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IT substitution for energy leads to a resilient structure for a survival strategy of Japan's electric power industry

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Abstract

The dramatic surge in information technology (IT) around the world, and an evolving global economy, are subjecting firms to megacompetition. This is the case, particularly in Japan's electric power industry, where the power rate is one of the highest in the world; hence it is noted that Japan's industry has lost its price competitiveness in the world market, resulting in stagnation of production, hence leading to stagnation in power demand. In addition, an increase in trends of customer's preferences and the variety of participants in the power supply race, have put electric power companies at the mercy of customers with alternative supply sources.

Given that uncertainty with respect to energy security, as well as power generation and distribution systems safety increases, as strongly cautioned by the recent blackout in the US and Canada, a dramatic conversion of existing strategies would be indispensable for electric power companies. A conversion from a high-demand-elasticity dependent, supply structure to a resilient structure is required. While the former aims at constructing a high-demand-elasticity supply structure, based on the myth of high growth of demand, the latter aims at maintaining profit, while minimizing the elasticities of factors with high uncertainty, such as energy resources and costly capital investment linked to a fluctuating power demand.

This paper demonstrates the significance of IT substitution for energy through consortia structure, thereby utilizing IT spillover and leading to resilience and leveraging consortia structure as Japan's electric power industry survival strategy. An empirical analysis using Japan's nine leading electric power companies over the last quarter century has been conducted.

Keywords: Resilience; Electric power industry; IT substitution for energy

1. Introduction

Contrary to strong international competitiveness up until the end of the 1980s, Japan's industry has lost its competitiveness during the course of the lost decade in the 1990s. A dramatic surge in information technology (IT) around the world and the rise of a global economy, compel firms in the midst of mega-competition. This is particularly the case with Japan's electric power industry, which existed under these closed market conditions without strong competitors; and secured successful economic growth. These non-competitive circumstances, together with Japan's fragile energy supply structure, cast Japan's electric power industry, in the world's highest power rate structure. Consequently, Japan lost its price competitiveness in world market which then stunted Japan's economic activities leading to low or negative economic growth, which then diminished demand for electricity.

Megacompetition not only accelerates this stagnation, but also creates a new competitive structure for the electric power industry by allowing new competitors in a closed market, which, in response to diversification trend in customer's preferences, compels customers to switch to other suppliers. The advancement of IT enables customers to choose suppliers as well as power sources at their own initiative.

Thus, *resilience and leveraging consortia* is a critical survival strategy for the electric power industry in Japan. Recent blackouts in the US and Canada, indicate that not only is Japan affected and not immune, but also other highly industrialized countries.

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To date, many studies have analyzed the structural sources of the high cost structure of Japan's electric power industry (Shinjyo, 1990; Yeager and Stahlkopf, 2001). Shinjyo demonstrated a strong fear denoting that without restructuring power supply system, Japan's industry will inevitably fall into a vicious cycle between losing price competitiveness and economic stagnation. However, these studies continue to provide warnings or partial countermeasures without envisioning concrete survival strategies in the total system perspective.

Watanabe et al. (2003a–c) postulated a concept of resilience as a source of survival strategy for high-technology firms. Resilience is the ability of an ecosystem or social system to continue functioning despite occasional and severe disturbance (Marten, 2001), and more generally, the capability of a sustained body to recover from, or adjust smoothly to external changes, shocks or crises. Pimentel et al. (2000) stressed that resilience plays a significant role in maintaining ecological integrity. Ulanowicz (1995) identifies a role of resilience, in terms of this integrity, as a core function of a system consisting of vigor, organization and resilience. Based on this resilience role as a core function for maintaining system integrity, Watanabe et al. (2003a–c) postulated that it is essential for high-technology firms to set a resilient structure, thereby maintaining an operating income to sales, while minimizing elasticities of factors with uncertainty. This concept could be supportive in envisioning a survival strategy for the electric power industry.

It is generally pointed out that IT contributed to the increase of resilience (Allenby and Unger, 2001; Jorgenson and Stiroh, 2001; Romm, 2001; Watanabe et al., 2003a–c). Chen (1994) demonstrated significant implications of information substitution for energy in the similar context. This work suggests the significant contribution of IT substitution for factors with uncertainty, particularly energy resources, to a shift to a resilient supply structure. Substitution for costly capital investment linked to fluctuating power demand would be also the case.

In order to accelerate this IT substitution for factors with uncertainty, effective utilization of IT developed by others and spillover in the market is important. This is particularly crucial for the electric power industry which contains not necessarily sufficient comparative advantage in this technology while incorporating transmission and distribution network facilities. The foregoing circumstances emerging amidst megacompetition in an IT driven global economy stimulates utilization of spillover IT. Particularly, winner takes all situation accelerates spillover dynamics between donor and host (Watanabe et al., 2001) and introduction of network base energy resources trade in a global context dramatically relaxes the constraints of technology distance. Griliches (1979) stressed that effective utilization of spillover technology depends on the efforts of the recipient firms and defined a concept of technology distance postulating that these efforts are proportional to recipient firms' economic and technological distance from donor firms. Introduction and acceleration of network base energy resources trade should dramatically alter traditional technology distance in a way to spurring technology spillover and its utilization.

There are a numbers of studies devoted to analyze the effects of technology spillover (e.g. Bernstein and Nadiri, 1988, 1989, 1991; Watanabe et al., 2003a–c). Similar to Bernstein and Nadiri, Watanabe et al. in their empirical analysis taking R&D consortia analyzed the effects of spillover, by using a translog cost function to demonstrate the significance of consortia type structures in utilizing technology spillover from different sectors effectively, given a virtuous cycle (i.e. successful stimulation and inducing interaction) between donor (supply side) and host (recipient side) sectors efforts to improve interaction as well as assimilation capacity. This approach provides a constructive suggestion envisioning a concrete trajectory for electric power industry, converting from an indigenous-oriented supply system to consortia-type supply system, by analyzing the effect of spillover technology from different sectors.

Building on these studies, this paper, on the basis of an empirical analysis, takes Japan's leading nine electric power companies over the last quarter century into account, and attempts to demonstrate the significance of resilience and leveraging consortia as a, survival strategy for the electric power industry amidst megacompetition in an IT driven global economy.

Section 2 analyzes external circumstances surrounding Japan's electric power industry. Section 3 discusses analytical framework by describing model synthesis and data construction. Empirical analysis and its interpretation are presented in Section 4. Section 5 briefly summarizes new findings and implications for electric power industry's survival strategy in a mega-competition, under an IT driven globalizing economy.

2. External circumstances surrounding the electric power industry

2.1. Institutional sources and external circumstances surrounding Japan's electric power industry

Fig. 1 projects institutional sources and external circumstances compelling Japan's electric power industry to shift to new survival strategy.

These sources and circumstances can be classified into the following three layers:

(i) Institutional sources casting high power rate structure,

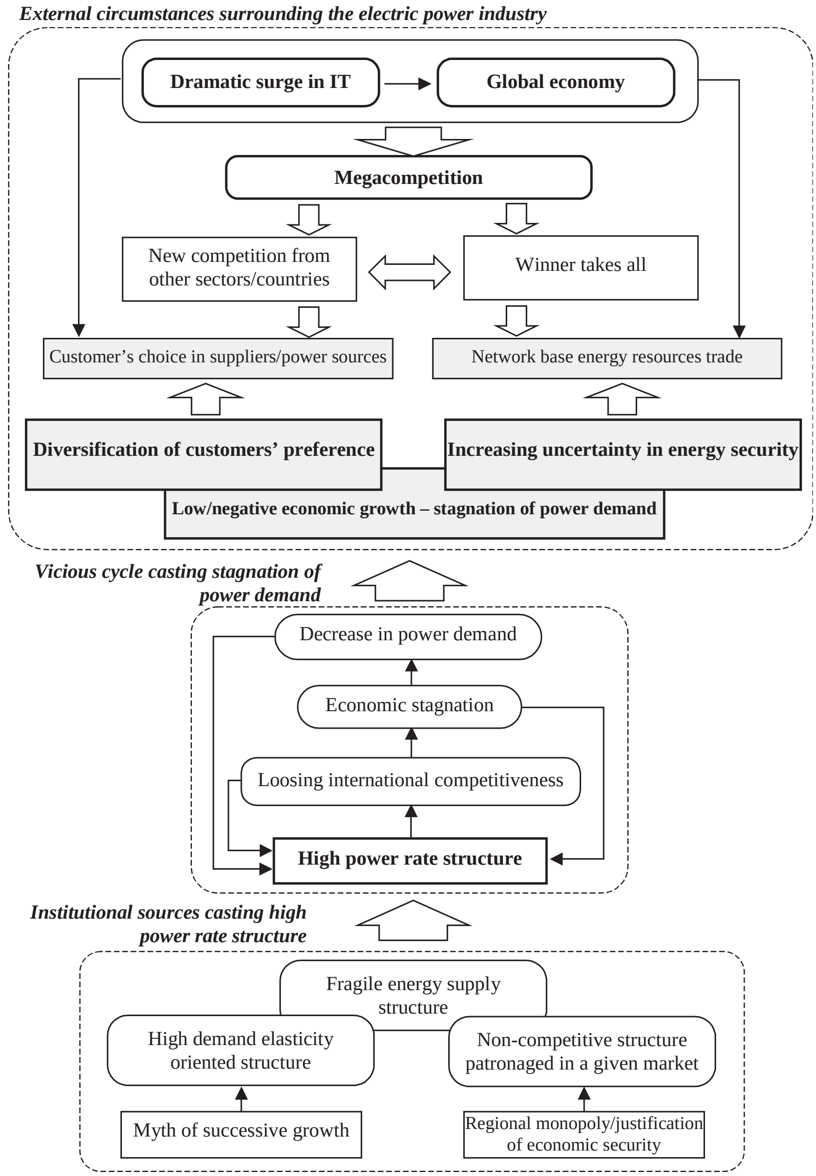

Fig. 1. Institutional sources and external circumstances surrounding Japan's electric power industry.

(ii) Vicious cycle (i.e. negative feedback cycle, unsuccessful stimulation and non-induced interaction) casting stagnation of power demand, and
(iii) New external circumstances surrounding the electric power industry.

2.1.1. *Institutional sources casting high power rate structure*

Japan's power rate is one of the highest in the world, resulting in Japan's industry losing its price competitiveness in the global market.

Fig. 2 compares power rates in leading countries by demonstrating Japan's conspicuous high cost structure.

This high cost structure can be attributed not only to Japan's fragile energy supply structure, but also to a high-demand-elasticity oriented structure and non-competitive structure. Non-competitive structures can be attributed to a regional monopoly and justification of economic security, and subsequent patronage in a given market. This can be a consequence of a fatal fragile energy supply structure. In addition, a high-demand-elasticity oriented structure is derived from the myth of successive growth formulated during the course of the rapid economic growth period.

2.1.2. *Vicious cycle casting stagnation of power demand*

Confronted with megacompetition in an IT driven global economy, Japan's high power rate structure has

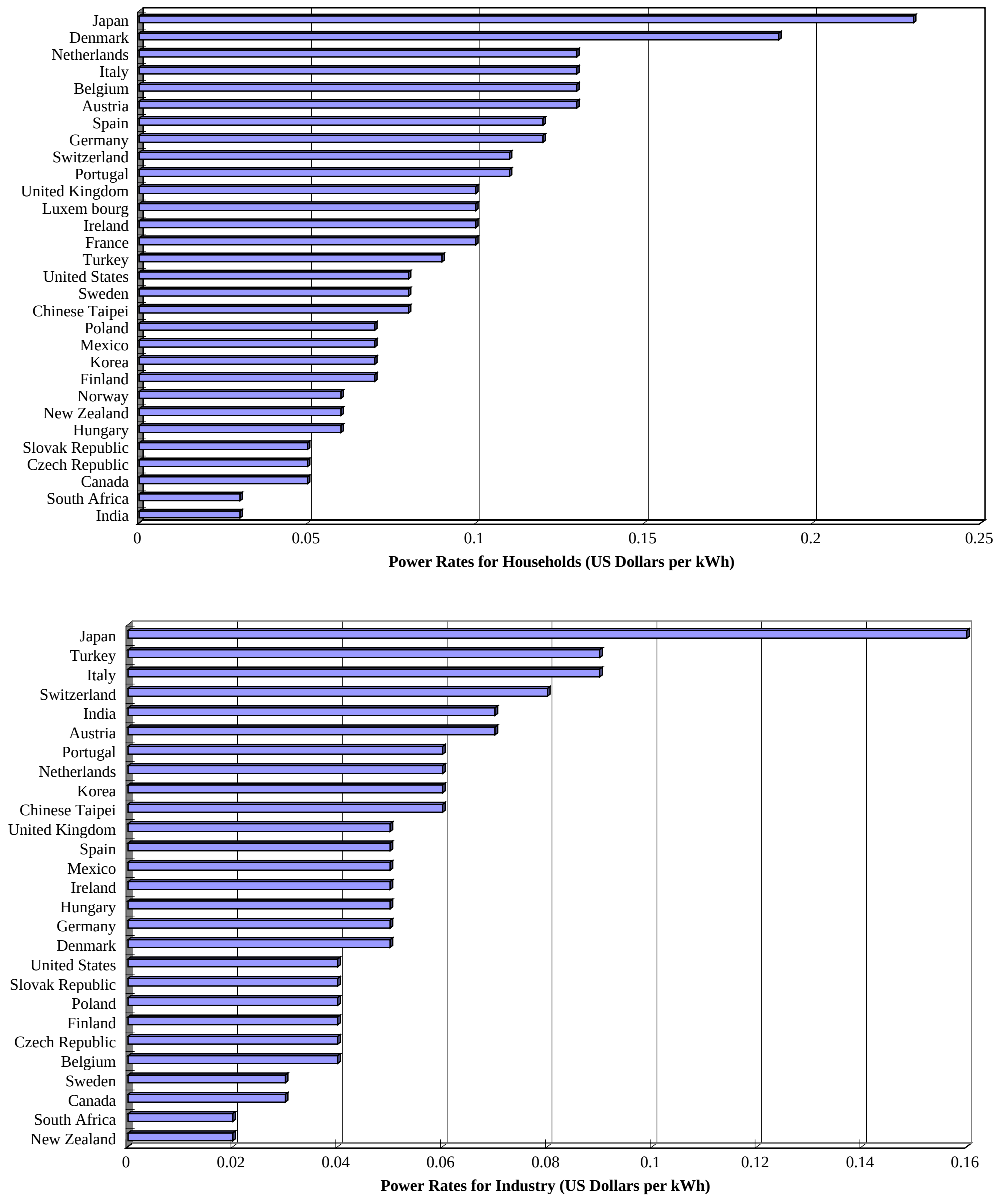

Fig. 2. Comparison of electric power rate in leading countries (Fourth Quarter of 2000). Source: Key world energy statistics IEA (2001).

compelled its industry to loose international competitiveness, resulting in an economic stagnation, leading to decreasing power demand. Decreased international competitiveness has made securing investment difficult which then leads to a higher power rate structure. Economic stagnation and a decrease in power demand, also react to further higher power rate structures, due to rigidness of management and operations, as well as an increase in constraints in resource procurements. Thus, a triple vicious cycle between the decrease or stagnation of competitiveness, and economic activities such as power demand and higher power rate, allow Japan's electric power demand to suffer, as demonstrated in Fig. 3.

2.1.3. *External circumstances surrounding the electric power industry*

A dramatic surge in information technology (IT) around the world, coupled with rapid globalization, compel firms to be in the midst of megacompetition and accelerate the foregoing vicious cycle in Japan's electric power industry.

Megacompetition not only accelerates such a vicious cycle, but also emerges new competitive structure for the electric power industry, by allowing new competitors in a patronaged market as demonstrated in Table 1, which compels customers to switch to other suppliers, in response to the diversification trends in customer's preferences.

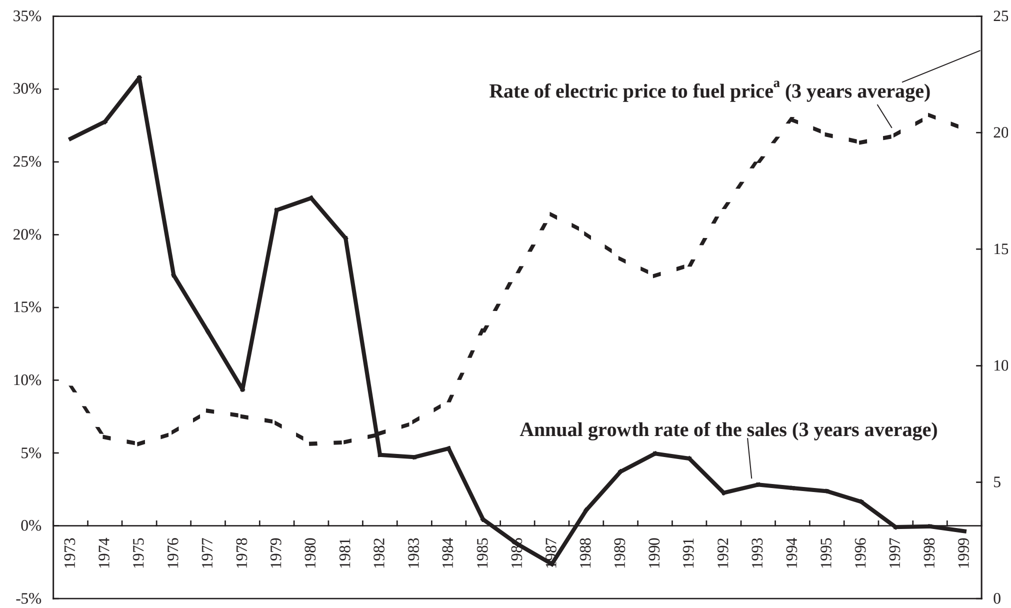

Fig. 3. Vicious cycle in Japan's electric power industry. (a) Fuel price was calculated by the following equation: Fuel price = fuel cost/(kWh/average generation efficiency). Source: Handbook of electric power industry (The Federation of Electric Power Companies, annual issues).

Table 1
New competitors in Japan's electric power industry (as of October 2001)

Name	Origin	Capacity (kW)	Year of participation (notification)	Power source	
Diamond power	General trading	206,700	June 2000	Other companies	Thermal, Hydroelectric
Marubeni	General trading	32,200	August. 2000	Subsidiary	HydroElectric
Asahi glass	Glass manufacturing	40,900	Sept. 2000	Itself	Thermal
Erex	Finance, general trading	33,000	Jan. 2001	Other companies	Thermal
Nippon steel	Steel manufacturing	31,000	Jan. 2001	Other companies	Thermal
Ennet	Telecommunication, gas	93,020	Jan. 2001	Itself and others	Thermal
Summit Energy	General trading	54,000	Feb. 2001	Parent company and others	Thermal
Daio paper	Paper & pulp	524,110	March 2001	Itself	Thermal
Sanix	Waste disposal	74,000	April 2001	Itself	Thermal

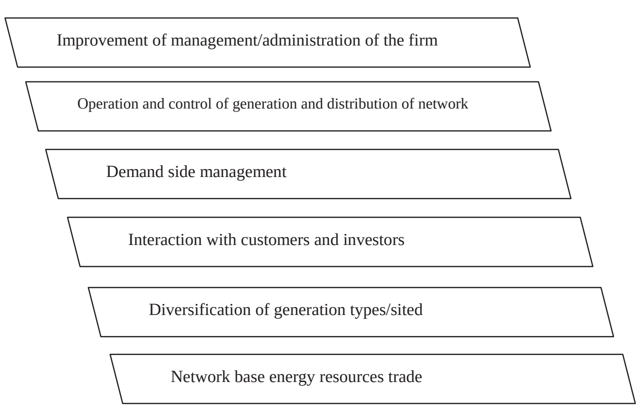

Fig. 4. Dissemination of IT in the electric power industry.

Advancement of IT enables customers to choose suppliers, as well as power sources at their own initiatives (Kawamoto et al., 2002). Since megacompetition creates a winner takes it all situation, advancement of IT under a megacompetition also compels dramatic structural changes in the supply structure and system, with respect to energy resources by enabling network base energy resources trade as illustrated in Fig. 4.

Thus, due to experiencing megacompetition in an IT driven global economy, Japan's electric power industry is compelled to the "*penta-lemma*" structure as demonstrated in Section 1.

2.2. Basic trajectory of survival strategy for Japan's electric power industry

Fig. 5 illustrates the basic trajectory of survival strategy for Japan's electric power industry amidst megacompetition in an IT driven global economy.

Given that power demand continues to stagnate in a low or negative economic growth, customer selections are accelerated constantly in megacompetition, and

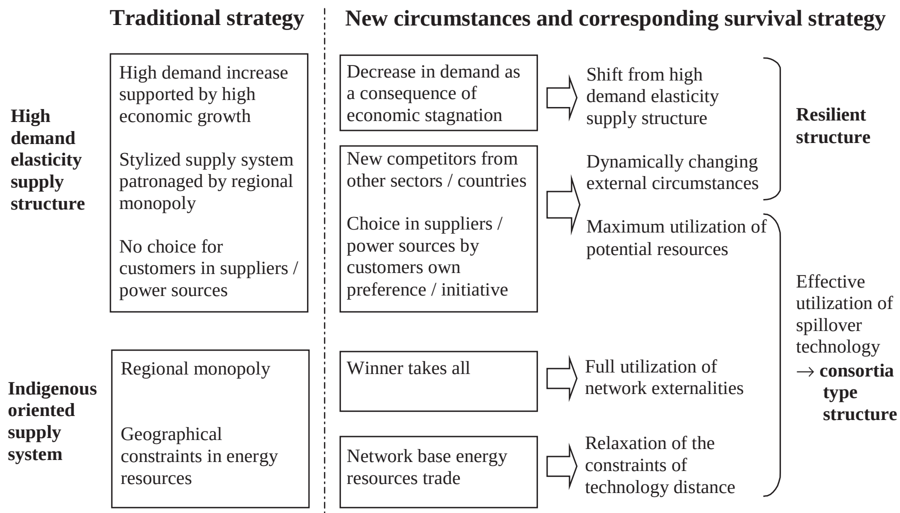

Fig. 5. Basic trajectory of survival strategy for Japan's electric power industry amidst megacompetition in an IT driven global economy.

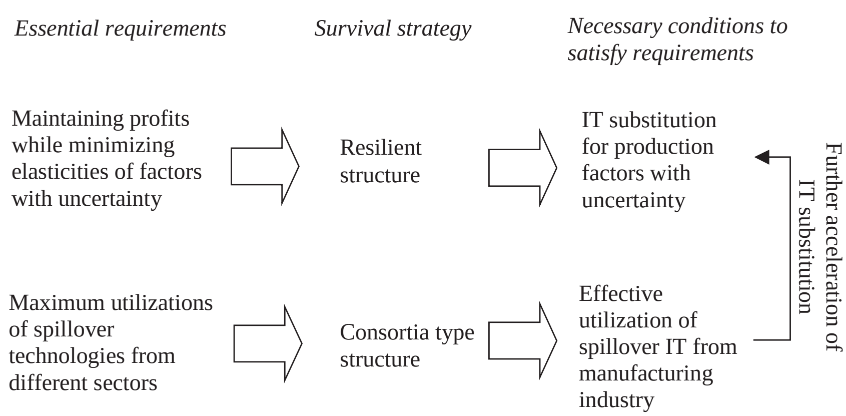

Fig. 6. Essential requirements for survival strategy and necessary conditions to satisfy requirements.

uncertainty with respect to energy security and systems safety, dramatically increase under the winner takes it all situation; five factors of the "penta-lemma" structure compel Japan's electric power industry to overcome these challenges with a dramatic conversion of existing strategies. As indicated in Section 1, the *resilience and leveraging consortia structure* could be based on this conversion, and converging to this structure is a critical survival strategy for the electric power industry in Japan.

2.3. *Essential requirements for survival strategy and necessary conditions*

Fig. 6 illustrates the essential requirements for the electric power industry for its survival strategy amidst megacompetition in an IT driven global economy, and necessary conditions to satisfy these requirements.

Fig. 6 suggests that resilience and leveraging consortia structures lead to a new trajectory, which incorporates necessary conditions to satisfy essential requirements for the survival strategy. This new trajectory incorporates

(i) IT substitution for production factors with uncertainty, and
(ii) effective utilization of spillover IT from manufacturing industry which contributes to further acceleration of IT substitution.

Fig. 7 illustrates mechanism of IT substitution for factors with uncertainty while Fig. 8 illustrates mechanism of IT's contribution to stimulating technology spillover.

On the basis of the identification of the essential requirements and necessary conditions for a survival strategy of Japan's electric power industry, the following sections attempt to analyze the current condition of the Japanese electric power industry.

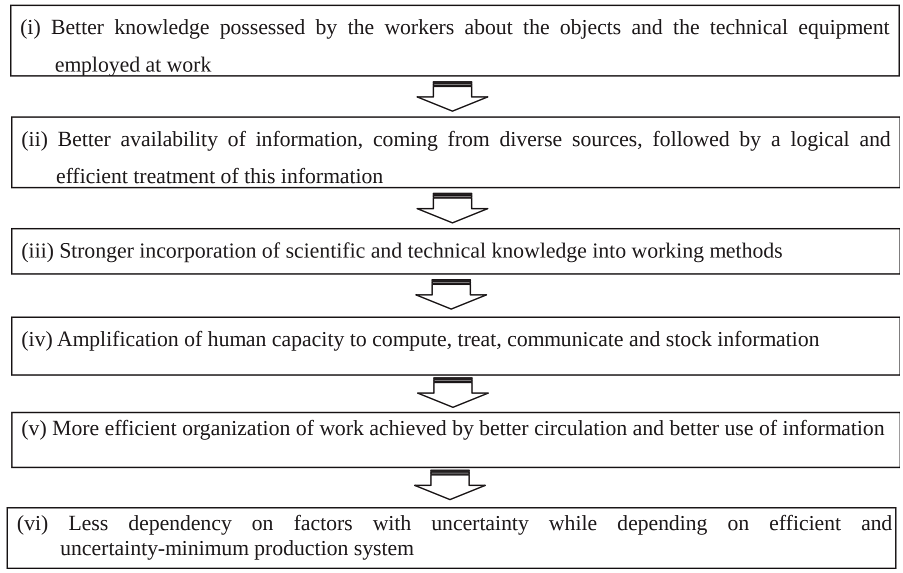

Fig. 7. Mechanism of IT substitution for factors with uncertainty to increasing resilience.

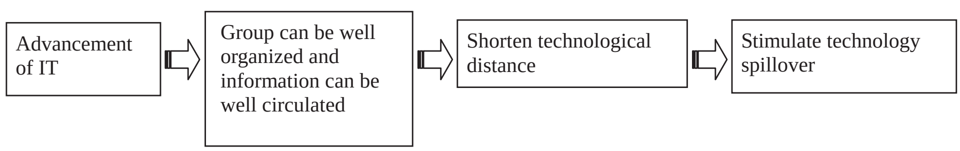

Fig. 8. Mechanism of IT's contribution to stimulating technology spillovers.

3. Analytical framework

3.1. Model synthesis

3.1.1. Model for the analysis of IT substitution and spillover

Since the focus of the analysis is to identify the state of (i) IT substitution for factors with uncertainty, (ii) contribution of own IT to cost decrease, and (iii) the effects of IT spillover from other sectors in the electric power industry, it can be noted that IT incorporated translog cost function is useful. Utilizing this function, IT substitution for factors with uncertainty can be identified by measuring relevant elasticities of substitution.

In addition, IT contribution to cost decrease, as well as spillover effects can be measured by analyzing the elasticities of indigenous IT, as well as spillover IT, to cost of the electric power industry, respectively.

3.1.2. Construction of translog cost function[1]

It is assumed that in the Japanese industry there exists the following twice differentiable aggregate cost function:

$$C = C(Y,\ P_i,\ Te,\ ITe,\ ITm), \qquad (1)$$

where C: gross cost; Y: production, P_i: prices of production factors i; Te: technology stock generated by indigenous R&D[2]; ITe: indigenous IT stock; and IT_m: aggregated IT stock in Japan's manufacturing industry.

The following translog cost function can be obtained by making Taylor expansion to the secondary term:

$$\begin{aligned}\ln C = {} & C_0 + \alpha_Y \ln Y + \sum \alpha_i \ln P_i + \alpha_{Te} \ln Te \\ & + \alpha_{ITe} \ln ITe + \alpha_{ITm} \ln ITm \\ & + \tfrac{1}{2}\sum\sum \beta_{ij} \ln P_i \ln P_j + \sum \beta_{Yi} \ln Y \ln P_i \\ & + \sum \beta_{Tei} \ln Te \ln Pi + \sum \beta_{ITei} \ln ITe \ln Pi \\ & + \sum \beta_{ITmi} \ln ITm \ln Pi + \sum \beta_{YTe} \ln Y \ln Te \\ & + \sum \beta_{YITe} \ln Y \ln ITe + \beta_{YITm} \ln Y \ln ITm \\ & + \beta_{TeITe} \ln Te \ln ITe + \beta_{TeITm} \ln Te \ln ITm \\ & + \beta_{ITeITm} \ln ITeITm, \end{aligned} \qquad (2)$$

where, $i, j = L, K, E$ (labor, capital and energy).

Under the assumption of the symmetrical nature of coefficients and of the linear homogeneity of the cost function, the following restrictions are imposed on

[1] See analysis of substitution of the fuels in the electric power industry by using translog cost function Kumakura and Oyama (1981) and Young-Seok (1995).

[2] Technology stock is accumulation of knowledge developed through the course of R&D activities (Watanabe, 1999).

parameters in Eq. (2):

$$\sum_i \alpha_i = 1, \tag{3}$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ij} = \sum_i \beta_{Yi} = \sum_i \beta_{Tei} = \sum_i \beta_{ITei} = \sum_i \beta_{ITmi} = 0. \tag{4}$$

In addition, for twice differentiable cost function the following condition should be satisfied:

$$\beta_{ij} = \beta_{ji} \quad i \neq j. \tag{5}$$

Taking partial differentiation of both sides of Eq. (2) by $\ln P_i$ the following equation can be obtained:

$$\frac{\partial \ln C}{\partial \ln P_i} = \alpha_i + \sum_j \beta_{ij} \ln P_j + \beta_{Yi} \ln Y + \beta_{Tei} \ln Te + \beta_{ITei} \ln ITe + \beta_{ITmi} \ln ITm. \tag{6}$$

Adopting Sheppard's adjustment, the left-hand side can be represented by cost share as follows:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i}{C}\frac{\partial C}{\partial P_i} = \frac{P_i X_i}{C} = m_i. \tag{7}$$

Synchronizing Eqs. (6) and (7) the following equation can be obtained:

$$m_i = \alpha_i + \sum_j \beta_{ij} \ln P_j + \beta_{Yi} \ln Y + \beta_{Tei} \ln Te + \beta_{ITei} \ln ITe + \beta_{ITmi} \ln ITm. \tag{8}$$

By conducting a regression analysis imposing constraints (3)–(5), parameters of Eq. (8) can be identified. Conducting regression analysis of Eq. (2) by substituting these identified parameters for parameters in Eq. (2), other parameters in Eq. (2) can be identified.

By utilizing this translog cost function:

(i) IT substitution for production factors with uncertainty such as energy and capital—*resilience*,
(ii) IT contribution to cost decrease, and
(iii) spillover effect of manufacturing industry's IT—*leveraging consortia* can be measured.

3.1.3. Identification of IT substitution for production factors with uncertainty

In order to identify IT substitution for production factors with uncertainty, the Allen partial elasticity of substitution indicates a substitution or complement relation between these factors is measured. The Allen partial elasticity of substitution is depicted by the following equations:

$$\sigma_{ij} = (\beta_{ii} + m_i^2 - m_i)/m_i^2 \quad (i = j),$$
$$\sigma_{ij} = (\beta_{ji} + m_i m_j)/(m_i m_j) \quad (i \neq j). \tag{9}$$

In this analysis, the Allen partial elasticities of substitution between the electric power industry's own IT stock (*ITe*) and capital (*K*) as well as energy are measured as follows:

(i) *ITe* and *K*,
(ii) *ITe* and *E*.

3.1.4. Measurement of the IT contribution to cost decrease

Taking partial differentiation of both sides of Eq. (2) by the electric power industry's own IT stock $\ln ITe$, the following equation depicting IT elasticity to cost, can be obtained:

$$\frac{\partial C}{\partial ITe}\frac{ITe}{C} = \frac{\partial \ln C}{\partial \ln ITe} = \alpha_{ITe} + \sum \beta_{ITei} \ln P_i + \beta_{YITe} \ln Y + \beta_{TeITe} \ln Te + \beta_{ITeITm} \ln ITm. \tag{10}$$

3.1.5. Measurement of the impacts of technology spillover

Since the spillover effect of IT stock in Japan's manufacturing industry (*ITm*) to the electric power industry can be represented by the elasticity of *ITm* to cost of the electric power industry $(\partial C/\partial ITe)(ITe/C)$ (Bernstein and Nadiri, 1988, 1989), this elasticity which can be depicted by the following equations is measured:

$$\frac{\partial C}{\partial ITm}\frac{ITm}{C} = \frac{\partial \ln C}{\partial \ln ITm} = \alpha_{ITm} + \sum \beta_{ITmi} \ln P_i + \beta_{YITm} \ln Y + \beta_{TeITm} \ln Te + \beta_{ITeITm} \ln ITe. \tag{11}$$

3.2. Data construction

3.2.1. Cost share

M_i	Cost share of production factor *i*, where *i*: *L* (labor); *K* (capital); and *E* (energy)
m_L	*GLC* (gross labor cost)/*GC* (gross cost)
m_K	*GCC* (gross capital cost)/*GC*
m_E	*GEC* (gross energy cost)/*GC*
GLC	Expenditure for employees,
GCC	Depreciation, payment for interest, and payment for repair
GEC	Expenditure for fuels, and
GC	*GLC* + *GCC* + *GEC*

All available in the Handbook of Electric Power Industry (The Federation of Electric Power Companies, annual issues).

3.2.2. Explanatory factors

P_L (wages)	GLC/EP (employed persons)
P_K (capital prices)	GCC/kW (power capacity)
P_E (fuel prices)	GEC/(kWh/average generation efficiency)

All available in the Handbook of Electric Power Industry except materials deflator which is available by Economic Statistics Annual (The Bank of Japan, annual issues).

Te_t (technology stock generated by indigenous R&D at time $t) = Re_{t-m} + (1-\rho)Te_{t-1}$, where Re_{t-m} is the indigenous R&D expenditure at time $t-m; m$ the lead time from R&D to commercialization; and ρ the rate of obsolescence of technology.

Re is available from firms' securities report (Ministry of Finance, annual issues). m and ρ are available by Techno-Economic Database (Watanabe, 1999).

3.2.3. IT stock

3.2.3.1. Aggregate IT stock in Japan's manufacturing industry (ITm). IT stock was constructed using the data from the Ministry of International Trade and Industry's (MITI)[3] "Current Status of Japanese Information Processing," which referred the "Survey on Information Processing in Japan" by Japan Information Processing Development Center. "Capital Matrix of the Input–Output Tables" was also used to supplement the IT-related investment that is not covered by the Survey. The resultant IT stock is explained by the IT-related expenses and investment listed in Table 2 (Wei, 2001).

3.2.3.2. Indigenous IT stock (ITe). Similarly, indigenous IT stock in electric power companies (nine (9) leading companies)[4] was constructed by estimating IT-related expenses and investment of these companies (*ITEe*) as follows:

$ITEe = ITEpu \times 10\eta \times (1+\kappa)$ (see footnote 5),[5] where $ITEpu$: average of a company's IT-related expenditure in public utilities; $\eta = Es_7/(Es_7 + Gs_3)$; and $\kappa = Es_2/Es_7$ (Es_7: sales of top 7 electric power companies; and Es_2: smaller 2 electric power companies).

Table 2
IT-related expenses and investment

Labor cost		Outsourced personal expenses, education and training cost, personal expenses, service charge, etc.
Capital cost	Hardware	Depreciation cost, rent fee, lease fee, installation charge, maintenance charge
	Software	Use charge, purchase cost, programming charge, consignment cost, machine rent charge, calculation consignment cost, data input charge
	Network	Network charge, network subscription charge, online service charge

4. Analysis and interpretation

Utilizing the synthesized model and applying constructed data, empirical analysis of (i) IT substitution for production factors with uncertainty, (ii) IT contribution to cost decrease and (iii) the spillover effect of the manufacturing industry's IT, are conducted focusing on leading nine (9) electric power companies.

4.1. IT substitution for production factors with uncertainty—resilience

Results of the estimation of parameters of Eq. (8) under the constrains of Eqs. (3)–(5) are summarized in Table 3.

Referring Table 3, we note that most of the coefficients estimated, indicate statistical significance at the 1% level except $\alpha_K, \beta_{YL}, \beta_{ITmL}$ at the 5%, $\alpha_E, \beta_{YK}, \beta_{TeE}$ at the 10%, and other coefficients ($\beta_{ITeL}, \beta_{IteK}, \beta_{ITeL}, \beta_{ITmK}$) at the 20% level, respectively.

On the basis of the estimated parameters, the estimated Allen partial elasticities of substitution between own IT stock and capital (σ_{ITeK}), as well as IT stock and energy (σ_{ITeE}) in the Japanese electric power industry, are computed as summarized in Table 4. Fig. 9 illustrates the trends of this elasticity of substitution, with respect to IT and capital, as well as energy.

Referring Table 4 and Fig. 9, the following noteworthy observations were obtained:

4.1.1. Relation between IT stock and capital

IT stock was complement to capital right up until the middle of the 1980s. This trend indicates that IT investment was increasing in cooperation with the increase in traditional capital investment, as hardware-oriented investment for power plant, machinery, power

[3] MITI renamed the Ministry of Economy, Trade and Industry on January 6, 2001 under the structural reform of the Japanese government.

[4] Nine (9) leading electric power companies are Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku and Kyusyu Electric Power Company.

[5] $ITEpu = (ITEe_7 + ITEg_3)/10 = ITEe_7(1 + (ITEg_3/ITEe_7))/10 \approx ITEe_7(1 + Gs_3/Es_7)/10 = ITEe_7((Es_7 + Gs_3)/Es7)/10 = ITEe_7/(10\eta)$ where $ITEe_7$ and $ITEg_3$ are IT-related expenses and investment in top 7 electric power companies and top 3 city gas companies, respectively, and the ratio of these expenses and investment is assumed to be proportional to the ratio of sales. Therefore, $ITEe_7 = ITEpu \times (10\eta)$ $\therefore$ $ITEe = ITEe7 + ITEe2 = ITEe7(1 + ITEe2/ITEe7) \approx ITEe7(1 + Es2/Es7) = ITEpu \times 10 \times (1+\kappa)$ where IT-related expenses and investment is assumed to be proportional to the ratio of sales.

Table 3
Estimated coefficient of translog cost function for the Japanese electric power industry (1975–1999)

Parameter	Estimated value	t-value
α_L	0.9377	4.40
α_K	0.9588	2.39
α_E	−0.8965	−2.06
β_{LL}	0.1146	6.09
β_{LK}	−0.0685	−12.16
β_{LE}	−0.0482	−22.04
β_{KK}	0.2726	23.38
β_{KE}	−0.1717	−34.7
β_{EE}	0.2199	41.57
β_{YL}	−0.0558	−2.54
β_{YK}	−0.0688	−2.05
β_{YE}	0.1245	3.30
β_{TeL}	−0.0189	−2.82
β_{TeK}	0.0460	3.58
β_{TeE}	−0.0271	−1.88
β_{ITeL}	−0.0071	−1.38
β_{ITeK}	−0.0141	−1.23
β_{ITeE}	0.0213	1.73
β_{ITmL}	0.0174	2.26
β_{ITmK}	−0.0205	−1.19
β_{ITmE}	0.0031	—[a]

[a] The value of β_{ITmE} was calculated by the following equation: $\beta_{ITmE} = 0 - \beta_{ITmL} - \beta_{ItmK}$.

Table 4
Trends in Allen partial elasticity of substitution in the Japanese electric power industry (1975–1999)

	σ_{ITeK}	σ_{ITeE}
1975	−7.11	9.13
1976	−5.93	9.24
1977	−4.80	8.48
1978	−2.81	7.90
1979	−4.24	7.26
1980	−6.17	9.10
1981	−4.44	7.30
1982	−4.21	7.05
1983	−3.33	7.43
1984	−3.19	7.50
1985	−2.29	7.13
1986	−0.95	8.41
1987	−0.84	7.64
1988	−0.33	6.31
1989	−0.31	5.43
1990	−0.32	4.83
1991	−0.10	4.75
1992	−0.02	4.88
1993	0.08	5.60
1994	0.06	5.79
1995	−0.15	7.22
1996	−0.13	6.18
1997	−0.14	6.64
1998	−0.08	7.06
1999	−0.11	6.68

network cable, etc. However, the level of complementarity decreased during the course of the 1980s, and turned out to be nearly neutral level from the late 1980s. This indicates that capital investment has shifted to an IT intensive one in the 1980s as a consequence of the shift to a knowledge intensified industrial structure.

4.1.2. Relation between IT stock and energy

Contrary to such relationships between IT stock and capital, IT stock of the Japanese electric power industry demonstrated strong substitution for energy in all periods examined. This substitution was considered due to the industry's effort in overcoming constraints of energy after the energy crises in 1973 and 1979 (Watanabe, 1992, 1995a–c, 1999 [19, 20, 21, 23]).

This strong substitution for energy, changed to a declining trend during the period of the bubble economy (1997–1990) thus corresponding to the R&D stagnation in this period (Watanabe, 1992, 1995a–c). This declining trend changed to an increasing trend in the 1990s whilst corresponding to a shift from an industrial society to an information society.

However, the level of IT substitution for energy still remains lower than the level after the first energy crisis to the middle of the 1980s. This implies that further potential of IT substitution for energy in the Japanese electric power industry remains.

4.2. IT contribution to cost decrease

Based on the estimated coefficients tabulated in Table 3 and using Eq. (10), contribution of own IT stock (ITe) to cost decrease in the Japanese electric power industry by means of IT elasticity to cost, is measured.

Table 5 summarizes the result of the analysis by tabulating trends in elasticity of own IT stock, to cost in the Japanese electric power industry over the period 1975–1999. Fig. 10 illustrates this trends.

Table 5 and Fig. 10 demonstrate that IT elasticity for cost in the Japanese electric power industry demonstrated positively, and increased in the 1970s. This is considered due to transition of IT incorporation and substitution for traditional facilities. This elasticity changed to a decreasing trend from the beginning of the 1980s and to a negative, in the latter part of the 1980s. This is considered due to the incorporation of IT into traditional facilities.

Although this elasticity continued to decrease towards the beginning of the 1990s, this decreasing trend stagnated and changed to slightly increasing trend in the 1990s. This trend demonstrates the limit of cost decrease only by its own IT stock in the Japanese electric power industry. This limit also suggests the structural sources of the high power rate in the Japanese electric power industry.

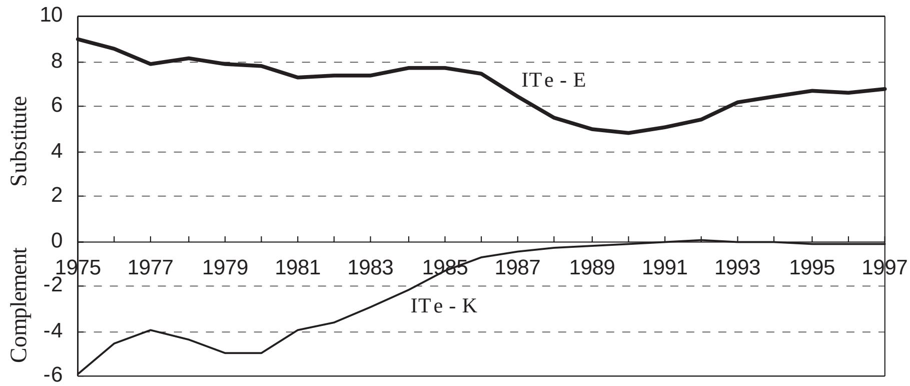

Fig. 9. Trends in Allen partial elasticity of substitution in the Japanese electric power industry (1975–1999)—3 years moving average.

Table 5
Trend in cost-down impact of own IT stock in the Japanese electric power industry (1975–1999)

Year	Elasticity of own IT to cost
1975	0.216
1976	0.345
1977	0.395
1978	0.447
1979	0.557
1980	0.623
1981	0.558
1982	0.52
1983	0.42
1984	0.308
1985	0.24
1986	0.078
1987	−0.029
1988	−0.091
1989	−0.216
1990	−0.312
1991	−0.462
1992	−0.413
1993	−0.451
1994	−0.412
1995	−0.424
1996	−0.178
1997	−0.156
1998	−0.251
1999	−0.239

4.3. Spillover effect of manufacturing industry's IT stock—leveraging consortia structure

Similar to the analysis in the preceding sub-section, the impacts of technology spillover by manufacturing industry's IT stock (*ITm*) on the electric power industry, are measured by means of its elasticity to cost as enumerated in Eq. (11). Spillover effects can be observed by this elasticity, and the negative value of this elasticity demonstrates the substantial contribution of spillover technology to the increase technology level of the electric power industry, thereby the decrease its cost.

Table 6 summarizes the result of the measurement and Fig. 11 illustrates the trend of these impacts over the period 1975–1999.

Referring Table 6 and Fig. 11, we note that while potential spillover effects increased nearly to reveal their potential in the latter part of the 1970s after the first energy crisis, these effects decreased due to the second energy crisis in 1979, and continued to decrease by the middle of the 1980s. This decreasing trend changed to an increasing trend from the mid-1980s, and the electric power industry effectively utilized substantial spillover effects from the manufacturing industry in the early half of the 1990s, corresponding to the emerging trend in IT. However, effective utilization of spillover technology in the electric power industry did not last long and changed to non-substantial utilization from the middle of the 1990s, hence corresponding to the long lasting economic stagnation in Japan. Shifts in the vicious cycle between high power rate, decrease in industry's international competitiveness and power demand stagnation in the Japanese electric power industry, correspond to the trend in loosing the benefits of effective utilization of spillover technology from the manufacturing industry. Japanese electric power industry seems not to have utilized the benefits of spillover effects from external IT stock.

4.4. Significance of resilience and leveraging consortia structure

4.4.1. Mechanism of IT substitution for energy and its significance

IT substitution for energy is essential for the Japanese electric power industry to convert to a resilient structure

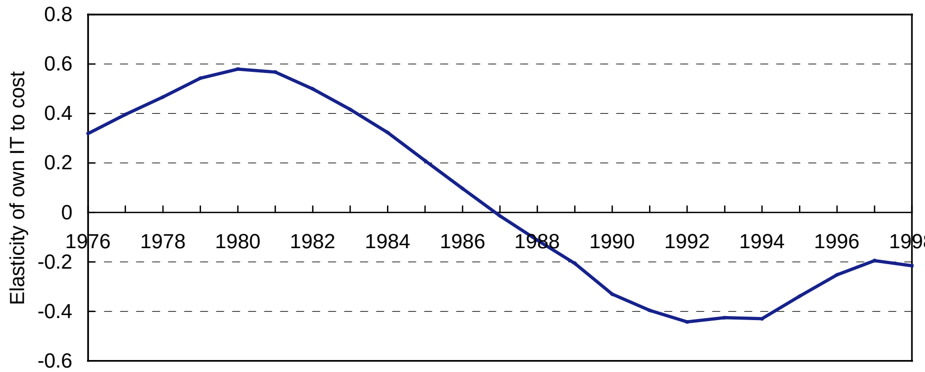

Fig. 10. Trend in elasticity own IT stock to cost in the Japanese electric power industry (1975–1999)—3 years moving average.

Table 6
Trend in spillover impact of the manufacturing industry's IT stock on the electric power industry in Japan (1975–1999)

Year	Elasticity of spillover IT to cost
1975	0.419
1976	0.374
1977	0.260
1978	0.000
1979	0.183
1980	0.293
1981	0.284
1982	0.249
1983	0.359
1984	0.507
1985	0.524
1986	0.355
1987	0.270
1988	0.049
1989	−0.031
1990	0.016
1991	−0.043
1992	−0.207
1993	−0.233
1994	−0.156
1995	0.200
1996	0.202
1997	0.391
1998	0.555
1999	0.646

while experiencing megacompetition in an IT driven global economy. Fig. 12 explains mechanism of this substitution.

IT substitution for energy can be expected by substitution for energy, not as a factor of production but via IT's incorporation in factors of production including capital, labor and energy, and their combinations (Chen, 1994).

Given such variety of IT incorporation leads the way to substantial IT substitution for energy, emergence of IT, both internally and externally would be crucial to the Japanese electric power industry for its survival strategy. Considering the limit of internal emergence of IT in the electric power industry as analyzed in the preceding section, effective utilization of external IT stock is seen to be essential. Given the IT's incorporation in broad factors of production including capital, labor and energy, effective utilization of spillover IT can be expected by consortia type structure.

4.4.2. Effects of IT substitution on a resilient structure

The effective utilization of external IT through consortia-type structures definitely contribute to increasing the electric power industry's IT stock, thus overcoming the limit of its internal IT stock. Increase in such IT stock accelerates IT substitution for factors with uncertainty as energy and costly capital investment linked to fluctuating power demand.

In order to evaluate the effects of such acceleration of IT substitution on the conversion to a resilient structure, an empirical inspection is attempted.

Table 7 summarizes factors governing operating income to sales (OIS) in Japan's electric power companies.

From Table 7, the elasticity of input energy resources to OIS can be depicted as follows:

$$k = \frac{\ln OIS - [a + b\ln(a' + b'\sin(ct + d) + \gamma D_{1994}) + g\ln YR + h\ln FD + \lambda t]}{\ln SV} \quad (12)$$

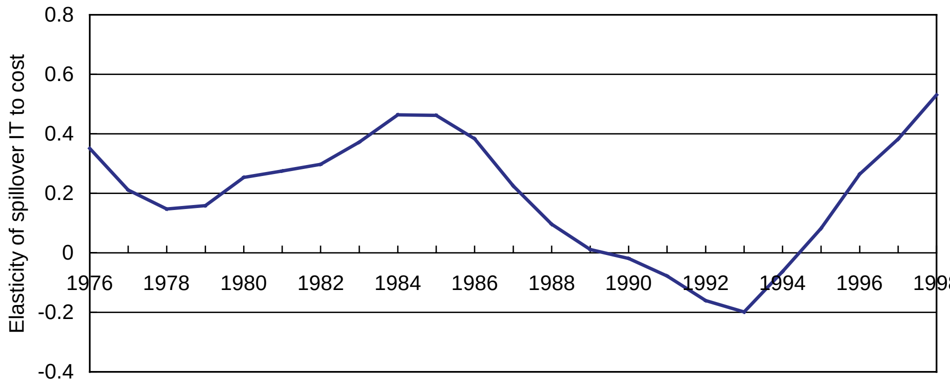

Fig. 11. Trend in spillover impacts of the manufacturing industry's IT stock on the electric power industry in Japan (1975–1999)—3 years moving average.

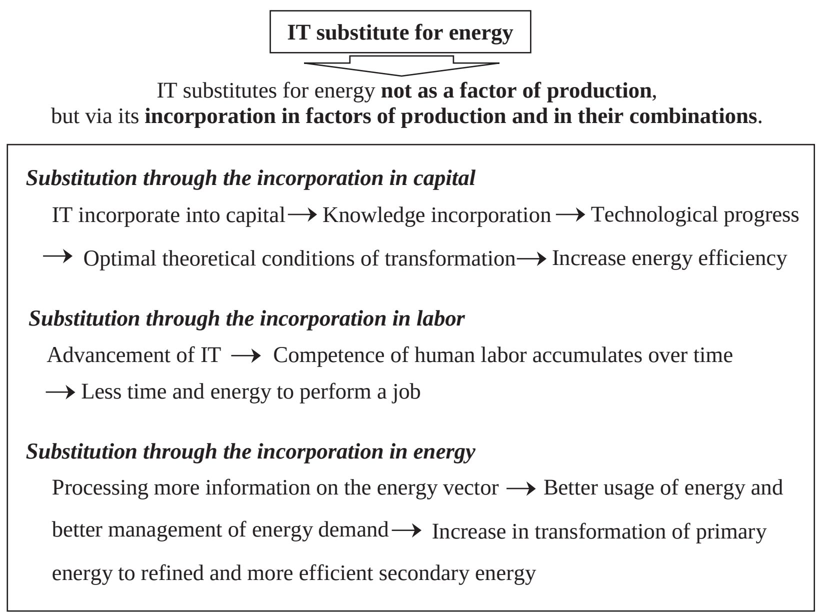

Fig. 12. Mechanism of IT substitution for energy.

Table 7
Factors governing operating income to sales (OIS) in Japan's electric power companies (1979–1998) $\ln \mathrm{OIS} = a + b\ln(a' + b'\sin(ct + d) + \gamma D_{1994}) + g\ln YR + \sum_i D_i h_i \ln FD + \sum_i D_i k_i \ln SV + \lambda t$

	a	b	g	h_1	h_2	K_1	k_2	λ	$Adj.R^2$	DW
Electric power (EP)	126.31	0.40	0.55	0.56	0.54	−1.63	−1.63	−0.05	0.833	1.23
(9 companies)	(2.07)	(1.34)	(3.28)	(3.06)	(2.91)	(−2.11)	(−2.12)	(−1.93)		

[a] $a' + b' \sin(ct + d) + \gamma D_{1994}$ represents trend in composite index (CI).
[b] YR the exchange rate of Yen (US$/Yen); FD: functionality development; SV: state of versatility and t: time trend.
[c] FD is represented by its own technology stock.
[d] SV is represented by input energy resources.
[e] D_i the dummy variable ($i = 1, 2$); D_1: 1979–1986 and D_2: 1987–1998.

from Eq. (9),

$$m_i \cdot m_j = \frac{\beta_{ij}}{(\sigma_{ij} - 1)}.$$

By substituting i for ITe (indigenous IT stock) and j for E (input energy resources), and by representing cost share (m_i, m_j) by Eq. (7), the following equation can be obtained:

$$m_{ITe} \cdot m_E = \frac{ITe \cdot P_{ITe}}{GC} \frac{E \cdot Pe}{GC} = \frac{\beta_{ITeE}}{(\sigma_{ITeE} - 1)},$$

$$\therefore IT_e \cdot E = \left(\beta_{ITeE} \cdot \frac{GC^2}{P_{ITe} \cdot P_e}\right) \frac{1}{\sigma_{ITeE} - 1}. \quad (13)$$

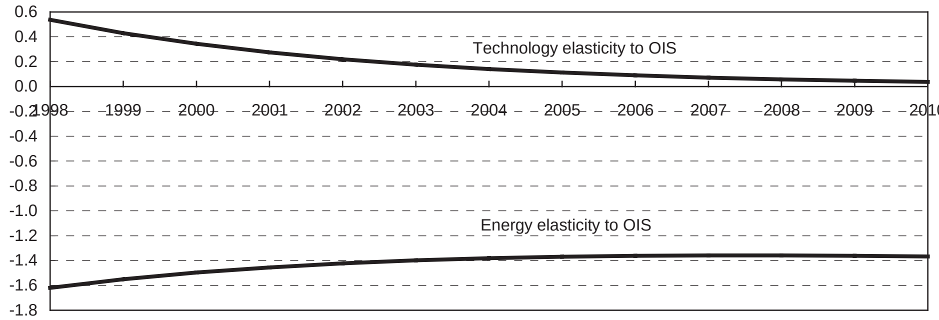

Fig. 13. Estimate of the trends in elasticities of input energy resources and technology stock to OIS in the Japanese electric power industry (1998–2010).

Under the conditions that when the relationship between IT and energy is substitutional and changes in gross cost is small enough to be supported by an advancement of IT, the relationship between change rates of IT and input energy resources can be approximated as follows:

$$\frac{\Delta ITe}{ITe} + \frac{\Delta E}{E} \approx -\frac{\Delta(\sigma_{ITeE} - 1)}{\sigma_{ITeE} - 1}. \tag{14}$$

Eq. (14) approximates the substituting relationship between IT and input energy resources as a function of the Allen partial elasticity of substitution.

Applying the estimated trend in Allen partial elasticity of substitution as tabulated in Table 4 to Eq. (14) and also decreasing trend in technology elasticity to OIS due to IT introduction into technology stock[6] to Eq. (12), an estimate of the trends in elasticities of input energy resources and technology stock to OIS in the Japanese electric power industry over the period 1998–2010 is conducted with the following assumptions:

(i) Increasing rate of IT stock is doubled than that of the late 1990s[7] due to the advancement of the effective utilization of external IT, and

(ii) Other fundamentals composing Eq. (12) such as OIS, economic cycle, exchange rate of Yen are no substantial change.

The result of the estimate is illustrated in Fig. 13.[8]

Fig. 13 suggests that the elasticity of input energy resources to OIS which is negative to OIS and indicates the highest value moves toward decreasing its absolute value while maintaining negative to OIS. This implies that while the OIS of the electric power industry is still damaged by the increase in dependency on energy, its sensitivity to energy supply situations decreases.

For the electric power industry, which inevitably depends on energy resources, it is difficult to decrease the elasticity of energy resources in general. Consequently, its decrease could lead to a resilient structure and an increase of OIS. The result of this analysis indicates that the acceleration of IT investment can achieve such favorite circumstances. Therefore, IT is considered to have great potential in substitute energy resources.

Fig. 13 also suggests that the elasticity of technology to OIS moves to decrease, leading to less dependence on technology with uncertainty, while maintaining OIS.

Both demonstrate that a shift to a resilient structure decreases dependencies on factors with uncertainty, thereby demonstrating the effectiveness of IT substitution for factors with uncertainty to a resilient structure in the Japanese electric power industry.

[6] Empirical analysis suggests approximately 20% per annum as follows: Since technology elasticity to power generation decreases as IT incorporates in technology stock, production function for Japan's nine (9) leading companies can be estimated as follows: $Y = AK^{\alpha}E^{\beta}T^{\gamma e^{-\lambda t}}$ where Y: electric power generation (kWh); A: scale factor; K: generation capacity (kW); E: input energy resources measured by MJ; T: technology stock; t: time trend ($t = 1$ (1974)–27 (2000)); α, β, γ: elasticities; and λ: coefficient depicting the decreasing trend in technology elasticity to power generation. Comparative empirical analysis over the period 1974–2000 identifies $\lambda = 0.20$ as statistically most significant value as follows:

λ	α	β	γ	$Adj.R^2$	DW	AIC
0.15	0.187	0.954	0.010	0.9997	1.12	−199.9
	(5.97)	(37.32)	(6.68)			
0.20	0.165	0.945	0.007	0.9998	1.20	−208.8
	(6.42)	(42.59)	(7.08)			
0.25	0.160	0.940	0.006	0.9996	1.11	−194.0
	(4.85)	(31.75)	(5.61)			

[7] Estimated as approximately 1% per annum.

[8] The estimate is attempted with the following conditions:

(i) IT and input energy resources have substitutional relationship,
(ii) change in gross cost is small supported by an advancement of IT,
(iii) decreasing trend in technology elasticity to OIS due to IT introduction into technology stock continues similar trend in the 1990s,
(iv) increasing rate of IT stock is doubled than that of the late 1990s due to the advancement of the effective utilization of external IT, and
(v) other fundamentals influencing the elasticities such as OIS, economic cycle, exchange rate of Yen are no substantial change.

5. Conclusion

In light of recognition of experiencing megacompetition in an IT driven global economy, Japan's electric power industry is compelled to the ''penta-lemma'' structure. This complex circumstance is characterized by the following five factors:

(i) Accelerated economic stagnation resulting in collapse of its own demand;
(ii) this allowed new competitors from other sectors and also from other countries to gain significant advantages;
(iii) consequently, customers could choose suppliers as well as power sources at their own preference and initiatives;
(iv) creating a winner takes it all situation, and
(v) these trends continued with the introduction of network based energy resources trading in a global context.

This analysis created a phenomenological model for understanding the sources of this complex problem and its possible solutions.

This analysis postulated that a simultaneous solution can be expected by a (i) resilient structure which aims at maintaining profits while minimizing the elasticities of factors with uncertainty, and a (ii) consortia type structure which aims at the maximum utilization of spillover technologies from different sectors, given a dramatic surge in IT around the electric power industry and its relevant industries and customers, the necessary conditions to satisfy the foregoing requirements were analyzed.

These structures lead to the following strategic direction for a survival strategy for Japan's electric power industry amidst megacompetition in an IT driven global economy, whilst casted by high power rate structure:

(i) IT substitution for production factors with uncertainty, and
(ii) effective utilization of spillover IT from manufacturing industry which contributes to further acceleration of IT substitution.

In order to demonstrate the significance of this postulated survival strategy, an empirical analysis was conducted that focused on Japan's leading nine (9) electric power companies, by developing an IT incorporated translog cost function for them.

An analysis for the identification of IT substitution, for factors with uncertainty including energy and capital demonstrated IT substitution for energy while complement with capital. While IT substitution for energy demonstrated increasing trends in these years, the substitution level is not necessarily sufficient. The complementary relationship between IT and capital demonstrated a dramatic decrease and shifted to neutral in the 1990s.

On the other hand, an analysis of the evaluation of the contribution of the electric power industry's own IT stock to cost decrease, demonstrated a significant contribution to decreasing its cost started from the beginning of the 1980s. However, this decreasing trend stagnated in the 1990s and changed to increase in these years. This trend demonstrates the limit of cost decrease only by its own IT stock in the Japanese electric power industry. This limit also suggests the structural sources of the high power rate in the Japanese electric power industry (Fig. 13).

Furthermore, an analysis on the evaluation of the contribution of spillover effects from IT stock of manufacturing industry to the electric power industry, demonstrates insufficient limited utilization of spillover effects which further decrease these years. This insufficient level suggests the necessity of the effective utilization of other industry's IT stock for increasing resilience for the electric power industry. Given that the substantial IT substitution for energy can be expected via IT's incorporation in broad factors of production and their combinations, effective utilization of IT spillover from an external industry, primarily the manufacturing industry seems to be essential. In addition, this can be expected by consortia structure.

All these analyses demonstrated the insufficient state of resilience and consortia type structure of the Japanese electric power industry resulting in facing the ''penta-lemma'' structure. Thus, our hypothetical view that a resilient and consortia type structure is essential for survival strategy for the Japanese electric power industry, casted by high power rate structure while amidst megacompetition in an IT driven global economy, was supported.

These findings suggest that further incorporation of IT in the electric power industry, by increasing its own IT investment, and also by increasing effective utilization of spillover IT is crucial. Given the non-sufficient comparative advantage in IT, further efforts for effective utilization of spillover IT would be particularly beneficial for the electric power industry. This suggests the significance of the improvement of the assimilation capacity by stimulating its own capacity building and activating interactions with broader sectors and customers.

Future studies should be focused on further elucidation of the mechanism enabling IT substitution for energy, and the possible substation for capital. In addition, comparative analyses of the impacts contributing to improving assimilation capacity would be also important.

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