Chapter 2
Formation of IT Features Through Interaction with Institutional Systems: Empirical Evidence of Unique Epidemic Behavior

Abstract While emerging information technology (IT) is hastening the paradigm shift from an industrial society to an information society and providing all nations of the world with numerous potential benefits, effective utilization of these benefits will differ greatly depending on the nation, particularly on their institutional elasticity. This can be attributed to the specific features of IT. Since IT performs its function in connection with institutional systems unlike technology in general, its specific features can be formed through dynamic interaction with an institutional system. Considering the unique features of IT formed through such dynamic interaction, this chapter focuses on an analysis of the epidemic behavior of IT and attempts to identify specific features of IT in light of interaction with institutions.

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2.1 Introduction

Innovation, such as the development of new technologies, has been undoubtedly recognized as a significant driving force in sustaining economic growth. Romer [1] points out that for society as a whole, innovation, discovery and technological change offers large net gains because the new goods or processes are more efficient and more valuable than the old ones. On the other hand, as the OECD [2] claims, growth depends on building and maintaining an environment that is conductive to innovation and the application of new technologies. Actually, new technology itself represents only potential, and in order to exploit such potential, institutional change is necessary [3].

A rapid surge in IT around the world is inevitably forcing traditional societies to transform their socioeconomic structures. As the Telecommunications Council [4] noted, IT is hastening the paradigm shift from an industrial society to an information

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society. However, if IT is merely introduced to replace part of the workforce so as to improve productivity, as was the case with automation, the full benefits of IT will not be utilized. This is because IT not only enhances task efficiency but also permeates through an organization, or a society, to have an impact on their structure and behavior. More precisely, IT waves, most recently exemplified by growing popularity of the Internet and mobile communications are characterized by so-called "network externalities"[1] [5, 6] that construct a virtuous cycle between expanding number of users and rising value of networks, and rapidly diffuse as social infrastructure to support socio-economic activities.

The OECD [3] analyzed the potential of IT to "automate" and "informate." It observed that more relative emphasis has been given to the "automate" option and that IT has often been introduced into organizations that were shaped independently of it. Thus, if an organization can reengineer itself to shift the balance away from the "automate" option towards the "informate" option, it can become a learning institution with a new sets of skills.

Accordingly, IT differs from other technologies in that it interacts with individuals, organization, and societies (or institutions) in order to be utilized, and its features are formed dynamically through this interaction, behaving differently depending on the institutional elasticity of that it interacts with. In other words, the unique features of IT are formed during the course of interaction with institutional systems [6, 7]. Consequently, *IT's unique features can be identified in its diffusion process with respect to individuals, organizations and societies*.

Research on *the diffusion of innovation* has been undertaken in broad fields independently for long years including anthropology, sociology, education, public health, communication, marketing, and geography. Rogers [8] attempted to systematize these works in his pioneer work in "Diffusion of Innovations". He defined "diffusion" as *the process by which an innovation is communicated through certain channels over time among the members of a social system*. He also identified four main elements in the diffusion of innovations: *innovation features, communication channels, time, and social system*. All of Rogers's postulates support our hypothetical view with respect to IT features formation process that IT's unique features can be identified in its diffusion process.

This diffusion process is actually quite similar to the contagion process of an epidemic disease [9] and exhibits S-shaped growth. This process is well modeled by the *simple logistic growth function*, an epidemic function which was first introduced by Verhulst in 1845 [10]. Since the logistic growth function has proved useful in modeling a wide range of innovation process, a number of studies applied this function in analyzing the diffusion process of innovations [9], Mansfield [11,12], Metcalfe [13], Norris and Vaizey [14].

While the simple logistic growth function treats the carrying capacity of a human system[2] fixed, this capacity is actually subject to change [15]. Among varieties of innovations, certain innovations alter their carrying capacity in the process of

[1] The value to a consumer of a product increases as the number of compatible users increases [20].

[2] Upper limit of the level of diffusion, see Sect. 2.2.2.

their diffusion which stimulates increase in the number of potential customers [16]. This increase, in turn, incorporates new features to the innovations. This is similar to an ecosystem in which species can sometimes alter and expand their niche [10]. Mayer [10] extended the analysis of logistic functions to cases where dual processes operate by referring an example when cars first replaced the population of horses but then took on a further growth trajectory of their own. He stressed that "if the carrying capacity of a system changes during a period of logistic growth, a second period of logistic growth with a different carrying capacity can superimpose on the first growth pulse." This is quite similar to the diffusion process of the innovations discussed above. Aiming at exhibiting this diffusion process that contains complex growth processes not well modeled by the single logistic, Mayer postulated *bi-logistic growth*.

In addition to the above diffusion processes exhibited by a single logistic growth and bi-logistic growth, in particular innovations, correlation of the interaction between innovations and institutions display systematic change in their process of the growth and maturity. This is typically the case of the diffusion process of IT in which *network externality* [17] functions to alter the correlation of the interaction which creates new features of the innovation, IT. In this case, the rate of adoption increases, usually exponentially until physical or other limits slow the adoption. Adoption is a kind of "social epidemic." Schelling [18] portrays an array of logistically developing and diffusing social mechanisms stimulated by these efforts. Meyer and Ausbel [19] introduced an extension of the widely used logistic model of growth by allowing it for a sigmoidally increasing carrying capacity. They stressed that "evidently, new technologies affect how resources are consumed, and thus if carrying capacity depends on the availability of that resource, the value of the carrying capacity would change." This explains, particularly, unique diffusion process of IT which diffuses by altering carrying capacity or creating a new carrying capacity in the process of its diffusion. Aiming at exhibiting this diffusion behavior, Mayer and Ausbel proposed *logistic growth within a dynamic carrying capacity*.

Provided that the unique features of IT are formed during the course of interaction with institutional systems and that these features can be identified in its diffusion process, we can expect to identify features formation process of IT and its specific features in light of interaction with institutions by analyzing its diffusion trajectory using logistic growth within a dynamic carrying capacity and by comparing it with diffusion processes of technology in general. Furthermore, given the significance of network externality and its contribution to enhance IT's carrying capacity, identification of the mechanism of IT's contribution to increasing returns to scale can be expected.

In light of the increasing importance of institutional elasticity in exploiting the full potential of IT, this paper attempts to derive specific IT features by focusing on the unique diffusion process, in other words epidemic behavior of IT.

Section 2.2 conducts comparative analysis of epidemic behavior between IT and other technologies. Section 2.3 extracts implications with respect to features formation process of IT and its specific features. Section 2.4 briefly summarizes the key findings of the analysis, presents conclusions and discusses implications for effective utilization of the potential benefits of IT.

2.2 Features of IT with Respect to Institutions

2.2.1 Formation Process of Specific Features of Technology

As repeatedly emphasized in numerous studies, IT is functioning as a driving force to transform the existing socioeconomic structure by permeating through people's daily life, organizational activities, and society as a whole, hastening the paradigm shift from an industrial society to an information society [4, 6, 7, 20].

Table 2.1 compares features of the core technologies in the 1980s and in the 1990s. During the 1980s, developing excellent manufacturing technology was a key for firms to be successful in an industrial society. Manufacturing technology has been developed by a supply side to provide end-users with products or has been introduced to factories to replace part of the workforce for improving productivity. Like other technologies, features of manufacturing technology are established or programmed at birth and once it leaves a supply side, it would not change its behavior substantially during its dissemination. In this case, individual firms are responsible for forming features of technology.

With the remarkable development of information technology, IT, especially increased electronic connectivity in the 1990s, socio-economic activities have been more relying on IT infrastructures. The worldwide Internet population has been increasing[3] and the Internet has made it easier and cheaper for all businesses to transact business and exchange information, leading to an expanding e-commerce market [6].

Contrary to manufacturing technology, suppliers of IT are more concerned about compatibility. This is because IT products are often utilized as communication tool. If an electronic file processed by NEC's personal computer is not compatible with that of Toshiba's, how valuable these computers are? If a subscriber to a certain mobile communications service career cannot make a call to a subscriber of another career, people should lose an incentive to purchase cellular telephones, or try to subscribe to a career that boasts dominant number of subscribers. On the other hand, any home appliances such as refrigerators or TV sets can be purchased without

Table 2.1 Comparison of features between manufacturing technology and IT

	1980s	1990s
Paradigm	Industrial society	Information society
Core technology	Manufacturing technology	IT
Key features	*Given, provided by suppliers*	*To be formed during the course of interaction with institutions*
Actors responsible for formation of features	Individual firms/organizations	Institutions as a whole

[3] According to Nua Internet Surveys, there were approximately 407.1 million internet users world wide as of November 2000.

being bothered by what other people possess. In this context, IT products are subject to phenomena so-called network externalities. With computers and telephones, for example, the more people use compatible systems or the more people are on a network, the more valuable the system or the network become, thus attracting more potential users [5].

In short, IT strongly possesses a self-multiplicative feature that closely interacts with individuals, organizations, and society in broad, institutions, during the course of its diffusion and behaves differently depending on institutions of that it interacts with. These observations suggest that features of IT are formed dynamically during the course of interaction with institutions and whether the potential benefits of IT can be exploited greatly depends on institutions.

This formation process of IT features is actually quite similar to the contagion process of an epidemic disease stimulated by this similarity and based on the above hypothetical view that unique features of IT are formed during the course of its dissemination process, an attempt to derive specific features of IT with respect to the interaction with institutions by examining the unique epidemic behavior of IT is conducted.

2.2.2 Analysis of Epidemic Behavior

2.2.2.1 Taxonomy of Epidemic Function

Following three functions as introduced in Sect. 2.1 were used for comparative analysis of epidemic behaviors between IT and other technologies:

Simple logistic growth function: $f(t) = \frac{K}{1+a\exp(-bt)}$ *where a and b: coefficients; and t: time trend.*

An epidemic function is used for analyzing the diffusion and maturity of innovative goods. The epidemic function enumerates the contagion process of an epidemic, and this model provides an analogy of the diffusion and maturity trajectory through the contagion process of innovative goods similar to a medical epidemic. The epidemic function incorporates a negative feedback in an exponential function as follows:

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = bf(t)\left(1 - \frac{f(t)}{K}\right), \tag{2.1}$$

where K indicates the upper limit of $f(t)$: carrying capacity.

$\left(1 - \frac{f(t)}{K}\right)$ depicts a negative feed back and this approaches 1 and 0 when $f(t) \to K$ and $f(t) \to K$, respectively. Therefore, the growth rate (the left hand side of (2.1) increases logistically at the initial stage and stagnates to 0 as $f(t)$ approaches to K, drawing an S-shaped curve as illustrated in Fig. 2.1.

The following equation can be obtained by integrating (2.1):

$$f(t) = \frac{K}{1 + a\ \exp(-bt)}. \tag{2.2}$$

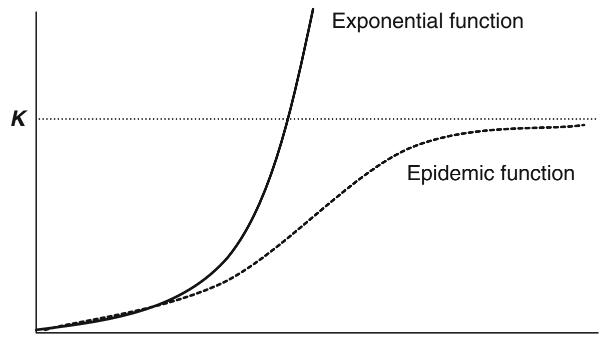

Fig. 2.1 Comparison between exponential function and epidemic function

Bi-logistic growth function: $f(t) = f_1(t) + f_2(t) = \frac{K_1}{1+a_1\ \exp(-b_1 t)} + \frac{K_2}{1+a_2\ \exp(-b_2 t)}$.
Bi-logistic growth function combines two phases of simple logistic growth function in the following function [10]:

$$f(t) = f_1(t) + f_2(t) = \frac{K_1}{1 + a_1\ \exp(-b_1 t)} + \frac{K_2}{1 + a_2\ \exp(-b_2 t)}. \tag{2.3}$$

Logistic growth function within a dynamic carrying capacity:

$$f(t) = \frac{K_K}{1 + a\ \exp(-bt) + \frac{b \cdot a_k}{b - b_K} \exp(-b_K t)}.$$

The epidemic function expressed by (2.1) assumes that the level of carrying capacity (K) is constant through the dissemination process of innovation. However, as reviewed in Sect. 2.1, in particular innovations, correlation of the interaction between innovation and institutions display systematic change in their process of the growth and maturity leading to creating new carrying capacity in the process of its diffusion. In these innovations, the level of carrying capacity will be enhanced as their diffusion proceed, and carrying capacity K in (2.1) should be treated as a following function:

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = bf(t)\left(1 - \frac{f(t)}{K(t)}\right), \tag{2.4}$$

where $K(t)$ is also an epidemic function enumerated by (2.5).

$$K(t) = \frac{K_K}{1 + a_K \exp(-b_K t)}, \tag{2.5}$$

where K_k indicates the ultimate upper limit.

The solution of a differential (2.4) under the condition (2.5) can be obtained as an (2.6).[4]

$$f(t) = \frac{K_K}{1 + a\ \exp(-bt) + \frac{b \cdot a_k}{b - b_K} \exp(-b_K t)}. \tag{2.6}$$

[4] See Appendix 1 for details of mathematical development.

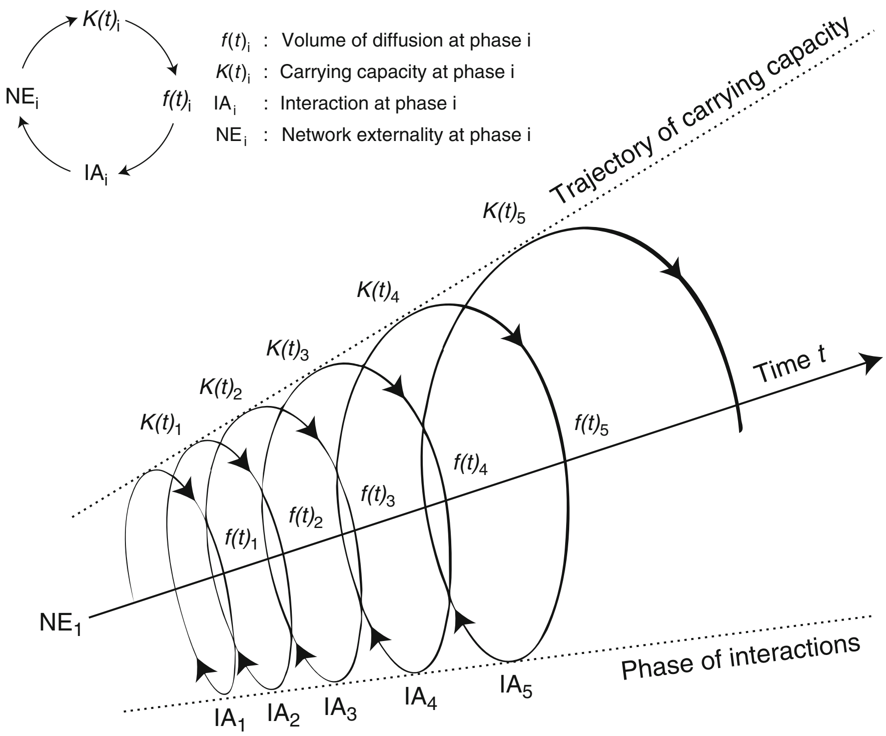

Fig. 2.2 Mechanism in creating a new carrying capacity in the process of IT diffusion

A dynamic carrying capacity $K(t)$ can be expressed by (2.7) by transforming (2.4).

$$K(t) = f(t)\left(\frac{1}{1-\left(\mathrm{d}f(t)/\mathrm{d}t\right)/bf(t)}\right). \tag{2.7}$$

Equation (2.7) demonstrates that $K(t)$ increases together with the increase of $f(t)$ as time goes by. This implies that (2.6) exhibits logistic growth within a dynamic carrying capacity as is displays such systematic change as illustrated in Fig. 2.2 number of customers (volume of diffusion) increases as time passes, which indicates interactions with institutions leading to increasing potential customers (carrying capacity) by increased value and function stimulated by network externality. Thus, IT's specific features are formed in this process.

2.2.2.2 Comparative Analysis of Epidemic Behavior

In order to verify the difference in diffusion process between IT and other technologies, diffusion patterns of (1) refrigerators, (2) color TV sets, and (3) cellular telephones were analyzed by applying the above mentioned three models. In the analysis, refrigerators and color TV sets were chosen because they are regarded as representative products of manufacturing technology, while cellular telephones represent one of the most popular IT products.

As indicators to measure diffusion patterns in Japan, annual shipments (1966–1999), annual domestic shipments (1966–2000), and quarterly domestic production volumes deducting imports and exports (1993–2000) were used for refrigerators, color TV sets, and cellular telephones, respectively.[5]

Refrigerators

Among three models, simple logistic growth function was most fitting for the diffusion pattern of refrigerators in that statistical indicators such as t-value and AIC (Akaike's Information Criterion) were most significant compared with those of other models, and adj.R^2 and DW were also relatively significant. As for the application of logistic growth function within a dynamic carrying capacity, a_k was small enough to lead the carrying capacity to almost fixed and the resultant trajectory traced a similar curve as simple logistic growth function did.

Figure 2.3 illustrates the trends in diffusion process of refrigerators in Japan from the year 1966 to 1999 with simple logistic growth function (figures in parentheses indicate t-value).

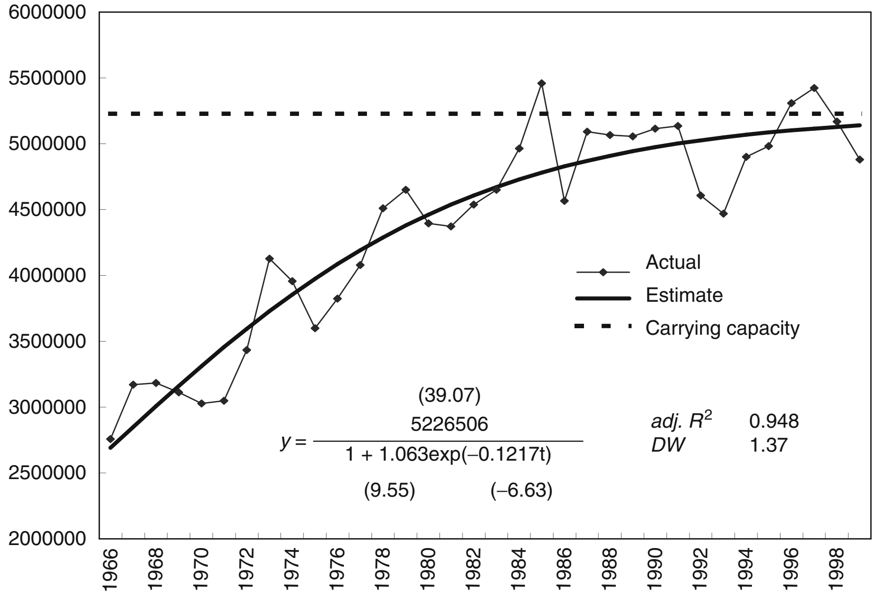

Fig. 2.3 Trends in diffusion process of refrigerators in Japan (1966–1999)
Source: Report on machinery statistics, MITI (annual issues)

[5] See Appendix 2 for data construction and sources.

Color TV sets

The diffusion process of color TV sets most fitted bi-logistic growth function for which all the statistical indicators showed significant values. Figure 2.4 depicts the transition of annual domestic shipment of color TV sets and related events from the year 1966 to 2000. In Japan, color TV broadcasting service was started in 1960. Since then, viewers gradually switched their TV sets from monochrome to color triggered by events such as World Exposition of Osaka in 1970. In 1973, color TV broadcasting became available in all TV programs, and viewers has come to be more concerned with the contents of TV programs, not color TV sets themselves.

Figure 2.5 illustrates the trends in diffusion process of color TV sets in Japan from the year 1966 to 2000 with bi-logistic growth function.

Cellular Telephones[6]

Figure 2.6 depicts the transition of quarterly production volume of cellular telephones and related events from the year 1993 to 2000. Though cellular telephones have relatively young history compared with that of refrigerators and color TV sets, continuous development of smaller and lighter handsets with a variety of functions has made their diffusion process rather complicated. One of the breakthroughs was NTT DoCoMo's introduction of i-mode service in February 1999 that enabled users to access to the Internet from their handsets. Since then, this kind of mobile

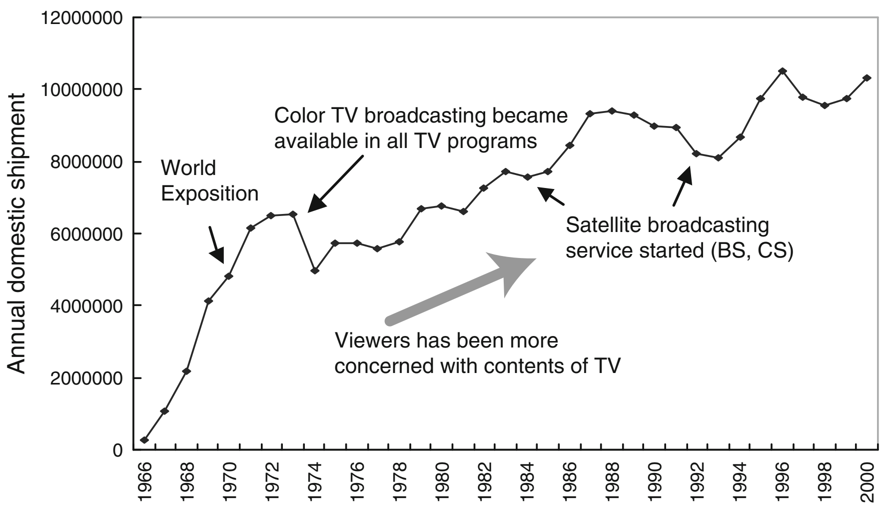

Fig. 2.4 Transition of annual domestic shipment of color TV sets and related events
Source: Japan Electronics and Information Technology Industries Association, Japan

[6] Cellular telephones include PHS (personal handy-phone systems) and automobile phones as well as cell phones.

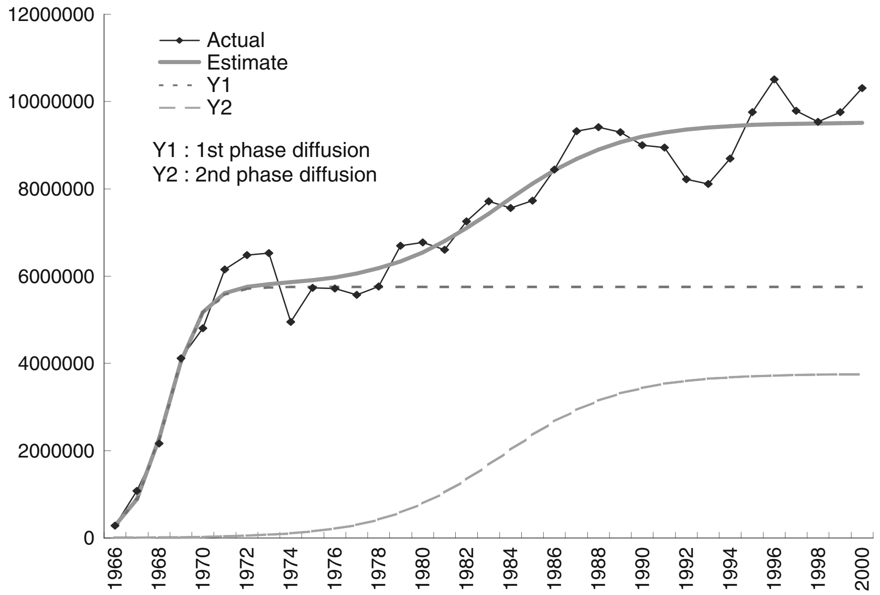

Fig. 2.5 Trends in diffusion process of color TV sets in Japan (1996–2000)
Source: Japan Electronics and Information Technology Industries Association, Japan

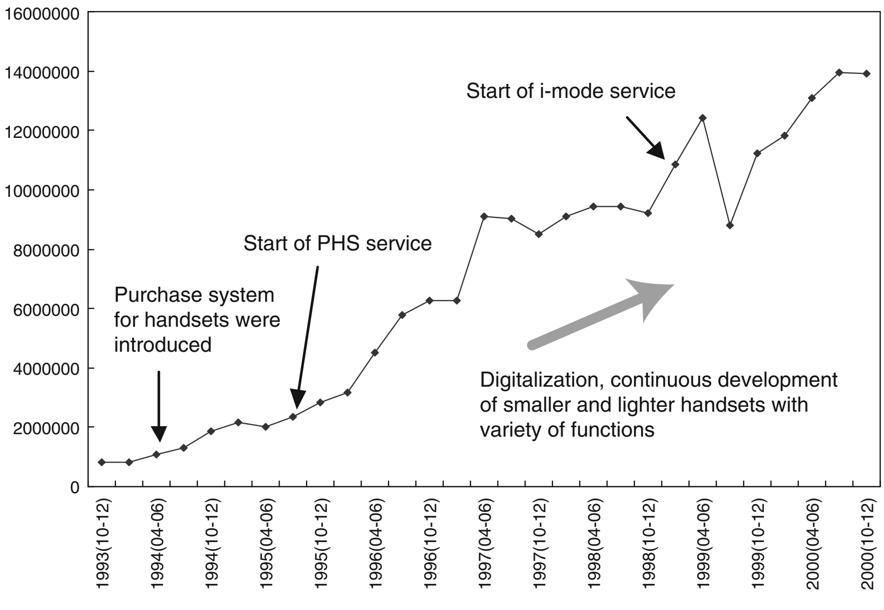

Fig. 2.6 Transition of quarterly domestic production volumes of cellular telephones and related events
Source: Current survey of production, METI (annual issues); trade statistics, MOF (annual issues)

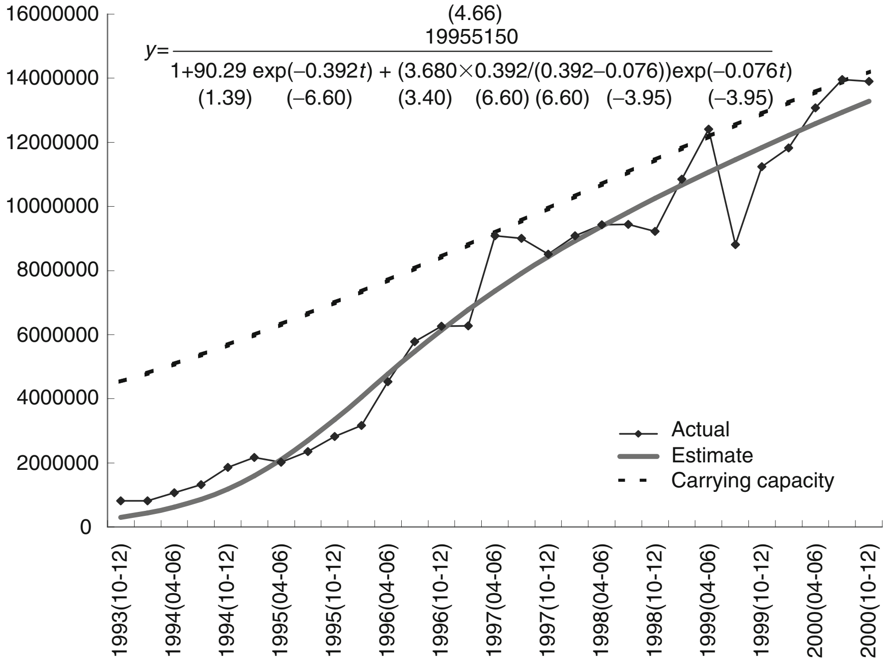

Fig. 2.7 Trends in diffusion process of cellular telephones in Japan (1993–2000)
Source: Current survey of production, METI (annual issues); trade statistics, MOF (annual issues)

Internet access service has been dramatically expanding and the number of subscribers reached about 31.4 million as of February 2001.[7] Java-compatible handsets have now been on sale since January 2001, which is expected to induce further increase in carrying capacity.

With these features, the diffusion process of cellular telephones was most fitting to logistic growth function within a dynamic carrying capacity, which showed the least AIC value among other models. Although adj.R^2 and DW were relatively significant for bi-logistic growth function, AIC is more reliable since the data was analyzed by non-linear regression. Figure 2.7 illustrates the trends in diffusion process of cellular telephones in Japan from the year 1993 to 2000 with logistic growth function within a dynamic carrying capacity.

2.2.2.3 Interpretations

Table 2.2 compares fittability of three epidemic functions: (1) Simple logistic growth function, (2) bi-logistic growth function, and (3) Logistic growth function within a dynamic carrying capacity for the diffusion process of three innovative goods: refrigerators, color TV sets, and cellular telephones.

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[7] http://www.tca.or.jp/

Table 2.2 Comparison of the fittability of three epidemic functions for the diffusion process of three innovative goods

Refrigerators

(1)	K	a	b				$adj.R^2$	AIC
	5,226,506 (39.07)	1.063 (9.55)	0.1217 (6.63)				0.948	8.523×10^{10}
(2)	K_1	a_1	b_1	K_2	a_2	b_2	$adj.R^2$	AIC
	3,399,421 (21.33)	0.2436 (2.22)	0.1101 (0.50)	1,677,219 (21.33)	22.17 (0.79)	0.2842 (3.89)	0.926	9.183×10^{10}
(3)	K_K	a	b	a_k	b_k		$adj.R^2$	AIC
	5,226,506 (38.97)	0.4637 (4.46)	0.1217 (6.62)	4.141×10^{-6} (1.50)	0.1217 (6.62)		0.949	8.706×10^{10}

Color TV sets

(1)	K	a	b				$adj.R^2$	AIC
	9,867,687 (18.61)	3.141 (5.60)	0.1385 (5.43)				0.923	1.018×10^{12}
(2)	K_1	a_1	b_1	K_2	a_2	b_2	$adj.R^2$	AIC
	5,758,095 (19.99)	71.90 (1.03)	1.281 (4.45)	3,759,613 (8.49)	973.0 (0.40)	0.3701 (2.75)	0.966	3.896×10^{11}
(3)	K_K	a	b	a_k	b_k		$adj.R^2$	AIC
	9,867,687 (18.61)	0.2109 (0.39)	0.1386 (5.43)	0.002653 (0.83)	0.1385 (5.43)		0.955	6.287×10^{11}

Cellular telephones

(1)	K	a	b				$adj.R^2$	AIC
	13,328,320 (16.59)	18.07 (3.81)	0.203 (7.54)				0.980	1.014×10^{12}
(2)	K_1	a_1	b_1	K_2	a_2	b_2	$adj.R^2$	AIC
	9,944,280 (16.42)	32.40 (2.64)	0.308 (7.23)	12,016,010 (16.42)	10,538 (1.12)	0.299 (9.20)	0.993	7.102×10^{11}
(3)	K_K	a	b	a_k	b_k		$adj.R^2$	AIC
	19,955,150 (4.66)	90.29 (1.39)	0.392 (6.60)	3.680 (3.40)	0.076 (3.95)		0.984	6.370×10^{11}

Figures in parentheses indicate t-value.

Looking at Table 2.2, we note the following findings with respect to the identification of epidemic behavior for respective innovative goods:

(a) AIC suggests that simple logistic growth function for refrigerators, bi-logistic growth function for color TV sets, and logistic growth function within a dynamic carrying capacity for cellular telephones demonstrate most fittable functions, respectively.

(b) Refrigerators have single function and more than half a century history since they have penetrated in a market. Their diffusion volume has almost saturated to 5.2 ± 0.5 million in the last 15 years. Table 2.2 demonstrates these trends by indicating that function (1) (simple logistic growth function) is statistically most significant. Function (3) (logistic growth function within a dynamic carrying capacity) follows function (1) with respect to its fittability. However, if we compare statistics of functions (1) and (3) in Table 2.2, we note that a dynamic carrying capacity is negligibly small (e.g. a_k : 4.141×10^-6) and carrying capacity of function (1) $(K = 5,226,506)$ and function (3) $(K_K = 5,226,506)$ has reached the same level. These support the former postulate that the diffusion process of refrigerators can be identified by the single logistic growth function.

(c) Similar to refrigerators, color TV sets have single function. However, their diffusion process is more complicated than refrigerators as they had substitution process with mono-color TV sets. In the initial diffusion process, color TV sets were co-evolution with monochrome TV sets. Since color broadcasting has become available in all TV broadcasting programs in 1973 in Japan, second diffusion emerged which is substantial diffusion process in a competitive market. Thus, diffusion process of color TV sets is typical bi-logistic growth. Table 2.2 demonstrates this trend by indicating that function (2) is statistically most significant.

Contrary to these diffusion processes in refrigerators and color TV sets, the diffusion process of cellular telephones is most complicated as it has multi-functions. Although cellular telephones have young history on their diffusion than refrigerators and color TV sets, they have the highest IT density. Such high IT density enables cellular telephones create new functions during the course of their interactions with customers leading them to be multi-functions goods. Diffusion process of this type of innovation could be well modeled by logistic growth within a dynamic carrying capacity. Table 2.2 demonstrates this postulate by AIC. Although AIC supports this postulate and other statistics also demonstrate better fittability than function (1), other statistics except AIC demonstrates slightly less significant than function (2). This could be interpreted that the diffusion process of cellular telephones has not yet matured and still is in transition from bi-logistic growth to logistic growth within a dynamic carrying capacity.

(d) Among three innovative goods examined, cellular telephones have definitely the highest IT density and multi-functions. Their diffusion process is identified to logistic growth within a dynamic carrying capacity that represents such diffusion process as correlation of the interaction between innovations and institutions displays systematic change in their process of the growth and maturity. This demonstrates our hypothetical view that IT's specific features are formed through dynamic interaction with an institutional system.

2.2.3 Features of IT

As examined in Sect. 2.2, cellular telephones that contain the highest IT density as a crystal of mobile communications technology, one of the most representative and most popular information technology, was verified that its diffusion process, or behavior, well matches the logistic growth function within a dynamic carrying capacity. Consequently, (2.7) implies and Fig. 2.2 demonstrates that IT's epidemic behavior closely interrelates with continuous increase in number of potential users. It means that during the course of diffusion, IT interacts with individuals, organizations, and society as a whole, changes its behavior depending on institutions of that it interacts with, and extends potential users with its newly acquired features. This characterizes unique diffusion process of IT in that it alters carrying capacity or creates a new carrying capacity in the process of its diffusion, thereby acquires new specific features.

Figure 2.8 compares diffusion process of manufacturing technology and IT. Each time IT interacts with institutions, it effects institutions and potential users within them to change as well as acquires new features depending on institutions. Thus,

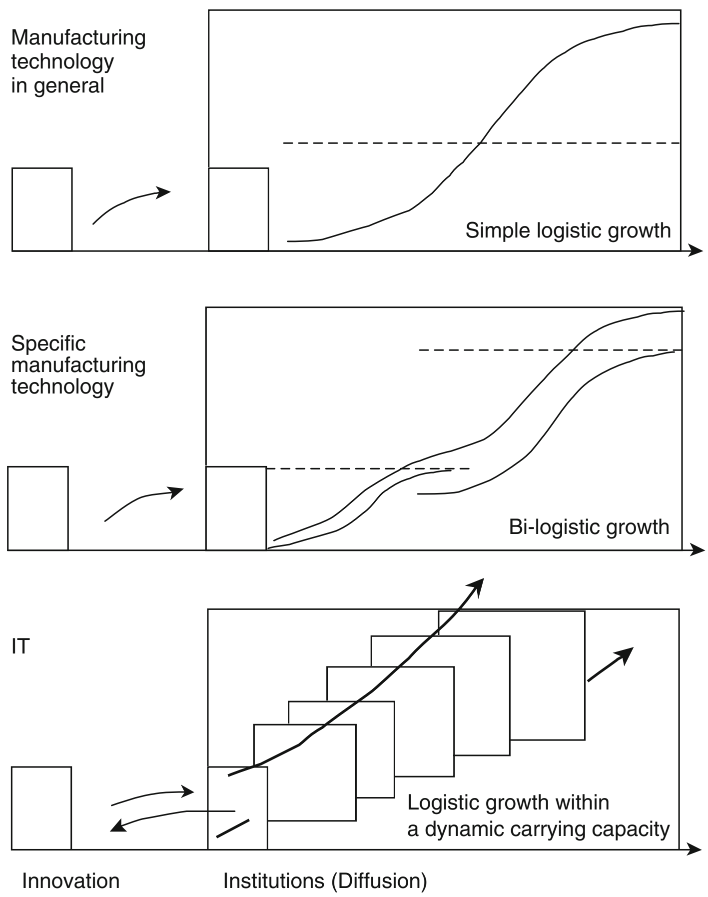

Fig. 2.8 General concept of technology diffusion process – comparison between manufacturing technologies and IT

IT's diffusion process is stimulated by interaction with institutions and institutional change is also stimulated by interaction with IT, leading to co-evolution of technology itself and institutions as well as constructing a virtuous cycle between rising technology value and increasing potential users.

By focusing on the above observed unique epidemic behavior of IT, the following specific features of IT with respect to interaction with institutions can be derived. Since IT behaves differently depending on the institutions of that it interacts with, whether a nation can fully exploit the benefits of IT greatly depends on the nation's institutional elasticity to the following features of IT:

– *Disseminative*

As the logistic growth function within a dynamic carrying capacity itself represents, dynamic evolution of a carrying capacity can be directly connected to a disseminative feature of IT. As the famous Moore's Law shows,[8] technological development of IT is very rapid. This rapid development of the technology together with network externalities enable IT related products and services to disseminate rapidly. The Economic Planning Agency [21] points out that appropriately judging the surrounding environment and quickly commercializing new products and services are crucial to survive in an information society. To make the best use of the disseminative nature of IT, organizations are required to make decisions quickly and react elastic to changing environments. Increasing significance of global technology spillover should be realized in a similar context [22].

– *Interactive*

The leading player of the IT industry is now shifting from personal computers to networks [23]. With the development of advanced and global networks, such as the Internet and mobile communications, more and more people can communicate and exchange information without being restricted by time and distance. Each time people use networks to communicate or exchange information, they actually interact with IT, and phenomena of network externalities that push up the carrying capacity rise the value of networks through the interaction between people and IT. Accordingly, interactiveness of IT is an important feature to explain IT's unique behavior.

Inside organizations, the interactive nature of IT improves efficiency of decision making process and induces structural transformation of organizations from hierarchical to network-type [4]. In order to exploit the potential benefits of IT, a reorganization of work that introduces new work practices is necessary [2]. In this sense, sticking to a conservatively hierarchical organization hinders efficient communication within an organization in spite of the interactive environment provided by IT.

– *Co-evolutional*

As Figs. 2.2 and 2.8 illustrate, features of IT and institutions evolve together during the course of their interaction that derives co-evolutional feature of IT. With its disseminative feature, IT diffuses as a social infrastructure and transforms economic,

[8] Chip capacity doubles every 18 months.

social, and cultural system of nations. In an information society, where IT functions as social infrastructure, growth depends more than ever on responding to the changing demands of the workplace and society more broadly [2]. In this context, with the indigenous nature of IT as a social infrastructure, the most effective way to maximize the benefits of IT should be the spontaneous evolution of the society itself as the technological development proceeds.

In addition to these three features, the following two features that are more or less common to all technologies are conspicuous in the behavior of IT.

– *Global*

IT, especially a network technology, realizes global information exchange independent of time, distance, and even borders. The global information exchange enables incessant flow of unknown but maybe effective cultures and services, as well as global procurement of goods and human resources which leads to reduction in production costs. To make the best use of this global nature, high adaptability to changing environment and ability to absorb heterogeneous cultures are required. The melting pot of the US well matches this heterogeneous environment and enjoys the benefits of globalization brought by IT [24].

– *Invisible*

IT should be referred to as cross-industrial technology [21] and would play its role as a social infrastructure that invisibly supports social and economic activities. The Digital Economy 2000 [6] claims that IT innovations can be applied across the economy and throughout the economic process: IT provides new ways of managing and using a resource that is common to every sector and aspect of economic life. On this invisible infrastructure, various services are expected to be created across all industries. Because of the unlimited potentiality of IT, creativity and entrepreneurship play a key role to create new businesses and achieve high growth using this infrastructure.

Finally, as network externalities contribute significantly to enhance IT's carrying capacity, increasing returns to scale phenomena are observed in high IT intensity industry. Table 2.3 demonstrates these phenomena by measuring SCE (scale of economies) [25] in major Japanese manufacturing industry over the period 1976–1998.

Table 2.3 Comparison of SCE in Japan's manufacturing industry

	SCE (%)
General machinery	32.34
Electrical machinery	29.60
Transportation equipment	28.27
Precision instruments	17.53
Chemicals	−18.87
Primary metals	−21.94
Pulp and paper	−22.53
Metal products	−30.29
Ceramics	−47.10

As summarized in Table 2.3, high IT intensity sectors as general machinery, electrical machinery, transportation equipment, and precision instruments display positive SCE demonstrating increasing returns to scale while other sectors with relatively low IT intensity demonstrate decreasing returns to scale (see Appendix 3 for mathematical development of SCE).

2.3 Implications

As analyzed so far, since unique features of IT such as *disseminative*, *interactive*, *co-evolutional, global*, and *invisible* are formed during the course of interaction with institutional systems, institutional elasticity plays a significant role in inducing and diffusing IT as well as fully exploiting potential benefits of IT. If a nation's indigenous institution can react elastic to the advancement of IT, diffusion process of IT is accelerated, then that nation should be able to exploit potential benefits of IT, resulting in enhancing its international competitiveness.

In general, Japanese managerial activities and systems reflect its institutional characteristics. The centuries of isolation from foreign influences ("*sakoku*") during the Edo period (1603–1867) has meant that the Japanese population is culturally and ethnically more homogeneous than in most other countries [26]. This fairly homogeneous population, together with highly dense population in Japan, has contributed to develop unique features of the Japanese organizational and behavioral norms such as group orientation and feeling comfortable to "be the same" as others (neighbors) are McMillan [27] concisely characterizes the Japanese as consensual, highly stable, homogeneous, disciplined, and long term oriented.

During the "catching-up" period up to the end of the 1980s when manufacturing technology was considered as a core technology of an industrial society, Japanese business management such as lifetime employment, seniority system, and *keiretsu* well matched the nation's institutions and successfully established the feeling of "family ties" that led the nation to achieve high economic growth. Japanese manufacturers intensely developed products with their own in-house technology since customers were most interested in the quality of products, not so much in compatibility among products of different manufacturers. In order to assure quality, firms preferred in-house procurement of manufacturing parts, or relied on their *keiretsu* companies that reflected Japanese long term orientation. In other words, Japanese firms used individual language that consequently excluded entities outside the family.

By contrast, IT enables global information exchange, thus induces global procurement of goods and mobility of human resources. Facing this new paradigm emerged with a dramatic advancement of IT in the 1990s, Japan can no longer depend on well-tried, low-risk paths and other benefits available to a country undergoing "catching-up" [26]. Furthermore, Japanese indigenous features such as homogeneousness and preferring high stability together with the existence of individual language peculiar to firms cannot react elastic to disseminative, interactive, co-evolutional, global, and invisible features of IT. Consequently, Japan's institutional system, which performed efficiently in the 1980s, is not efficient any more in an information society, and even hinders exploiting potential benefits of IT.

On the other hand, as MacRae [24] argued, the melting pot of the US makes the nation a great generator of new ideas, cultivates frontier spirit, and enhances flexibility to accept heterogeneous cultures, thus induces positive effects as a result of interaction with the above mentioned unique features of IT. In addition, the heterogeneous environment of the US stimulated the nation to establish standard language with that people or organizations can communicate implicitly. These features of the US institutional system did not perform effectively for an industrial society where steady and incremental advance was most appreciated.

Figure 2.9 summarizes how Japanese institutional systems and those of the US performed as the paradigm shift occurred from an industrial society to an information society. As analyzed above, though Japanese institutional systems were effective to the paradigm of an industrial society, they cannot be effectively applied to the new paradigm of an information society. Adversely, the US systems, which were ineffective in the paradigm of the 1980s, became pretty effective to the paradigm of the 1990s.

OECD [2] reported uneven trend growth of GDP per capita in OECD countries over the past decade compared with the 1980s. It described that trend growth in the 1990s was higher than in the 1980s in countries such as Australia, Canada, and the United States while growth declined markedly in such areas as Japan, Switzerland and Korea. Although there must be number of factors to explain these divergences,

	1980s	*1990s*
Paradigm	Industrial society	Information society
Core technology	Manufacturing technology	IT
Key features	**Given, Provided by suppliers**	**To be formed during the course of interaction with institutions**
Actors responsible for formation of features	Individual firms/organizations	Institutions as a whole

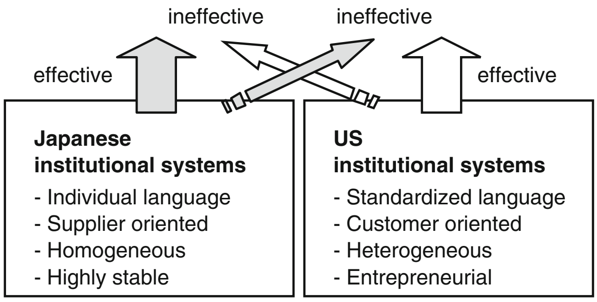

Fig. 2.9 Comparison of effectiveness between Japanese institutional systems and the US institutional systems under the paradigm shift

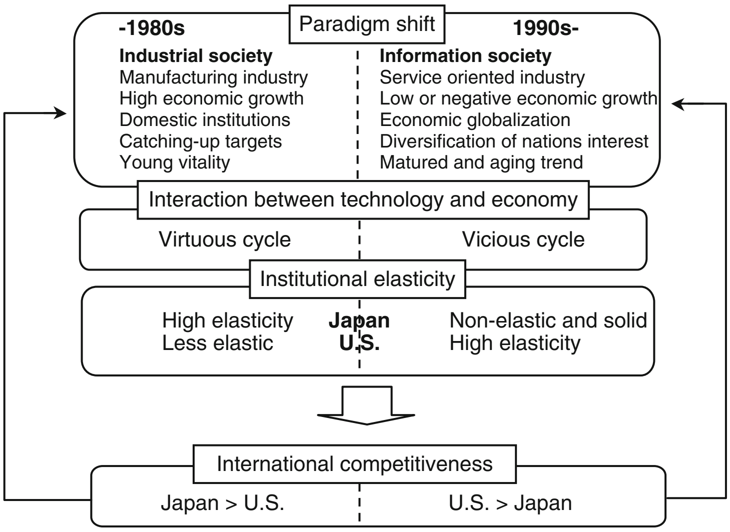

Fig. 2.10 Scheme leading Japan to lose its institutional elasticity

one of the factors should be attributed to Japan's solid institutional elasticity against unique features of IT that have been highlighted through dynamic interaction with institutional systems.

Figure 2.10 illustrates scheme leading Japan to losing its institutional elasticity by comparing the US 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.

As described above, during the period of an industrial society initiated by manufacturing industry, Japan's domestic institutions based on young vitality functioned efficiently towards "catching-up" target leading to high economic growth. In the 1990s, Japan's economy clearly contrasted with the preceding decades. Facing a new paradigm characterized by a shift to an information society initiated by service oriented industry, globalization, diversification of nations interest, aging trend, and subsequent low, zero or negative economic growth, Japan's traditional institutions did not function efficiently as they did in preceding decades.

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 losing Japan's international competitiveness that reacted further economic stagnation. Thus, Japan has been facing a dual vicious cycle leading to a solid institutional elasticity.

2.4 Conclusion

In light of the understanding that effective utilization of potential benefits of dramatic advancement of IT in an information society will differ greatly depending on the nation, particularly on their institutional elasticity and that this can be attributed to the specific features of IT which performs its function in connection with institutional systems, this chapter attempts to derive specific IT features by focusing on the unique diffusion process, in other words epidemic behavior of IT.

An empirical analysis on the diffusion process of innovative goods in Japan was conducted taking refrigerators, color TV sets and cellular telephones which represent innovative goods centered by manufacturing technology and IT, respectively. On the basis of the comparative analysis of epidemic behavior between IT and other technologies using the simple logistic growth function, bi-logistic growth function and logistic growth function within a dynamic carrying capacity, it was demonstrated that the specific features of IT are formed through dynamic interaction with an institutional system. In addition, certain specific features of IT characterized during the course of the interaction process and conspicuous in its unique epidemic behavior were identified including disseminative, interactive, co-evolutional as well as extremely invisible and global than technology in general. Furthermore, a mechanism of IT's contribution to increasing returns to scale was identified.

These analyses provided us significant insight that Japan's industrial and management system based on non-stylized management system unique to individual firms/organizations well functioned for innovation and diffusion of manufacturing technologies which supported industrial society. Furthermore, it has become evident that such non-stylized management system does not function well for innovation and diffusion of IT features of which are formed through dynamic interaction with an institutional system to which stylized management system is indispensable.

All these findings remind us the significance of the role of institutional elasticity in making full utilization of potential benefit of IT and also of the urgency of remediation of Japan's lost institutional elasticity. Thus, systems functions supportive to complement for remediation of the institutional elasticity with distinct features of IT would be crucial.

Appendix 1. Mathematical Development of Logistic Growth Function Within a Dynamic Carrying Capacity

Simple logistic growth function is expressed as follows:

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = bf(t)\left(1 - \frac{f(t)}{K}\right). \tag{2.8}$$

Given that innovation itself and the number of potential users change through the diffusion of innovation, logistic growth function within a dynamic carrying capacity is expressed by (2.9) where the number of potential users, carrying capacity (K) in the epidemic function is subject to a function of time t.

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} = bf(t)\left(1 - \frac{f(t)}{K(t)}\right). \tag{2.9}$$

Equation (2.10) is obtained from (2.9):

$$\frac{\mathrm{d}f(t)}{\mathrm{d}t} + (-b)\,f(t) = \left(-\frac{b}{K(t)}\right)\{f(t)\}^2\,. \tag{2.10}$$

Equation (2.10) corresponds to the Bernoulli's differential equation expressed by (2.11):

$$\frac{\mathrm{d}y}{\mathrm{d}x} + V(x)y = W(x)y^n. \tag{2.11}$$

Accordingly, (2.10) can be transformed to the linear differential equation expressed by (2.12).

$$\frac{\mathrm{d}z(t)}{\mathrm{d}x} + bz(t) = \frac{b}{K(t)} \text{ where } z(t) = \frac{1}{f(t)} \tag{2.12}$$

The solution for a linear differential (2.13) can be obtained as (2.14):

$$\frac{dy}{dt} + P(x)y = Q(x) \tag{2.13}$$

$$y = \exp\left(-\int P(x)dx\right)\cdot\left\{\int\left(Q(x)\cdot\exp\left(\int P(x)dx\right)\right)dx + c\right\} \tag{2.14}$$

Accordingly, the solution for (2.12) can be expressed as follows:

$$\begin{aligned} z(t) &= \exp\left(-\textstyle\int b\ \mathrm{d}t\right)\cdot\left\{\int\left(\frac{b}{K(t)}\exp(\textstyle\int b\ \mathrm{d}t)\right)\mathrm{d}t + c_1\right\} \\ &= \exp(-bt)\cdot\left\{b\int\left(\frac{1}{K(t)}\exp(bt)\right)dt + c_1\right\} \end{aligned} \tag{2.15}$$

$$\frac{1}{f(t)} = \exp(-bt)\cdot\left\{b\int\left(\frac{\exp(bt)}{K(t)}\right)\mathrm{d}t + c_1\right\}. \tag{2.16}$$

Assume that a carrying capacity $K(t)$ increases sigmoidally, $K(t)$ is expressed as follows:

$$K(t) = \frac{K_K}{1 + a_K\ \exp(-b_K t)}. \tag{2.17}$$

By substitution (2.17) for $K(t)$ in (2.16), (2.18) is obtained:

$$\frac{1}{f(t)} = \left\{b\int\left(\frac{\exp(bt)}{K_K/(1 + a_K\ \exp(-b_K t))}\right)\mathrm{d}t + c_1\right\}\exp(-bt)\,, \tag{2.18}$$

where

$$\begin{aligned}
&\int \left(\frac{\exp(bt)}{K_K/(1+a_K\ \exp(-b_K t))} \right) \mathrm{d}t \\
&= \frac{1}{K_K} \int \{\exp(bt) + a_K\ \exp((b-b_K)t)\} \mathrm{d}t \\
&= \frac{1}{K_K} \left\{ \int \exp(bt)\,\mathrm{d}t + \int a_K\ \exp((b-b_K)t)\,\mathrm{d}t \right\} \\
&= \frac{1}{K_K} \left\{ \frac{1}{b} \exp(bt) + \frac{a_K}{b-b_K} \exp((b-b_K)t) \right\} + c_2.
\end{aligned} \tag{2.19}$$

Accordingly, $f(t)$ can be developed as follows:

$$\begin{aligned}
\frac{1}{f(t)} &= b \left\{ \frac{1}{K_K} \left\{ \frac{1}{b} \exp(bt) + \frac{a_K}{b-b_K} \exp((b-b_K)t) \right\} + c_2 + c_1 \right\} \cdot \exp(-bt), \\
\frac{1}{f(t)} &= \frac{1}{K_K} \left\{ 1 + \frac{b \cdot a_K}{b-b_K} \exp(-b_K t) + c_3 \exp(-bt) \right\}, \\
\frac{1}{f(t)} &= \frac{1}{K_K} \left\{ 1 + c_3\ \exp(-bt) + \frac{b \cdot a_K}{b-b_K} \exp(-b_K t) \right\}, \qquad (2.20) \\
f(t) &= \frac{K_K}{1 + a\ \exp(-bt) + \frac{b \cdot a_K}{b-b_K} \exp(-b_K t)}. \qquad (2.21)
\end{aligned}$$

Appendix 2. Data Construction and Sources

In order to analyze the diffusion process of innovative products in Japan, domestic shipment (shipment for domestic demand) was regarded the most desirable indicator since it reflects the demand of customers for those products. However, since domestic shipment data was only available for color TV sets, we used production volumes for refrigerators and cellular telephones by making due adjustment for export and import balance.

A.2.1 Refrigerators

Annual shipment volume of refrigerators from the year 1966 to 1999 were obtained from the "Report on Machinery Statistics" conducted by the Ministry of International Trade and Industry (MITI).[9] Since the ratio of imports and exports

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

of refrigerators to their shipment as a whole has not been changing greatly, annual shipment volume was used for the analysis.

A.2.2 Color TV Sets

Annual domestic shipment volume of color TV sets from the year 1966 to 2000 were obtained from the Survey of Japan Electronics and Information Technology Industries Association (JEITA, annual issues).

A.2.3 Cellular Telephones

Since the ratio of imports and exports of cellular telephones to their domestic production volume as a whole has been changing and somewhat significant, the volume of imports and exports were considered for data construction. Quarterly production volume of cellular telephones from the year 1993 to 2000 was obtained from the "Report on Machinery Statistics" conducted by MITI, and quarterly volume of imports and exports from the year 1996 to 2000 was obtained from the "Trade Statistics" conducted by the Ministry of Finance. Although the volume of imports and exports of cellular telephones over the period of 1993–1995 was not available, since the ration of imports and exports to production is stable and relatively small before 1996, it was estimated by multiplying the same ratio of the year 1996 to production volumes.

Appendix 3. Mathematical Development of SCE

In order to measure SCE, the following production function was used:

$$\begin{aligned} V &= F\left(L, K, I, T, t\right) \\ &= F\left\{\left(L, I_l\right), \left(K, I_k\right), T, t\right\} \\ &= Ae^{\lambda t}\left(L^{\alpha_1} \cdot I_l^{\alpha_2}\right)\left(K^{\beta_1} \cdot I_k^{\beta_2}\right)T^{\gamma}, \end{aligned} \tag{2.22}$$

where A, scale coefficient; L, labor; K, capital; I, IT production factor; I_l, IT labor; I_k, IT capital; T, technology stock; and t, time trend. Duplication among each production element was deducted.

IT production factor was constructed using the data from the Ministry of International Trade and Industry's "Current Status of Japanese Information Processing," which referred the "Survey on Information Processing in Japan" by Japan

Table 2.4 IT related 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

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 production factor is explained by the IT related investment listed in Table 2.4.

In order to analyze SCE using the production function given by (2.22), incorporation ability of technology spillovers should be measured as follows in light of the active spillover characteristics of IT among industries [22]:

$$I = I_{\mathrm{i}} + Z_{\mathrm{IT}}\, I_{\mathrm{s}} \tag{2.23}$$

$$Z_{\mathrm{IT}} = \frac{1}{1+\frac{\Delta I_{\mathrm{s}}/I_{\mathrm{s}}}{\Delta I_{\mathrm{i}}/I_{\mathrm{i}}}} \cdot \frac{I_{\mathrm{i}}}{I_{\mathrm{s}}}, \tag{2.24}$$

where I_{i}, own IT stock; I_{s}, potential IT spillover; and Z_{IT}, IT assimilation capacity.

By introducing incorporated spillovers of labor and capital respectively, the production function given by the (2.22) can be described as follows:

$$V = A\, \mathrm{e}^{\lambda t} \left\{ L^{\alpha_1} \left(I_{li} + Z_{il} I_{ls}\right)^{\alpha_2} \right\} \left\{ K^{\beta_1} \left(I_{ki} + Z_{ik} I_{ks}\right)^{\beta_2} \right\} T^{\gamma}. \tag{2.24$'$}$$

Christensen and Greene [25] defined SCE as follows:

$$\mathrm{SCE} = 1 - \frac{\partial \ \ln C}{\partial \ \ln y}, \tag{2.25}$$

where C, total cost; and y, real output.

If the increase in total cost is less than 1% while the output increases by 1%, SCE is greater than 0, that is scale economy works. If $\mathrm{SCE} = 0$, it means constant returns to scale, and $\mathrm{SCE} < 0$ indicates diminishing returns.

By using the production function (2.22$'$), where technology-related factors are deducted from L and K to avoid duplication, elasticity of each factor of production is expressed as follows that correspond to the ratio of costs:

$$\begin{aligned}
\alpha_1 &= \frac{\text{GLC}}{\text{GDP}} = \frac{P_l \cdot L}{P_v \cdot V} \\
\alpha_2 &= \frac{\text{GILC}}{\text{GDP}} = \frac{P_{il} \cdot I_l}{P_v \cdot V} \\
\beta_1 &= \frac{\text{GCC}}{\text{GDP}} = \frac{P_k \cdot K}{P_v \cdot V} \\
\beta_2 &= \frac{\text{GICC}}{\text{GDP}} = \frac{P_{ik} \cdot I_k}{P_v \cdot V} \\
\gamma &= \frac{\text{GTC}}{\text{GDP}} = \frac{P_t \cdot T}{P_v \cdot V}
\end{aligned} \tag{2.26}$$

Considering that GDP = GLC + GCC + GTC + GIC and by substituting GILC + GICC with GIC, (2.27) is obtained:

$$\alpha_1 + \alpha_2 + \beta_1 + \beta_2 + \gamma = 1. \tag{2.27}$$

From (2.26), the following equation is obtained:

$$\begin{aligned}
\alpha_1 &= \frac{\text{GLC}}{\text{GDP}} = \frac{P_l \cdot L}{P_v \cdot V} & & \text{GDP} = \frac{P_l \cdot L}{\alpha_1} \\
\alpha_2 &= \frac{\text{GILC}}{\text{GDP}} = \frac{P_{il} \cdot I_l}{P_v \cdot V} & & \text{GDP} = \frac{P_{il} \cdot I_l}{\alpha_2} \\
\beta_1 &= \frac{\text{GCC}}{\text{GDP}} = \frac{P_k \cdot K}{P_v \cdot V} & \Rightarrow & \text{GDP} = \frac{P_k \cdot K}{\beta_1} \\
\beta_2 &= \frac{\text{GICC}}{\text{GDP}} = \frac{P_{ik} \cdot I_k}{P_v \cdot V} & & \text{GDP} = \frac{P_{ik} \cdot I_k}{\beta_2} \\
\gamma &= \frac{\text{GTC}}{\text{GDP}} = \frac{P_t \cdot T}{P_v \cdot V} & & \text{GDP} = \frac{P_t \cdot T}{\gamma}
\end{aligned} \tag{2.26$'$}$$

Given constant output to the production function (2.22′), total cost (C) is obtained by minimizing cost under constant price of production factors:

$$\begin{aligned}
C = V^{\frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} (\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma) \left(\frac{1}{A\,\mathrm{e}^{\lambda t}}\right)^{\frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \\
\times \left(\frac{P_l}{\alpha_1}\right)^{\frac{\alpha_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \left(\frac{P_{il}}{\alpha_2}\right)^{\frac{\alpha_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \left(\frac{P_k}{\beta}\right)^{\frac{\beta}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \\
\times \left(\frac{P_{ik}}{\beta_2}\right)^{\frac{\beta_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \left(\frac{P_t}{\gamma_2}\right)^{\frac{\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}
\end{aligned} \tag{2.28}$$

(2.28) is obtained by substitution (2.26′) in (2.29).

$$
\begin{aligned}
\ln\, C &= \ln\{C(V, P_l, P_{il}, P_k, P_{ik}, P_t)\} \\
&= \frac{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} \\
&= \frac{\alpha_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} + \frac{\alpha_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} \\
&+ \frac{\beta_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} + \frac{\beta_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} \\
&+ \frac{\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \ln\, \mathrm{GDP} + \ln(\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma)
\end{aligned} \tag{2.29}
$$

SCE, defined by (2.25) can be obtained from (2.28):

$$
\mathrm{SCE} = 1 - \frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}. \tag{2.30}
$$

Accordingly, coefficients $\alpha_1, \alpha_2, \beta_1, \beta_2, \gamma$ are estimated from (2.26) as follows under the assumption of cost minimization:

$$
\begin{aligned}
\frac{\alpha_1}{\beta_2} &= \frac{\mathrm{GLC}}{\mathrm{GICC}} \\
\frac{\alpha_2}{\beta_2} &= \frac{\mathrm{GILC}}{\mathrm{GICC}} \\
\frac{\beta_1}{\beta_2} &= \frac{\mathrm{GCC}}{\mathrm{GICC}} \\
\frac{\gamma}{\beta_2} &= \frac{\mathrm{GTC}}{\mathrm{GICC}}
\end{aligned} \tag{2.31}
$$

Average of coefficients ratios are obtained from (2.32) using (2.31).

$$
\begin{aligned}
\widehat{\left(\frac{\alpha_1}{\beta_2}\right)} &= \exp\left[\frac{1}{n}\sum \frac{\mathrm{GLC}}{\mathrm{GICC}}\right], \\
\widehat{\left(\frac{\alpha_2}{\beta_2}\right)} &= \exp\left[\frac{1}{n}\sum \frac{\mathrm{GILC}}{\mathrm{GICC}}\right], \\
\widehat{\left(\frac{\beta_1}{\beta_2}\right)} &= \exp\left[\frac{1}{n}\sum \frac{\mathrm{GCC}}{\mathrm{GICC}}\right], \\
\widehat{\left(\frac{\gamma}{\beta_2}\right)} &= \exp\left[\frac{1}{n}\sum \frac{\mathrm{GTC}}{\mathrm{GICC}}\right],
\end{aligned} \tag{2.32}
$$

where n denotes number of samples.

Equation (2.34), a Cobb–Douglas production function can be obtained under the assumption of cost minimization by calculating a new variable $(\hat{Z})$ with the estimate of (2.32) as below:

$$\widehat{Z} \equiv \ln(I_k)+\widehat{\left(\frac{\alpha_1}{\beta_2}\right)}\ln(L)+\widehat{\left(\frac{\alpha_2}{\beta_2}\right)}\ln(I_l)+\widehat{\left(\frac{\beta_1}{\beta_2}\right)}\ln(K)+\widehat{\left(\frac{\gamma}{\beta_2}\right)}\ln(T), \quad (2.33)$$

$$\ln(V) = \ln A + \hat{\beta}_2 \cdot \hat{Z} + \lambda t. \quad (2.34)$$

Since $\hat{\beta}_2$ is obtained by (2.34), we can calculate the estimators of $\alpha_1, \alpha_2, \beta_1, \gamma$ by multiplying $\left(\alpha_1 \overset{\wedge}{/} \beta_2\right), \left(\alpha_2 \overset{\wedge}{/} \beta_2\right), \left(\beta_1 \overset{\wedge}{/} \beta_2\right), \left(\gamma \overset{\wedge}{/} \beta_2\right)$ by $\hat{\beta}_2$. Based on the results of $\alpha_1, \alpha_2, \beta_1, \beta_2, \gamma$, we can measure SCE by (2.31).

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