1B05 Comparative Analysis of Institutional Elasticity for Maximizing the Effect of Industrial Technology Policy

- Comparison of Diffusion Trajectory of PV Technology in Japan, USA and Europe

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1. Introduction

Innovation plays a significant role in maintaining sustainable global economy [1, 3]. Most important is to recognize that innovation is a very subtle entity subject to conditions of institutional systems [4], more specially, institutional elasticity. Given that institutional systems is a coherent system indigenous to the nation and a very inorganic entity created in the process of historical development [2], how to maximize potential innovation in each country largely depends on how to best coordinate institutions. Thus, the effects of innovation policy depend on how it functions coordinate and deploy such institutions [6], and given that it relies on the state of institutional elasticity, maintaining institutional elasticity can be significant for maximizing the effect of the policy [7]. Therefore, a comparative analysis of institutional elasticity from the viewpoint of innovation policy could provide significant historical suggestions. To date, a number of studies have identified the impacts of technological innovation and its diffusion process with certain relevance with institutions.

The logistic growth function has proved useful in modeling a wide range of innovation processes. Watanabe *et al.* [8] traced logistic growth function within a dynamic carrying capacity to identify functionality development of IT and postulated that logistic growth within a dynamic carrying capacity approach entails major features of functionality development. As Watanabe *et al.* [9] postulated, photovoltaic power generation (PV) follows the similar trajectory of IT's functionality development as it incorporates the following identical nature similar to IT: (i) PV is categorically of the same nature as semiconductors, (ii) the "footloose" character of the technology which can maximize the benefit of learning effects and economies of scale, (iii) the interdisciplinary nature of its development, which can maximize the benefit of technology spillover, and (iv) efficient learning is linked to technology spillover and both have mutually stimulation interactions.

In this paper, following logical steps are postulated to identify the links between institutional elasticity and efficiency of innovation policy:

(i) institutions play significant role in stimulating innovations and their diffusion (**institutional innovation**),
(ii) the state of innovations and their diffusion can be represented by the trends in functionality development (**functionality development**),
(iii)trends in functionality development is sensitive to institutions, particularly its elasticity (**institutional elasticity**),
(iv) functionality development can be traced by the trends in dynamic carrying capacity in a logistic technology diffusion process (**logistic growth within a dynamic carrying capacity approach**), and
(v) trajectory of PV depicted by logistic growth within a dynamic carrying capacity approach could provide a good insight of institutional elasticity for maximizing the effect of energy technology policy (**trajectory of PV characterized by dynamic carrying capacity approach**).

Thus, by comparing this carrying capacity, state of institutional elasticity and its structural sources can be interpreted. Promoted by this postulate, aiming at identifying conditions enabling elastic institutions which maximize the effects of innovation policy, this paper undertakes a comparative analysis of institutional elasticity between Japan, the USA and Europe focusing on energy technology by means of case study taking development and diffusion trajectory of PV over the last quarter century.

Section 2 provides a clear concept of institutions. **Section 3** is devoted to constructing model synthesis and data construction necessary for the analysis of the synthesized model. Analysis and interpretation of its results are presented in **Section 4**. **Section 5** briefly summarizes concluding remarks.

2. The Role of Institutions for Innovation

Given that innovation is a very subtle entity subject to conditions of institutional systems [4] depending on interaction between internal technology and external technology as illustrated in **Fig. 1**, institutions can be manifested as the soft instrument which stimulates interaction between internal technology and external technology.

Although these institutional systems can function well leading to a virtuous cycle generating successive innovation and successful diffusion, they are very fragile and may readily change to a vicious cycle such as what prevailed in Japan during the 1990s lasting up to now [7]. **Fig. 2** illustrates the scheme which led Japan to lose its institutional elasticity by comparing it to the USA system which indicates that, contrary to the dual virtuous cycle up to the end of the 1980s, Japan has been suffering from a dual vicious cycle. During the period of an industrial society initiated by manufacturing industry, Japan's domestic institutions functioned efficiently leading to high economic growth. Facing a new paradigm in the 1990s characterized by a shift to an information society, Japan's traditional institutions did not function efficiently. Consequently, a virtuous cycle between institutional elasticity and economic development changed to a vicious cycle between non-elastic institutions and economic stagnation. This vicious cycle resulted in the loss of Japan's international competitiveness that resulted in further economic stagnation. Thus, Japan has been facing a dual vicious cycle leading to a solid institutional elasticity.

Structural sources that compelled such a change from a virtuous cycle in the 1980s to a vicious cycle in the 1990s can be attributed to a fundamental difference of features between core technologies in an industrial society in the 1980s and an information society in the 1990s. IT strongly possesses a self-propagating feature that closely interacts with institutions. Its functionality is formed dynamically during the course of interaction with institutions. The state of IT innovations can be represented by the trends in functionality development which is sensitive to institutional elasticity. All supports a hypothetical view that institutional elasticity is crucial for innovations and their diffusion in an information society.

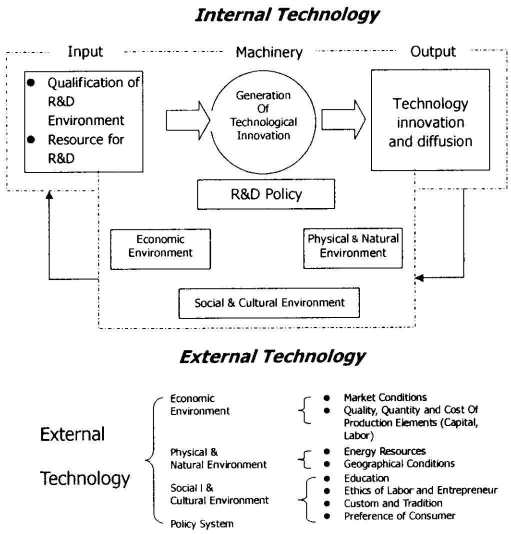

Fig. 1. Scheme of Institutional Systems for Innovation.
Source: Watanabe *et al.* (1991) [5].

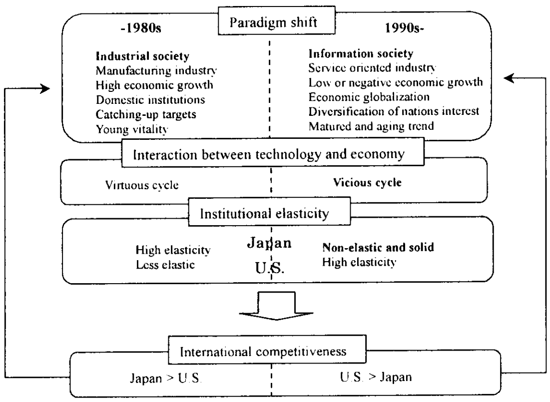

Fig. 2. Scheme Leading Japan to Lose Its Institutional Elasticity.
Source: Watanabe et al. (2002) [8].

3. Model Synthesis and Data Construction

3.1 Model Synthesis

Provided that the state of innovations and their diffusion are traced by the trajectory of functionality and this functionality is formed dynamically during the course of interaction with institutions, a model tracing the trajectory of functionality is synthesized and data for the analysis by the synthesized model are constructed. In order to identify self-propagating behavior of IT driven innovation in their diffusion process, particularly through dynamic interaction with institutional systems, epidemic function approach is focused as this behavior resembles epidemic diffusion. Different from simple logistic growth function (SLF) and bi-logistic growth function (BLF), logistic growth function within a dynamic carrying capacity (LFDCC) is adopted in this paper to reflect that the level of carrying capacity of the innovations will enhance as their diffusion proceeds and functionality develops.

The LFDCC can be formulated as following equations:

$$f(t) = \frac{K_k}{1 + a\exp(-bt) + \frac{b \cdot a_k}{b - b_k}\exp(-b_k t)} \quad (1)$$

$$K(t) = \frac{K_k}{1 + a_k \exp(-b_k t)} \quad (2)$$

where $f(t)$: diffusion level of innovative goods;
a, b, a_K and b_K : coefficients;
K: carrying capacity (ceiling of the adoptions of innovative goods);
K_k: ultimate carrying capacity; and
t : time trend.

Following factors can be used to characterize carrying capacity structure:

- *Velocity of diffusion (depends on a coefficient b):*

$$\frac{df(t)}{dt} / f(t) = b\left(1 - \frac{f(t)}{K(t)}\right) \quad (3)$$

- *Degree of functionality (degree of non-SLF structure):* a_k/a and b_k/b indicate degree of functionality.
- *Year to reach* $K(t^{\#}) = K_k/2$:

$$K(t^{\#}) = \frac{K_k}{2} = \frac{K_k}{1 + a_k \exp(-b_k t^{\#})} \quad (4)$$

therefore $t^{\#} = \frac{\ln a_k}{b_k}$. (5)

From equations (1) and (2), the carrying capacity can be also formulated as follow:

$$K(t) = f(t)\left(\frac{1}{1 - (df(t)/dt)/bf(t)}\right) \quad (6)$$

Equation (6) demonstrates that the dynamic carrying capacity $K(t)$ increases with the number of adopters (customers) $f(t)$ as time goes by. Increase in $K(t)$ induces $f(t)$, which in turn activates interactions with institutions leading to an increase in potential customers (carrying capacity) by increasing the value and function stimulated by network externalities.

3.2 Data Construction

In order to assess the institutional structure by means of degree of functionality by comparing development and diffusion trajectory of PV and its carrying capacity measured by equations (1) and (2), data construction is attempted with respect to cumulative PV production in Japan, the USA and Europe over the last quarter century. **Fig. 3** demonstrates the trends in PV development in the world over the period 1975-2000. We note that, while Japan maintained world highest level of PV production despite the falling trend in the international oil prices started from 1983, the production level of the USA exceeded Japan's level from 1993 and maintained the position of the world leader of PV production. However, Japan's PV production dramatically increased from 1999 and substituted for the USA's world top level again. Utilizing these data on the PV production in the world market over the last quarter century, the cumulative PV production in Japan, the USA and Europe can be calculated and the trends are demonstrated in **Fig. 4**.

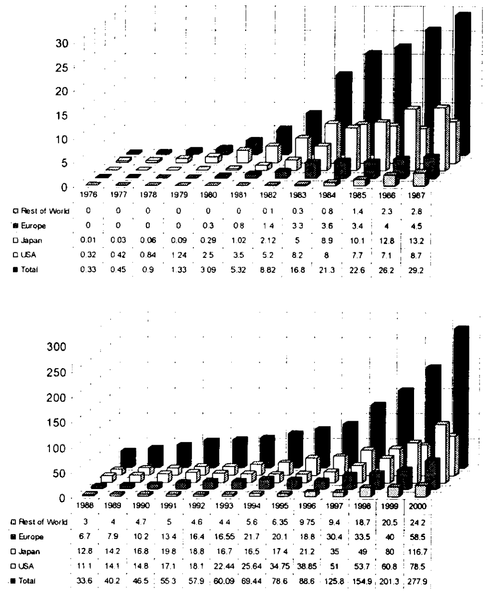

Fig. 3. Trends in World PV Development (1976-2000): MW.
Sources: Paul Maycock, PV News and Chihiro Watanabe

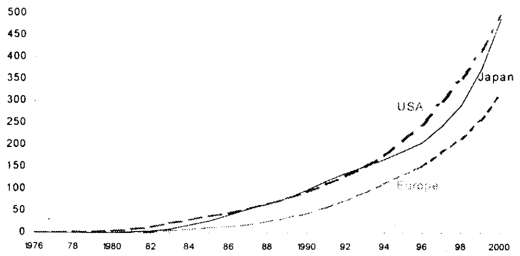

Fig. 4. Trends in Cumulative PV Production in Japan, the USA and Europe (1976-2000): MW.

4. Analysis and Interpretation

Utilizing the constructed data on trends in cumulative PV production in Japan, the USA and Europe over the period 1976-2000 and applying these data in equation (1), diffusion trajectory of PV in three countries/region over the last quarter century is estimated. The results of the numerical estimation are summarized in **Table 1** which demonstrates all coefficients indicate statistically significant with extremely high representability.

Table 1 Estimation Results for the Diffusion Process Analyses of PV Production in Japan, USA and Europe (1976-2000)

Japan						
K_K	a	b	a_K	b_K	adj. R^2	DW
9452.8	17964	0.587	947.2	0.167	1.000	0.64
(3.31)	(1.57)	(5.74)	(3.89)	(29.79)		
USA						
K_K	a	b	a_K	b_K	adj. R^2	DW
3355.1	26142	0.890	444.5	0.182	1.000	0.69
(15.36)	(1.45)	(8.42)	(26.60)	(139.88)		
Europe						
K_K	a	b	a_K	b_K	adj. R^2	DW
7937.6	9367	0.540	629.4	0.173	1.000	1.18
(2.31)	(33.94)	(7.90)	(3.16)	(28.79)		

Applying the estimation results to equation (1) and (2), **Fig. 5** illustrates trends in cumulative production both actual and estimated as well as its carrying capacity in Japan, the USA and Europe over the last quarter century.

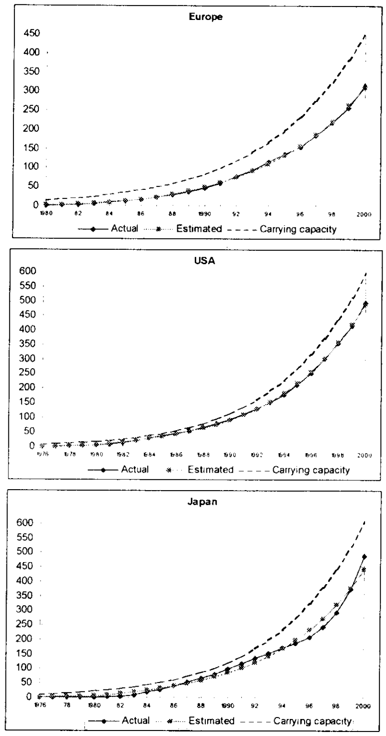

Fig. 5. Cumulative PV Production (Actual and Estimated) and Its Carrying Capacity in Japan, the USA and Europe: MW.

Based on the estimated results, factors characterizing carrying capacity structure in Japan, the USA and Europe over the last quarter century are compared as summarized in the first part of **Table 2**. It suggests that the USA demonstrates the highest velocity of diffusion while Japan and Europe share the similar lower level. The USA also demonstrates the lowest degree of functionality while Japan and Europe demonstrate higher level. Consequently, the USA's dynamic carrying capacity is anticipated to reach 50% of the ultimate ceiling in 2009 while Japan and Europe are anticipated in 2016 and 2012, respectively. The second part of Table 2 interprets institutional structure affecting the differences of these carrying capacity structures in Japan, the USA and Europe.

Table 2 Comparison of Institutional Structure and Its Elasticity in PV Development and Diffusion between Japan, the USA and Europe

Carrying capacity structure	USA	Japan	Europe
1. Ultimate carrying capacity	Lowest (3355.1)	Highest (9452.8)	Middle (7937.6)
2. Velocity of diffusion (b)	Highest (0.890)	Middle (0.587)	Lowest (0.540)
3. Degree of functionality $(\frac{a_K}{a} / \frac{b_K}{b})$	Lowest (0.01 / 0.20)	Higher (0.05 / 0.28)	Highest (0.06 / 0.32)
4. Year to reach $K(t^*)=K_k/2$ $(\frac{\ln a_K}{b_K})$	Earliest (2009)	Latest (2016)	Middle (2012)
	⇩	⇩	⇩
Institutional structure			
Production	Mass prod. based on conventional tech.	R&D driven mass production	Steady production
Exports share out of shipment in 1998	70%	27%	28% (Germany)
Supply / Demand	Supply / export oriented	Equilibrium in supply and demand	Strong demand inducement
R&D	University / industry initiative	Strong Government initiative	Central Government initiative
Consortia	University-industry tie-ups	Strong R&D consortia	EU initiative collaboration
Standardization	Reasonable	Developing	Strong
Deregulation	Well	Underdeveloped	Well-developed
Institutional elasticity (cf. Institutional elasticity for IT)	Less elastic (Elastic)	Elastic (Less elastic)	Elastic (Reasonable)

Noteworthy observations obtained from Table 2 include:

(i) **Export-oriented supply side initiative** in the USA PV development (export ratio is 63.3 % in 1996 and 72.9 % in 1997, while the same ratio in Japan is 34.9 % and 30.6 %, respectively) is considered the major source of the USA's highest velocity in its PV diffusion, while the lowest functionality development. This lowest functionality can also be attributed to the labor quality of the USA. Labor quality of the US PV factories is lower than that of Japan and Germany, therefore, US firms new functionality development is conducted in Germany rather than in the home country, while assembly of cells does not require the same level of expertise which enables export-oriented mass production.

(ii) Contrary to such USA's policy, Japan's equilibrium in supply push (primarily by the National R&D Program such the New Sunshine Program) and demand pull (primarily by the New Energy Foundation's Subsidy Program), and Europe's strong demand inducement lead to higher functionality while their diffusion velocities are lower than the USA.

(iii) Government's strong initiative in inducing PV R&D in Japan and Europe as well as strong R&D consortium in Japan (PVTEC) and EU initiative collaboration in Europe also can be appreciated to contribute to higher degree of functionality in Japan and Europe.

(iv) Contrary to Europe's strong standardization and USA's well proceeded deregulation, Japan's standardization and deregulation are behind the level of Europe and the USA, which are expected to learn Europe and USA's system.

(v) Japan's highest ultimate carrying capacity can be attributed to its high level of learning exercise in PV development.

In general, contrary to its less elastic institutional system in an information society emerged in the 1990s, Japan's institutional system in PV development and diffusion demonstrates elastic performance which could be a model for Japan's efforts in adopting a shift from an industrial society to an information society.

5. Concluding Remarks

In light of an understanding that innovation is a very subtle entity subject to institutional elasticity while institutions are coherent entities indigenous to a nation, this paper attempts a comparative analysis of institutional elasticity between Japan, the USA and Europe. With an expectation to extract significant suggestions with respect to institutional elasticity for maximizing effects of technology policy an empirical analysis was conducted focusing on PV diffusion trajectories in three countries/region over the last quarter century. Based on the five postulates, numerical comparison by means of a logistic growth function within a dynamic carrying capacity was conducted.

As a result of the analysis some noteworthy findings on the carrying capacity structure and institutional structure for 3 countries/region are obtained. These findings demonstrate the hypothetical view that institutional dynamism plays a significant role in this dynamic interaction between learning, diffusion and technology spillovers leading to the optimal utilization of potential resources in innovation.

One important suggestion is that, in general, contrary to its less elastic institutional system in an information society, Japan's institutional system in PV development and diffusion demonstrates elastic performance which could be a model for Japan's efforts in adopting a shift from an industrial society to an information society.

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