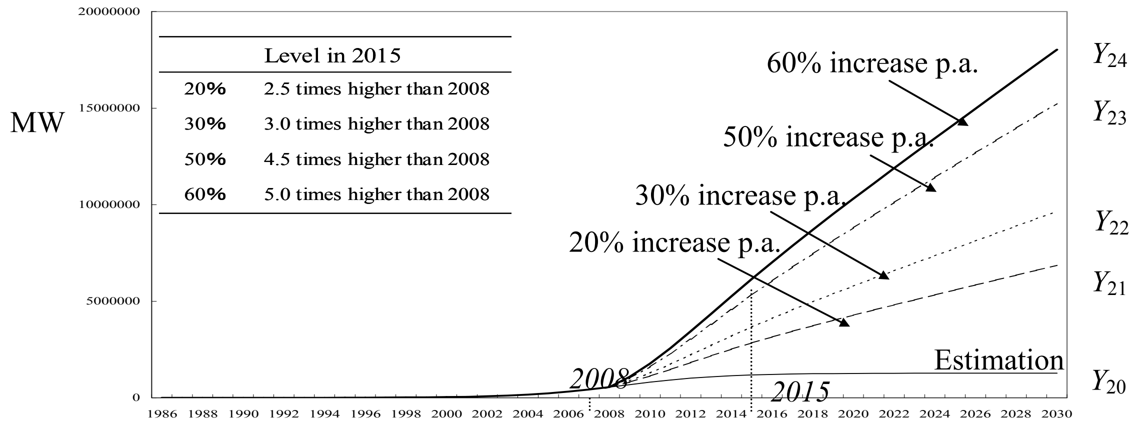

Fig. 19. Prospects of PV Development in Japan *(1976-2030)*[a].

[a] Estimate based on the Bi-logistic growth model over the period 1976-2007; estimate scenario over the period 2008-2030 are 20%, 30%, 50%, and 60% p.a. higher increase than the estimate by the Bi-logistic growth model, respectively.
Source: Authors' estimation scenario based on World Energy Outlook 2008 [5].

On the basis of the foregoing scenario, with the possible estimate of the increase in oil prices as 5 US$/b p.a. increase from 2009 as illustrated in Fig. 19 (this estimate is lower than that of IEA), comparative analysis of the inducing impacts of oil prices increase on the advancement of Japan's PV was attempted, **Table 5** summarizes the result of the analysis.

Table 5 compares inducing impacts of oil prices increase on the advancement of PV between direct impact and comprehensive impacts with utmost fear. While the former simply analyzes the correlation between oil prices and PV development, the latter analyzes the impacts of the "utmost fear ever experienced" by taking the impacts of the balance between the highest level and the level in respective year. Table 5 clearly indicates that comprehensive impacts with utmost fear demonstrate statistical significance.

Table 5 then compare statistical significance between 6 scenario estimated with respect to possible accelerated PV development as a consequence of oil prices increase as estimated in Fig. 19 and indicates that 60% increase p.a. scenario demonstrates statistically most significance.

These analyses demonstrate that dramatic hike in oil prices induces accelerated PV development as a reaction to utmost fear and a dramatic increase in oil prices as US$137/b experienced in July 2008 induces dramatic acceleration of Japan's PV development as 5 times higher level than that of 2008 in 2015.

Table 5 Comparison of the Inducing Impacts of Oil Prices Increase on the Advancement of Japan's PV *(1986-2015)*

Direct impact	*adj.* R^2	*DW*	*AIC*	*F*
$\ln Y_{20} = -6.380 + 4.395 D_1 \ln P + 4.450 D_2 \ln P + 4.251 D_3 \ln P + 2.298 D_4$ (-2.34) (4.90) (6.77) (6.88) (6.44)	0.907	1.17	0.56	71.35
$\ln Y_{21} = -6.912 + 4.601 D_1 \ln P + 4.584 D_2 \ln P + 4.575 D_3 \ln P + 2.131 D_4$ (-2.32) (4.69) (6.38) (6.77) (5.46)	0.904	0.97	5.92	69.42
$\ln Y_{22} = -7.179 + 4.704 D_1 \ln P + 4.652 D_2 \ln P + 4.737 D_3 \ln P + 2.048 D_4$ (-2.30) (4.57) (6.16) (6.67) (4.99)	0.902	0.89	8.88	67.92
$\ln Y_{23} = -7.712 + 4.911 D_1 \ln P + 4.786 D_2 \ln P + 5.061 D_3 \ln P + 1.881 D_4$ (-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	*adj.* R^2	*DW*	*AIC*	*F*
$\ln Y_{20} = 17.050 - 3.497 D_1 \ln(P_{max} - P) - 1.400 D_2 \ln P - 1.644 D_3 \ln(P_{max} - P) + 2.353 D_4$ (14.48) (-8.40) (-4.62) (-3.88) (7.17)	0.921	1.54	-4.32	85.065
$\ln Y_{21} = 14.881 - 2.814 D_1 \ln(P_{max} - P) - 0.929 D_2 \ln P - 1.044 D_3 \ln(P_{max} - P) + 2.669 D_4$ (13.01) (-7.42) (-3.40) (-2.78) (7.93)	0.943	1.35	-9.74	121.27
$\ln Y_{22} = 15.678 - 3.084 D_1 \ln(P_{max} - P) - 1.118 D_2 \ln P - 1.188 D_3 \ln(P_{max} - P) + 2.656 D_4$ (13.74) (-8.15) (-4.10) (-3.17) (7.91)	0.948	1.49	-9.89	132.40
$\ln Y_{23} = 17.273 - 3.624 D_1 \ln(P_{max} - P) - 1.495 D_2 \ln P - 1.476 D_3 \ln(P_{max} - P) + 2.628 D_4$ (14.60) (-9.24) (-5.28) (-3.79) (7.54)	0.952	1.69	-7.70	144.73
$\ln \boldsymbol{Y}_{24} = 18.071 - 3.893 \boldsymbol{D}_1 \ln(\boldsymbol{P}_{max} - \boldsymbol{P}) - 1.683 \boldsymbol{D}_2 \ln \boldsymbol{P} - 1.620 \boldsymbol{D}_3 \ln(\boldsymbol{P}_{max} - \boldsymbol{P}) + 2.615 \boldsymbol{D}_4$ (14.73) (-9.57) (-5.74) (-4.01) (7.24)	**0.952**	**1.75**	**-5.53**	**145.65**
$\ln Y_{25} = 18.868 - 4.163 D_1 \ln(P_{max} - P) - 1.872 D_2 \ln P - 1.763 D_3 \ln(P_{max} - P) + 2.601 D_4$ (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

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).

(4) Effects of Utmost Fear in Inducing PV Development

On the basis of the result of the empirical analysis, effects of utmost fear in inducing PV development were analyzed.

PV production X can largely be attributed to the inducement of international oil prices P as follows:

$$X = F(P) \tag{1}$$

Given that g and ρ indicate initial increase rate of X and rate of obsolescence of cumulative stock of PV Y, respectively, Y can be depicted as follows:

$$Y \approx \frac{X}{g+\rho} \tag{2}$$

Provided that $g + \rho \equiv A$ is stable, equation (2) can be rewritten as follows:

$$Y \approx \frac{X}{A} \tag{3}$$

Taylor expansion of equation (1) to the first term

$$\ln X = a + b_1 \ln P \tag{4}$$

$$\ln AY = a + b_1 \ln P \tag{4′}$$

$$\ln Y = (a - \ln A) + b_1 \ln P \equiv a_1 + b_1 \ln P \tag{4″}$$

where a, b_1, and a_1 ($= a - \ln A$): coefficients.

Following habit persistent hypothesis in consumption theory, comprehensive impacts of Y increase with utmost fear can be depicted as follows:

$$\ln Y = a_2 + b_2 \ln(P^* - P) \tag{5}$$

where P^*: utmost highest prices of oil; and a_1, b_1: coefficients.

Price elasticity to cumulative PV stock can be developed from equations (4″) and (5) as follows[1]:

$$\varepsilon_1 \equiv \frac{\partial \ln Y}{\partial \ln P} = b_1 \qquad \text{for direct impact} \tag{6}$$

[1] From equation (5), under $P^* >> P$ condition,

$$\ln Y = a_2 + b_2 \ln P^* (1 - \frac{P}{P^*}) \approx a_2 + b_2 \ln P^* - b_2 \frac{P}{P^*} = a_2' - b_2' P$$

where $a_2' = a_2 + b_2 \ln P^*$, and $b_2' = \frac{b_2}{P^*}$

$$\frac{d \ln Y}{dP} = -b_2', \quad \frac{d \ln Y}{d \ln P} = \frac{d \ln Y}{dP} P = -b_2' P = -b_2 \frac{P}{P^*}$$

$$\varepsilon_2 \equiv \frac{\partial \ln Y}{\partial \ln P} = -b_2 \frac{P}{P^*} \qquad \text{for comprehensive impacts with utmost fear} \qquad (7)$$

On the basis of equations (6) and (7), both elasticity of oil prices to PV development in direct impact (DI) and comprehensive impacts with utmost fear (CIUF) were compared.

Figs. 20 and **21** demonstrate the result of the comparison. Looking at the Figures we note that CIUF proves extremely lower elasticity of oil prices to PV development demonstrating consistent PV development independent from oil prices decrease (explicit ratchet effect).

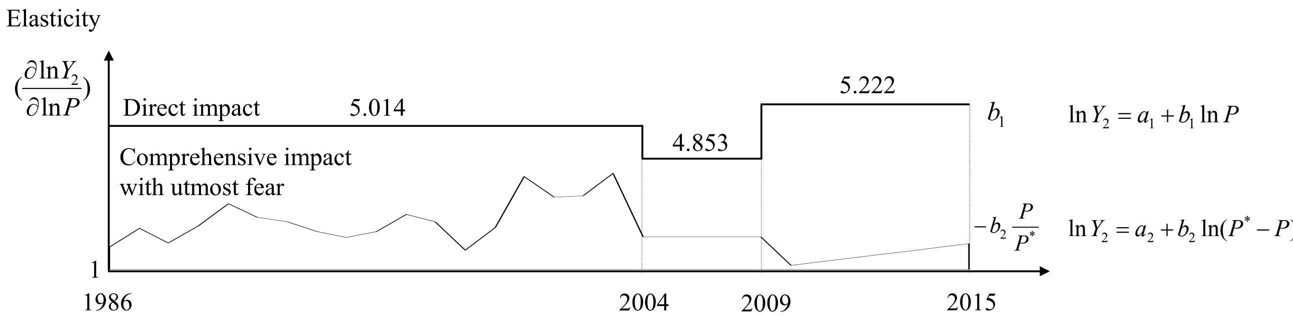

Fig. 20. Elasticity of Oil Prices to PV Development in Comprehensive Impacts with Utmost Fear *(1986-2015).*

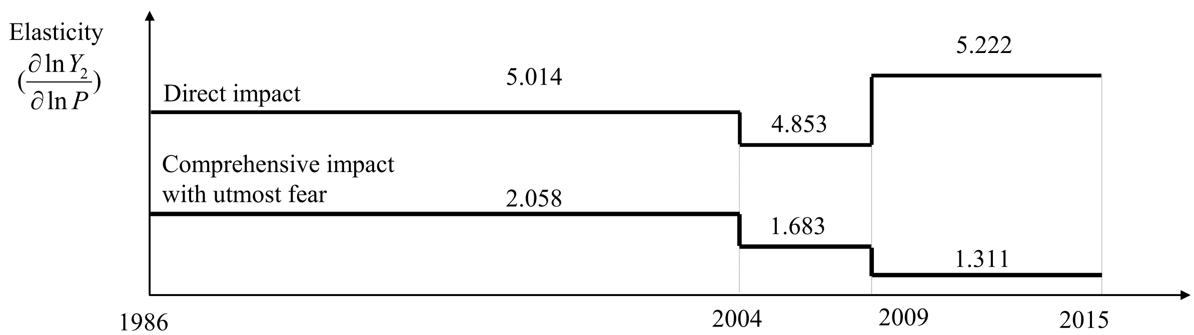

Fig. 21. Elasticity of Oil Prices to PV Development in Comprehensive Impacts with Utmost Fear *(1986-2015)*.

(5) Impacts of Oil Prices Increase in Inducing PV Development Endeavors

Such inducement can be demonstrated by significant correlation between oil prices and number of PV endeavors measured by number of PV development projects. Such endeavors enable substitution of supra-functionality PV for resistance to its introduction.

Fig. 22 demonstrates trends in number of PV endeavors by means of number of PV development projects appeared in monthly issue of PV News over the period 1997-2008.

Table 6 summarizes the result of the correlation analysis between oil prices and number of PV development in Japan and also in abroad over the period 1997-2008. Table 6 indicates statistically significance demonstrating that oil prices increase definitely induces PV development endeavors both in Japan and in abroad.

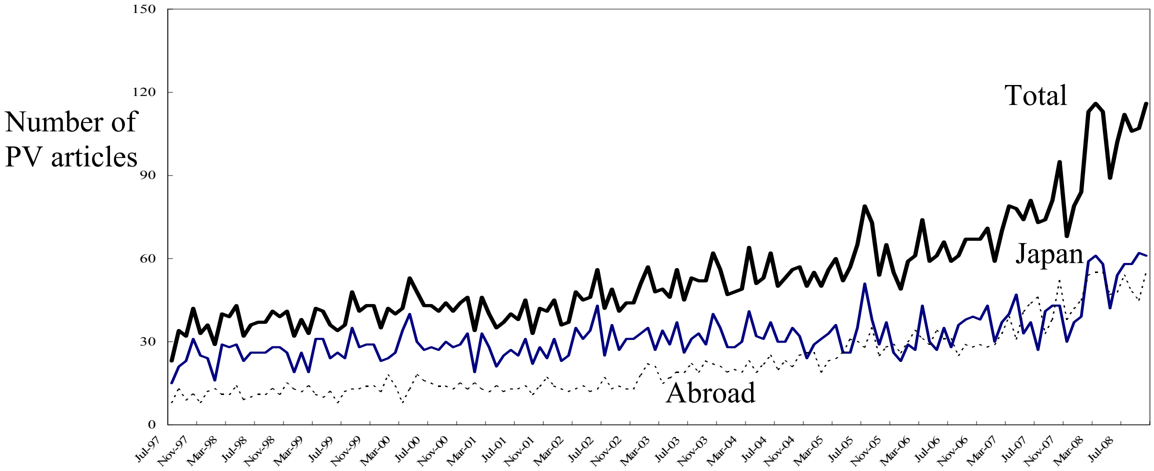

Fig. 22. Trends in Number of PV Endeavors *(Jul. 1997-Oct. 2008)*[a].

[a] Number of projects endeavoring to PV development introduced by PV News (see details in Appendix).
Source: PV News (PV Energy System Inc., monthly issue).

Table 6 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
$\ln N_{Japan} = 2.839 + 0.118 D_1 \ln P + 0.146 D_2 \ln P + 0.198 D_3 \ln P + 0.168 D_4$ (39.96) (5.14) (7.81) (12.37) (13.47)	0.881	1.47
$\ln N_{abroad} = 1.010 + 0.467 D_1 \ln P + 0.533 D_2 \ln P + 0.600 D_3 \ln P + 0.183 D_4$ (13.36) (19.11) (26.90) (35.32) (13.77)	0.975	1.10
$\ln N_{total} = 2.821 + 0.260 D_1 \ln P + 0.302 D_2 \ln P + 0.361 D_3 \ln P + 0.123 D_4$ (62.38) (7.79) (25.49) (35.51) (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. 2007*	*Mar. 2007-Sep. 2009*
D_1	1	0	0
D_2	0	1	0
D_3	0	0	1

Prompted by these observations, the following analysis demonstrates PV development endeavors amongst Japan, abroad and total over the period 1997-2008:

$$N = Ae^{b_i D_i t} \quad (i = 1\text{-}3) \qquad (8)$$

$$\ln N = \ln A + b_i D_i t \qquad (8')$$

where N: PV development endeavors; A and b_i: coefficients; D_i: dummy variable; and t: time trend.

Equation (8′) can be developed as following equation (9):

$$\frac{\Delta N}{N} = b_i D_i \tag{9}$$

Based on equation (9), increase rate of PV development endeavors can be identified. **Table 7** demonstrates the significant impacts of PV development endeavors and dramatic increase trend.

Table 7 Impacts of PV Development Endeavors in Japan and Abroad (Jul. 1997-Oct. 2008): 3 months moving average

	adj. R^2	DW
$\ln N_{Japan} = 3.117 + 0.0028 D_1 t + 0.0032 D_2 t + 0.0050 D_3 t + 0.176 D_4$ (157.05) (5.10) (13.70) (25.06) (14.09)	0.883	1.40
$\ln N_{abroad} = 2.202 + 0.008 D_1 t + 0.010 D_2 t + 0.012 D_3 t + 0.172 D_4$ (112.94) (13.87) (43.89) (62.72) (14.01)	0.978	1.00
$\ln N_{total} = 3.492 + 0.004 D_1 t + 0.006 D_2 t + 0.008 D_3 t + 0.121 D_4$ (262.36) (10.44) (35.34) (56.87) (14.18)	0.973	1.06

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; and D_i (i = 1-4): dummy variables with following classifications:

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

On the basis of correlation analysis in Table7, dramatic increase rate can be identified as summarized in **Table 8**.

Table 8 Increase Rate of PV Development Endeavors in Japan and Abroad *(Jul. 1997-Oct. 2008)*: 3 months moving average

	D_1 (97/8 – 02/3)	D_2 (02/4 – 07/2)	D_3 (07/3 – 08/10)	D_3 / D_2 increase
Japan	3.3	3.8	6.0	60%
Abroad	9.6	12	14.4	20%
Total	4.8	7.2	9.6	33%

Table 8 demonstrates a conspicuous increase rate of PV development endeavors and also this suggests that Japan's distinguished efforts for new innovation toward a post-oil society. Furthermore, Japan accomplished the highest increase rate of PV development endeavors compared to aboard and total.

Consequently, Japan's innovation toward PV development is further anticipated.

5. Conclusion

In light of the increasing concern regarding Japan's model for transforming a crisis to a spring board for new innovation in the current environment of simultaneous global economic stagnation and also a signal of the possibility of a paradigm shift to a post-oil society triggered by the dramatic increase in oil prices in mid-2008, this paper attempted to identify a new entrepreneurial strategy toward such a society by applying Japan's notable dynamism.

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.

Based on the review of Japan's notable dynamism in transforming a crisis into a springboard for new innovation and also the increasing significance of production, diffusion and consumption integration, utmost fear hypothesis leveraging the new innovation toward a post-oil society was examined by means of an empirical analysis on the development trajectory in Japan's PV development.

Noteworthy findings obtained include:

(i) Japan constructed a sophisticated co-evolutionary dynamism between innovation and institutional systems by transforming external crises into a springboard for new innovation.
(ii) This was typically demonstrated by technology substitution for energy in the 1970s enabling Japan to achieve a high-technology miracle in the 1980s.
(iii) This can be attributed to the unique features of the nation to have 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.
(iv) Since the dramatic increase in oil prices has signaled the possibility of a paradigm shift to a post-oil society, a new entrepreneurial strategy toward such a society is strongly expected.
(v) By applying a habit persistence hypothesis in which utmost gratification of consumption plays a decisive role in consumption, an utmost fear hypothesis was demonstrated.
(vi) Utmost fear plays a similar role to utmost gratification in leveraging a shift from resistance of innovation to supra-functionality development aiming at establishing a non-oil dependent resilient society.

These findings suggest the following policy implications suggestive to firms with respect to their entrepreneurial strategy under open innovation in a post-oil society:

(i) Utmost fear plays a similar role to utmost gratification in leveraging a shift from resistance of innovation to supra-functionality development aiming at establishing a non-oil dependent resilient society.
(ii) Japan's notable model in transforming external crises into a springboard for new innovation should be broadly applied.
(iii) Technology substitution for constraints should be pursued in the scope of the integration between production, diffusion and consumption function.
(iv) Utmost functionality development should be endeavored aiming at supra-functionality substitution for resistance of innovation.
(v) Utmost fear hypothesis should be applied for leveraging new innovation toward a post-oil society.
(vi) PV development should be accelerated for new institutional innovation in a post-oil society.

Further works should focus on the establishment of introduction and application of utmost fear hypothesis in broader fields.

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Appendix Optimal Functionality Development in Response to Utmost Fear

(1) Model Construction MP (mobile phone), Web and PV (photovoltaic) in Japan,

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

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				
$FD = FD(t) = \dfrac{N(t)}{Y(t)}$	Functionality development (FD)				
$\eta = \eta(t) = \dfrac{Y(t)}{N(t)} = \dfrac{1}{FD(t)}$	Production to carrying capacity	*Second phase variable*	$\Rightarrow \theta(t) \equiv FD(t) - 1$	ψ_1	$C_1 = \psi_1 \cdot \theta$
$s = s(t) = \dfrac{\dot{N}(t)}{Y(t)}$	Investment intensity (II)	*Control variable*			

(ii) System's Dynamics

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

Stationary level of FD

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

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

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

Constant Levels of Investment Intensity (II)

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

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.

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

(2) Optimal Control Problem for Functionality Development

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

(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

$$\frac{\partial H}{\partial s} = -\frac{1}{1-s} + \psi_1 = 0 \Rightarrow \boldsymbol{s} = 1 - \frac{1}{\boldsymbol{\psi}_1} = \frac{\boldsymbol{\psi}_1 - 1}{\boldsymbol{\psi}_1}$$

(Investment intensity that maximizes utility)

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

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 $\frac{(a+\rho)\cdot\rho}{a}=\frac{1-a\cdot\theta}{(\theta+1)^2}$ ➡ $\frac{(a+\rho)\cdot\rho}{a}=\frac{(1-a\cdot(FD-1))}{FD^2}$ ➡ $\frac{(a+\rho)\rho}{a}\cdot FD^2+a\cdot FD-(1+a)=0$

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[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.