Pergamon

Technovation 23 (2003) 205–219

technovation

www.elsevier.com/locate/technovation

Formation of IT features through interaction with institutional systems—empirical evidence of unique epidemic behavior

Chihiro Watanabe [a,*], Reiko Kondo [b], Noritomo Ouchi [a], Haihong Wei [a]

[a] *Department of Industrial Engineering and Management, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan*
[b] *Broadcasting Technology Division, Ministry of Public Management, Home Affairs, Posts and Telecommunications, 2-1-2 Kasumigaseki, Chiyoda-ku, Tokyo 100-8926, Japan*

Received 3 July 2001; accepted 8 October 2001

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 paper focuses on an analysis of the epidemic behavior of IT and attempts to identify specific features of IT in light of interaction with institutions.

Keywords: IT; Epidemic behavior; Institutions

1. Introduction

Innovation, such as the development of new technologies, has undoubtedly been recognized as a significant driving force in sustaining economic growth. Romer (1994) 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 (2001) 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 (OECD, 1997).

A rapid surge in IT around the world is inevitably forcing traditional societies to transform their socioeconomic structures. As the Telecommunications Council (2000) noted, IT is hastening the paradigm shift from an industrial society to an information 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] (e.g. Ruttan, 2001; US DOC, 2000) 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 (1997) 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

* Corresponding author. Tel.: +81-3-5734-2248; fax: +81-3-5734-2252.
E-mail address: chihiro@me.titech.ac.jp (C. Watanabe).

[1] The value to a consumer of a product increases as the number of compatible users increases (Oster, 1994).

0166-4972/02/$ - see front matter © 2002 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0166-4972(01)00106-7

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 (e.g. Cairncross, 1997; US DOC, 2000). 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 many years including anthropology, sociology, education, public health, communication, marketing, and geography. Rogers (1962) 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' 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 (Griliches, 1957) 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 (Meyer, 1994). 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 (e.g. Griliches, 1957; Mansfield 1963, 1969; Metcalfe, 1970; Norris and Vaizey, 1973).

While the simple logistic growth function treats the carrying capacity of a human system[2] fixed, this capacity is actually subject to change (Marchetti, 1976). Among varieties of innovations, certain innovations alter their carrying capacity in the process of their diffusion which stimulates increase in the number of potential customers (Coombs et al., 1987). This increase, in turn, incorporates new features into the innovations. This is similar to an ecosystem in which species can sometimes alter and expand their niche (Meyer, 1994). Meyer (1994) 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, Meyer 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 (Oster, 1994) 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 (1998) portrays an array of logistically developing and diffusing social mechanisms stimulated by these efforts. Meyer and Ausbel (1999) 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, Meyer 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.

[2] Upper limit of the level of diffusion, see mathematical implications of this capacity 2.2.

Table 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

Section 2 conducts comparative analysis of epidemic behavior between IT and other technologies. Section 3 extracts implications with respect to features formation process of IT and its specific features. Section 4 briefly summarizes the key findings of the analysis, presents conclusions and discusses implications for effective utilization of the potential benefits of IT.

2. Features of it with respect to institutions

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 (e.g. US DOC, 2000; MPT, 2000; Telecommunications Council, 2000; Cairncross, 1997).

Table 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 (US DOC, 2000).

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

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, 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 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 (Ruttan, 2001).

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. Analysis of epidemic behavior

2.2.1. Taxonomy of epidemic function

Following three functions as introduced in Section 1 were used for comparative analysis of epidemic behaviors between IT and other technologies:

2.2.1.1. Simple logistic growth function

$f(t)=\frac{K}{1+a\exp(-bt)}$ where a and b are coefficients; and t is the 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:

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

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

$\left(1-\frac{f(t)}{K}\right)$ depicts a negative feed back and this approaches 1 and 0 when $f(t)\ll K$ and $f(t)\rightarrow K$, respectively. Therefore, the growth rate (the left hand side of Eq. (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. 1.

The following equation can be obtained by integrating Eq. (1):

$$f(t)=\frac{K}{1+a\exp(-bt)} \quad (2)$$

2.2.1.2. Bi-logistic growth function

$$f(t)=f_1(t)+f_2(t)=\frac{K_1}{1+a_1\exp(-b_1t)}+\frac{K_2}{1+a_2\exp(-b_2t)}$$

Bi-logistic growth function combines two phases of simple logistic growth function in the following function (Meyer, 1994):

$$f(t)=f_1(t)+f_2(t)=\frac{K_1}{1+a_1\exp(-b_1t)}+\frac{K_2}{1+a_2\exp(-b_2t)} \quad (3)$$

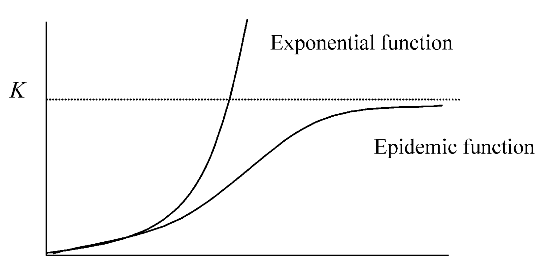

Fig. 1. Comparison between exponential function and epidemic function.

2.2.1.3. Logistic growth function within a dynamic carrying capacity

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

The epidemic function expressed by Eq. (1) assumes that the level of carrying capacity (K) is constant through the dissemination process of innovation. However, as reviewed in Section 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 Eq. (1) should be treated as a following function:

$$\frac{df(t)}{dt}=bf(t)\left(1-\frac{f(t)}{K(t)}\right) \quad (4)$$

where $K(t)$ is also an epidemic function enumerated by Eq. (5).

$$K(t)=\frac{K_K}{1+a_K\exp(-b_Kt)} \quad (5)$$

where K_K indicates the ultimate upper limit.

The solution of a differential Eq. (4) under the condition (5) can be obtained as Eq. (6).[4]

$$f(t)=\frac{K_K}{1+a\exp(-bt)+\frac{b\cdot a_K}{b-b_K}\exp(-b_Kt)} \quad (6)$$

A dynamic carrying capacity $K(t)$ can be expressed by Eq. (7) by transforming Eq. (4).

$$K(t)=f(t)\left(\frac{1}{1-(df(t)/dt)/bf(t)}\right) \quad (7)$$

Eq. (7) demonstrates that $K(t)$ increases together with the increase of $f(t)$ as time goes by. This implies that Eq. (6) exhibits logistic growth within a dynamic carrying capacity as it displays such systematic change as illustrated in Fig. 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.

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

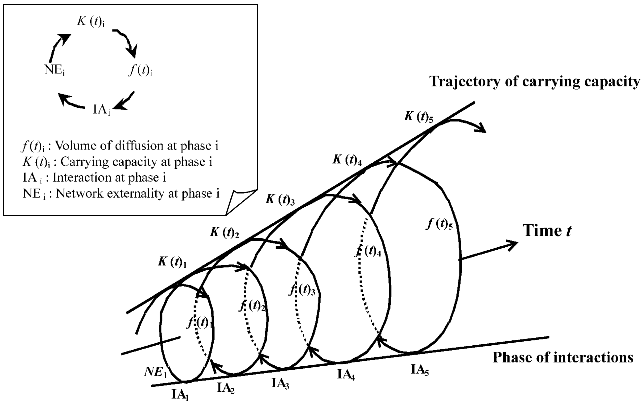

Fig. 2. Mechanism in creating a new carrying capacity in the process of IT diffusion.

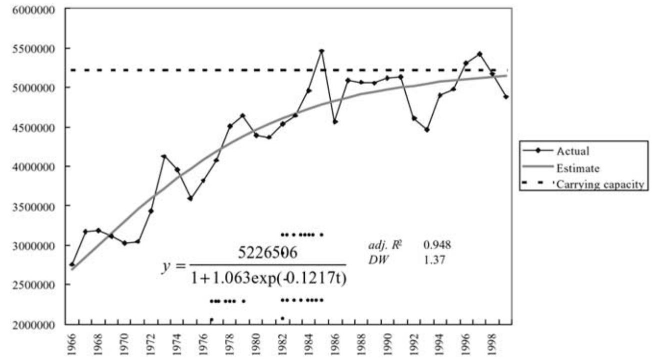

Fig. 3. Trends in the diffusion process of refrigerators in Japan (1966–1999). Source: Report on Machinery Statistics, MITI (annual issues).

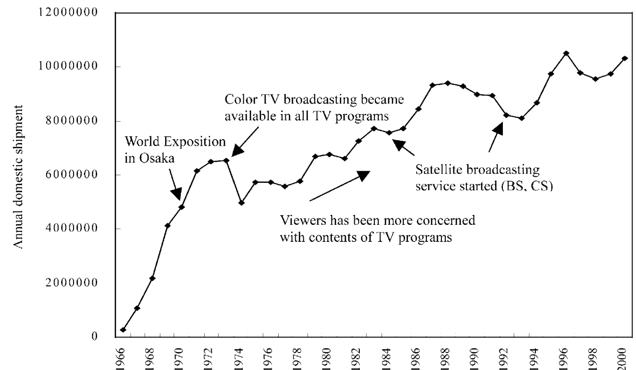

Fig. 4. Transition of annual domestic shipment of color TV sets and related events. Source: Japan Electronics and Information Technology Industries Association, Japan.

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]

2.2.2.1. 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 curve similar to the simple logistic growth function.

Fig. 3 illustrates the trends in diffusion process of refrigerators in Japan from 1966 to 1999 with simple logistic growth function (figures in parentheses indicate *t*-value).

2.2.2.2. 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. Fig. 4 depicts the transition of the annual domestic shipment of color TV sets and related events from 1966 to 2000. In Japan, a 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 the World Exposition in Osaka in 1970. In 1973, color TV broadcasting became available for all TV programs, and viewers became more concerned with the contents of TV programs, not color TV sets themselves.

Fig. 5 illustrates the trends in the diffusion process of color TV sets in Japan from 1966 to 2000 with Bi-logistic growth function.

2.2.2.3. Cellular telephones[6] Fig. 6 depicts the transition of quarterly production volume of cellular telephones and related events from 1993 to 2000. Though cellular telephones have a 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

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

[6] Cellular telephones include PHS (Personal Handy-phone Systems) and automobile phones as well as cell phones.

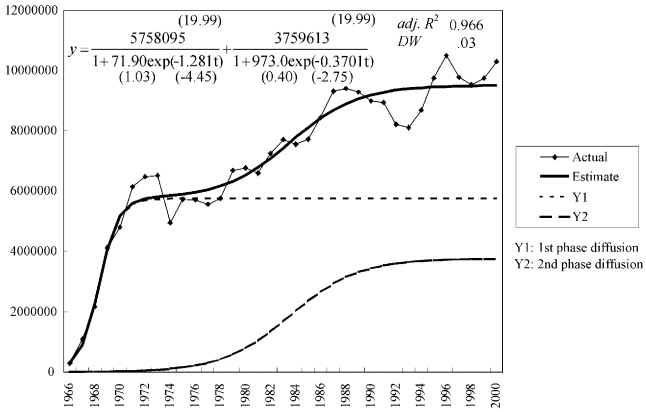

Fig. 5. Trends in the diffusion process of color TV sets in Japan (1996–2000). Source: Japan Electronics and Information Technology Industries Association, Japan.

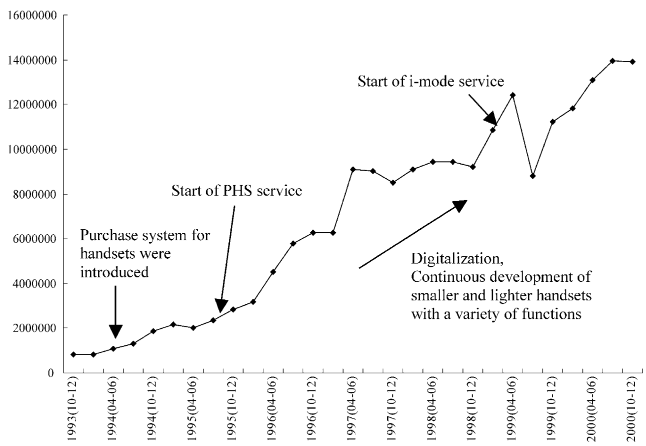

Fig. 6. Transition of quarterly domestic production volumes of cellular telephones and related events. Source: Current Survey of Production, METI (annual issues); Trade Statistics, MOF (annual issues).

rather complicated. One of the breakthroughs was NTT DoCoMo's introduction of an i-mode service in February 1999 that enabled users to access the Internet from their handsets. Since then, this kind of mobile Internet access service has been dramatically expanding and the number of subscribers reached about 31.4 million as of February 2001 (http://www.tca.or.jp/). Java-compatible handsets have now been on sale since January 2001, which is expected to induce a further increase in carrying capacity.

With these features, the diffusion process of cellular telephones best fit was 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. Fig. 7 illustrates the trends in the diffusion process of cellular telephones in Japan from 1993 to 2000 with logistic growth function within a dynamic carrying capacity.

2.2.3. Interpretations

Table 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.

Looking at Table 2, we note the following findings with respect to the identification of epidemic behavior for respective innovative goods:

1. 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 the best fit functions, respectively.
2. Refrigerators have a single function and more than half a century of history since they penetrated the a market. Their diffusion volume has almost saturated to 5.2±0.5 million in the last 15 yr. Table 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, we note that a dynamic carrying capacity is negligibly small (e.g. a_k: 4.141E-06) and the carrying capacity of function (1) (K=5226506) and function (3) (K_K=5226506) has reached the same level. These support the former theory that the diffusion process of refrigerators can be identified by the single logistic growth function.
3. Similar to refrigerators, color TV sets have a single function. However, their diffusion process is more complicated than refrigerators as they underwent a substitution process with mono-color TV sets. In the initial diffusion process, color TV sets were in co-evolution with monochrome TV sets. Since color broadcasting has become available for all TV broadcasting programs since 1973 in Japan, a second diffusion emerged which is a substantial diffusion process in a competitive market. Thus, the diffusion process of color TV sets is a typical Bi-logistic growth. Table 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 multifunctions. Although cellular telephones have a younger history for their diffusion than refrigerators and color TV sets, they have the highest IT density. Such high IT density enables cellular telephones to create new functions during the course of their interactions with customers leading them to be multifunctional goods. The diffusion process of this type of innovation could

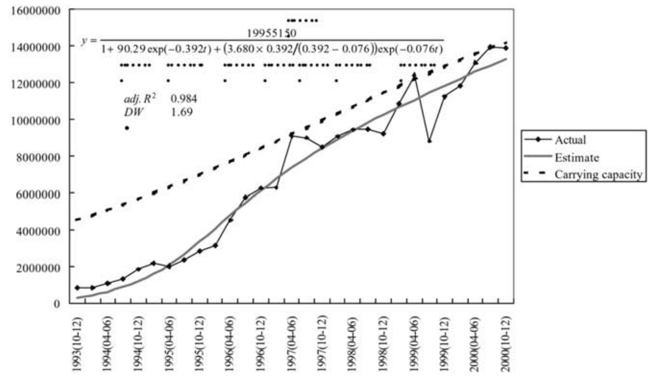

Fig. 7. Trends in the diffusion process of cellular telephones in Japan (1993–2000). Source: Current Survey of Production, METI (annual issues); Trade Statistics, MOF (annual issues).

Table 2
Comparison of the fittability of three epidemic functions for the diffusion process of three innovative goods[a]

Refrigerators									
	K	a	b				adj. R^2	DW	AIC
	5,226,506	1.063	0.1217				0.948	1.37	8.523E+10
	(39.07)	(9.55)	(6.63)						
	K_1	a_1	b_1	K_2	a_2	b_2	adj. R^2	DW	AIC
	3,399,421	0.2436	0.1101	1,677,219	22.17	0.2842	0.926	1.51	9.183E+10
	(21.33)	(2.22)	(0.50)	(21.33)	(0.79)	(3.89)			
	K_K	a	b	a_k	b_k		adj. R^2	DW	AIC
	5,226,506	0.4637	0.1217	4.141E-06	0.1217		0.949	1.37	8.706E+10
	(38.97)	(4.46)	(6.62)	(1.50)	(6.62)				
Color TV sets									
	K	a	b				adj. R^2	DW	AIC
	9,867,687	3.141	0.1385				0.923	0.48	1.018E+12
	(18.61)	(5.60)	(5.43)						
	K_1	a_1	b_1	K_2	a_2	b_2	adj. R^2	DW	AIC
	5,758,095	71.90	1.281	3,759,613	973.0	0.3701	0.966	1.03	3.896E+11
	(19.99)	(1.03)	(4.45)	(8.49)	(0.40)	(2.75)			
	K_K	a	b	a_k	b_k		adj. R^2	DW	AIC
	9,867,687	0.2109	0.1386	0.002653	0.1385		0.955	0.48	6.287E+11
	(18.61)	(0.39)	(5.43)	(0.83)	(5.43)				
Cellular telephones									
	K	a	b				adj. R^2	DW	AIC
	13,328,320	18.07	0.203				0.980	1.42	1.014E+12
	(16.59)	(3.81)	(7.54)						
	K_1	a_1	b_1	K_2	a_2	b_2	adj. R^2	DW	AIC
	9,944,280	32.40	0.308	12,016,010	10,538	0.299	0.993	2.11	7.102E+11
	(16.42)	(2.64)	(7.23)	(16.42)	(1.12)	(9.20)			
	K_K	a	b	a_k	b_k		adj. R^2	DW	AIC
	19,955,150	90.29	0.392	3.680	0.076		0.984	1.69	6.370E+11
	(4.66)	(1.39)	(6.60)	(3.40)	(3.95)				

[a] Figures in parentheses indicate t-value.

be well modeled by logistic growth within a dynamic carrying capacity. Table 2 demonstrates this theory by AIC. Although AIC supports this theory and other statistics also demonstrate better fittability than function (1), statistics other than AIC demonstrate slightly less significance than function (2). This could be interpreted as the diffusion process of cellular telephones not yet being mature and still in transition from Bi-logistic growth to logistic growth within a dynamic carrying capacity.

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

2.3. Features of IT

As examined in Section 2.2, cellular telephones contain the highest IT density as a crystal of mobile communications technology, one of the most representative and most popular forms of information technology, and it was verified that its diffusion process, or behavior, matches well the logistic growth function within a dynamic carrying capacity. Consequently, Eq. (7) implies and Fig. 2 demonstrates that IT's epidemic behavior closely interrelates with the continuous increase in the 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 the institutions that it interacts with, and extends potential users with its newly acquired features. This characterizes the unique diffusion process of IT in that it alters carrying capacity or creates a new carrying capacity in the process of its diffusion, thereby acquiring new specific features.

Fig. 8 compares the 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 acquiring new features depending on the institutions. Thus, 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.

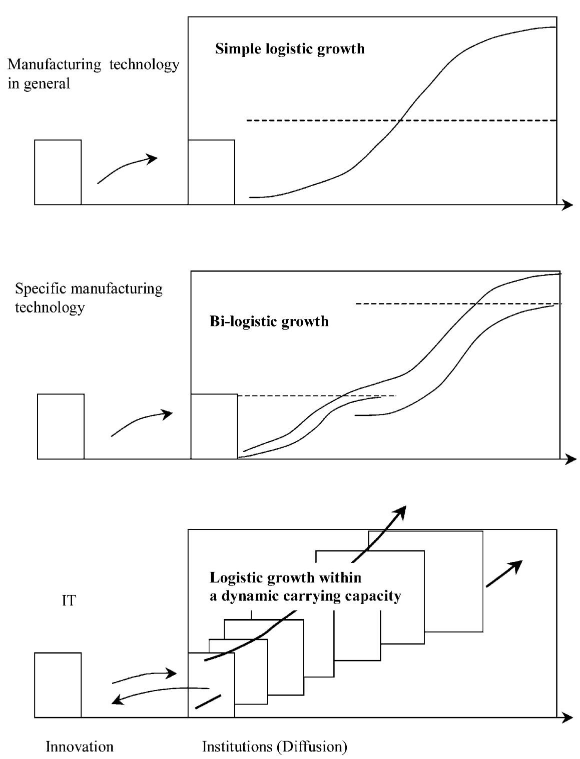

Fig. 8. General concept of the technology diffusion process—comparison between manufacturing technologies and IT.

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

2.3.1. 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,[7] 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 (EPA, 2000) points out that appropriately judging the surrounding environment and quickly commercializing new products and services are crucial to survival in an information society. To make the best use of the disseminative nature of IT, organizations are required to make decisions quickly and react elastically to changing environments. The increasing significance of global technology spillover should be realized in a similar context (Watanabe et al., 2001).

2.3.2. Interactive

The leading player in the IT industry is now shifting from personal computers to networks (Moschella, 1997). 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 the phenomenon of network externalities that push up the carrying capacity increases 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 the efficiency of the decision-making process and induces structural transformation of organizations from hierarchical to network-type (Telecommunications Council, 2000). In order to exploit the potential benefits of IT, a reorganization of work that introduces new work practices is necessary (OECD, 2001). In this sense, sticking to a conservatively hierarchical organization hinders

[7] Chip capacity doubles every 18 months.

efficient communication within an organization in spite of the interactive environment provided by IT.

2.3.3. Co-evolutional

As Figs. 2 and 8 illustrate, features of IT and institutions evolve together during the course of their interaction which derives the co-evolutional feature of IT. With its disseminative feature, IT diffuses as a social infrastructure and transforms the economic, social, and cultural systems of nations. In an information society, where IT functions as a social infrastructure, growth depends more than ever on responding more broadly to the changing demands of the workplace and society (OECD, 2001). 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.

2.3.4. 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 a reduction in production costs. To make the best use of this global nature, high adaptability to a changing environment and the 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 (MacRae, 1995).

2.3.5. Invisible

IT should be referred to as cross-industrial technology (EPA, 2000) and would play its role as a social infrastructure that invisibly supports social and economic activities. The Digital Economy 2000 (US DOC, 2000) 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 a high IT intensity industry. Table 3 demonstrates these phenomena by measuring the SCE (Scale of Economies) (Christensen and Greene, 1976) in major Japanese manufacturing industry over the period 1976–1998.

Table 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 3, high IT intensity sectors such 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 C for mathematical development of SCE).

3. Implications

As analyzed so far, since the unique features of IT such as *disseminative*, *interactive*, *co-evolutional*, *global*, and *invisible* are formed during the course of its interaction with institutional systems, institutional elasticity plays a significant role in inducing and diffusing IT as well as fully exploiting the potential benefits of IT. If a nation's indigenous institution can react elastically to the advancement of IT, the diffusion process of IT is accelerated, and that nation should then be able to exploit the potential benefits of IT, resulting in an enhancement of 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) have meant that the Japanese population is culturally and ethnically more homogeneous than in most other countries (Aggarwal, 1996). This fairly homogeneous population, together with a highly dense population in Japan, has contributed to the development of the unique features of the Japanese organizational and behavioral norms such as group orientation and feeling comfortable to 'be the same' as others (neighbors). McMillan (1996) 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 and thus induces global procurement of goods and mobility of human resources. Facing this new paradigm there emerged 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’ (Aggarwal, 1996). Furthermore, Japanese indigenous features such as homogeneousness and preferring high stability together with the existence of an individual language peculiar to firms cannot react elastically to the 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 the exploitation of the potential benefits of IT.

Conversely, as MacRae (1995) argued, the melting pot of the US makes the nation a great generator of new ideas, cultivates frontier spirit, and enhances the flexibility to accept heterogeneous cultures, thus inducing 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.

Fig. 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. Conversely, the US systems, which were ineffective in the paradigm of the 1980s, became pretty effective to the paradigm of the 1990s.

OECD (2001) reported an uneven trend growth of GDP per capita in OECD countries over the past decade compared with the 1980s. It described how 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 a number of factors to explain these divergences, one of the factors should be attributed to Japan’s solid institutional elasticity against the unique features of IT that have been highlighted through dynamic interaction with institutional systems.

Fig. 10 illustrates the scheme which led Japan to lose its institutional elasticity by comparing it to 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 a 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 the loss of Japan’s international competitiveness that resulted in further economic stagnation. Thus, Japan has been facing a dual vicious cycle leading to a solid institutional elasticity.

4. Conclusion

In light of the understanding that an effective utilization of the potential benefits of dramatic advancement of IT in an information society will differ greatly depending on the nation, particularly on their institutional elasticity, this can be attributed to the specific features of IT which performs its function in connection with institutional systems, this paper 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 on 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 inter-

	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

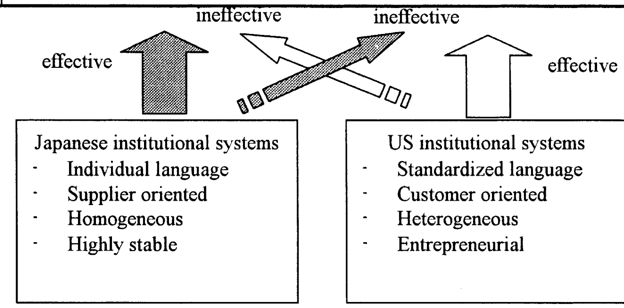

Fig. 9. Comparison of effectiveness between Japanese institutional systems and the US institutional systems under the paradigm shift.

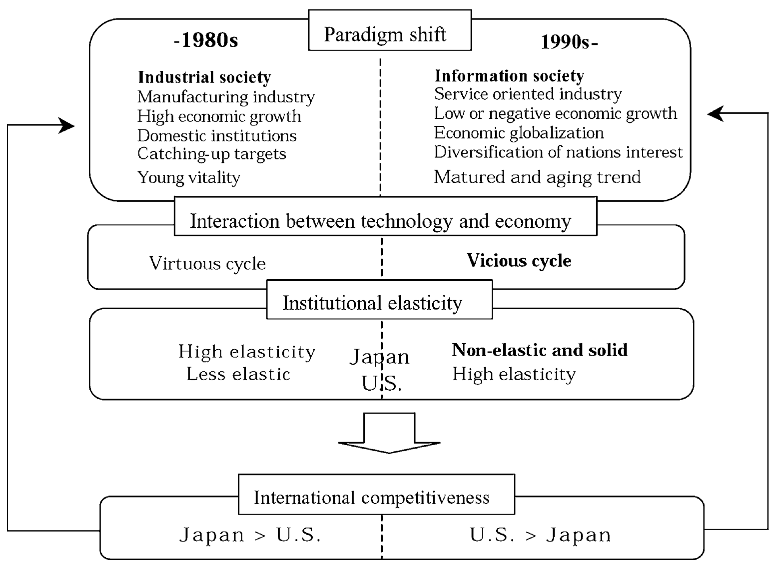

Fig. 10. Scheme leading Japan to lose its institutional elasticity.

action process and conspicuous in its unique epidemic behavior, were identified, including disseminative, interactive, co-evolutional as well as extremely invisible and more global than technology in general. Furthermore, a mechanism for IT's contribution to increasing returns to scale was identified.

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

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

Appendix A. Mathematical development of logistic growth function within a dynamic carrying capacity

Simple logistic growth function is expressed as follows:

$$\frac{df(t)}{dt}=bf(t)\left(1-\frac{f(t)}{K}\right) \quad (A1)$$

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 Eq. (A2) where the number of potential users, carrying capacity (K) in the epidemic function is subject to a function of time t.

$$\frac{df(t)}{dt}=bf(t)\left(1-\frac{f(t)}{K(t)}\right) \quad (A2)$$

Eq. (A3) is obtained from Eq. (A2):

$$\frac{df(t)}{dt}+(-b)f(t)=\left(-\frac{b}{K(t)}\right)\{f(t)\}^2 \quad (A3)$$

Eq. (A3) corresponds to the Bernoulli's differential equation expressed by Eq. (A4):

$$\frac{dy}{dx}+V(x)y=W(x)y^n \quad (A4)$$

Accordingly, Eq. (A3) can be transformed to the linear differential equation expressed by Eq. (A5).

$$\frac{dz(t)}{dx}+bz(t)=\frac{b}{K(t)} \text{ where } z(t)=\frac{1}{f(t)} \quad (A5)$$

The solution for a linear differential Eq. (A6) can be obtained as Eq. (A7):

$$\frac{dy}{dt}+P(x)y=Q(x) \quad (A6)$$

$$y=\exp\left(-\int P(x)dx\right)\cdot\left\{\int\left(Q(x)\cdot\exp\left(\int P(x)dx\right)\right)dx +c\right\} \quad (A7)$$

Accordingly, the solution for Eq. (A5) can be expressed as follows:

$$z(t)=\exp\left(-\int bdt\right)\cdot\left\{\int\left(\frac{b}{K(t)}\exp\left(\int bdt\right)\right)dt+c_1\right\} \quad (A8)$$

$$=\exp(-bt)\cdot\left\{b\int\left(\frac{1}{K(t)}\exp(bt)\right)dt+c_1\right\}$$

$$\frac{1}{f(t)}=\exp(-bt)\cdot\left\{b\int\left(\frac{\exp(bt)}{K(t)}\right)dt+c_1\right\} \quad (A9)$$

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

$$K(t)=\frac{K_K}{1+a_K\exp(-b_Kt)} \quad (A10)$$

By substitution of Eq. (A10) for $K(t)$ in Eq. (A9), Eq. (A11) is obtained:

$$\frac{1}{f(t)}=\left\{b\int\left(\frac{\exp(bt)}{K_K/(1+a_K\exp(-b_Kt))}\right)dt+c_1\right\}\exp(-bt) \quad (A11)$$

where

$$\int\left(\frac{\exp(bt)}{K_K/(1+a_K\exp(-b_Kt))}\right)dt$$

$$=\frac{1}{K_K}\int\{\exp(bt)+a_K\exp((b-b_K)t)\}dt \quad (A12)$$

$$=\frac{1}{K_K}\left\{\int\exp(bt)dt+\int a_K\exp((b-b_K)t)dt\right\}$$

$$\frac{1}{K_K}\left\{\frac{1}{b}\exp(bt)+\frac{a_K}{b-b_K}\exp((b-b_K)t)\right\}+c_2$$

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

$$\frac{1}{f(t)}=b\left\{\frac{1}{K_K}\left\{\frac{1}{b}\exp(bt)+\frac{a_K}{b-b_K}\exp((b-b_K)t)\right\}+c_2+c_1\right\}\cdot\exp(-bt)$$

$$\frac{1}{f(t)}=\frac{1}{K_K}\left\{1+\frac{b\cdot a_K}{b-b_K}\exp(-b_Kt)+c_3\exp(-bt)\right\} \quad (A13)$$

$$\frac{1}{f(t)}=\frac{1}{K_K}\left\{1+c_3\exp(-bt)+\frac{b\cdot a_K}{b-b_K}\exp(-b_Kt)\right\}$$

$$f(t)=\frac{K_K}{1+a\exp(-bt)+\frac{b\cdot a_K}{b-b_K}\exp(-b_Kt)} \quad (A14)$$

Appendix B. Data construction and sources

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

B.1. Refrigerators

The annual shipment volume of refrigerators from 1966 to 1999 was obtained from the 'Report on Machinery Statistics' conducted by the Ministry of International Trade and Industry (MITI).[8] Since the ratio of imports and exports of refrigerators to their shipment as a whole has not been changing greatly, annual shipment volume was used for the analysis.

B.2. Color TV sets

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

B.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 is somewhat significant, the volume of imports and exports were considered for data construction. Quarterly production volume of cellular telephones from 1993 to 2000 was obtained from the 'Report on Machinery Statistics' conducted by MITI, and quarterly volume of imports and exports from 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 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 for 1996 by production volumes.

Appendix C. Mathematical development of SCE

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

$$\begin{aligned} V &= F(L,K,I,T,t) \\ &= F\{(L,I_l),(K,I_k),T,t\} \\ &= Ae^{\lambda t}(L^{\alpha_1}\cdot I_l^{\alpha_2})K^{\beta_1}\cdot I_k^{\beta_2})T^{\gamma} \end{aligned} \quad \text{(C1)}$$

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.

The 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 the 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 production factor is explained by the IT related investments listed in Table 4.

In order to analyze SCE using the production function given by the Eq. (C1), incorporation ability of technology spillovers should be measured as follows in light of the active spillover characteristics of IT among industries (Watanabe et al., 2001):

$$I = I_i + Z_{IT} I_s \quad \text{(C2)}$$

$$Z_{IT} \frac{1}{1+\frac{\Delta I_s/I_s}{\Delta I_i/I_i}} \cdot \frac{I_i}{I_s} \quad \text{(C3)}$$

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 Eq. (C1) can be described as follows:

$$V = Ae^{\lambda t}\{L^{\alpha_1}(I_{li}+Z_{il}I_{ls})^{\alpha_2}\}\{K^{\beta_1}(I_{ki}+Z_{ik}I_{ks})^{\beta_2}\}T^{\gamma} \quad \text{(C4)}$$

Christensen and Greene (1976) defined SCE as follows:

$$\mathrm{SCE} = 1 - \frac{\partial \ln C}{\partial \ln y} \quad \text{(C5)}$$

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 SCE=0, it means constant returns to scale, and SCE<0 indicates diminishing returns.

By using the production function Eq. (C4), where technology-related factors are deducted from L and K to avoid duplication, elasticity of each factor of production is expressed as follows to correspond to the ratio of costs:

$$\alpha_1 = \frac{\mathrm{GLC}}{\mathrm{GDP}} = \frac{P_l\cdot L}{P_v\cdot V}$$

$$\alpha_2 = \frac{\mathrm{GILC}}{\mathrm{GDP}} = \frac{P_{il}\cdot I_l}{P_v\cdot V}$$

$$\beta_1 = \frac{\mathrm{GCC}}{\mathrm{GDP}} = \frac{P_k\cdot K}{P_v\cdot V} \quad \text{(C6)}$$

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

Table 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

$$\beta_2=\frac{\mathrm{GICC}}{\mathrm{GDP}}=\frac{P_{\mathrm{ik}}\cdot I_{\mathrm{k}}}{P_{\mathrm{v}}\cdot V}$$

$$\gamma=\frac{\mathrm{GTC}}{\mathrm{GDP}}=\frac{P_{\mathrm{t}}\cdot T}{P_{\mathrm{v}}\cdot V}$$

Considering that GDP=GLC+GCC+GTC+GIC and by substituting GILC+GICC with GIC, Eq. (C7) is obtained:

$$\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma+1 \qquad \text{(C7)}$$

From equation Eq. (C6), the following equation is obtained:

$$\begin{aligned}
\alpha_1&=\frac{\mathrm{GLC}}{\mathrm{GDP}}=\frac{P_{\mathrm{l}}\cdot L}{P_{\mathrm{v}}\cdot V} & GDP&=\frac{P_{\mathrm{l}}\cdot L}{\alpha_1}\\
\alpha_2&=\frac{\mathrm{GILC}}{\mathrm{GDP}}=\frac{P_{\mathrm{il}}\cdot I_{\mathrm{l}}}{P_{\mathrm{v}}\cdot V} & GDP&=\frac{P_{\mathrm{il}}\cdot I_{\mathrm{l}}}{\alpha_2}\\
\beta_1&=\frac{\mathrm{GCC}}{\mathrm{GDP}}=\frac{P_{\mathrm{k}}\cdot K}{P_{\mathrm{v}}\cdot V} \;\Rightarrow & GDP&=\frac{P_{\mathrm{k}}\cdot K}{\beta_1}\\
\beta_2&=\frac{\mathrm{GICC}}{\mathrm{GDP}}=\frac{P_{\mathrm{ik}}\cdot I_{\mathrm{k}}}{P_{\mathrm{v}}\cdot V} & GDP&=\frac{P_{\mathrm{ik}\cdot I_{\mathrm{k}}}}{\beta_2}\\
\gamma&=\frac{\mathrm{GTC}}{\mathrm{GDP}}=\frac{P_{\mathrm{t}}\cdot T}{P_{\mathrm{v}}\cdot V} & GDP&=\frac{P_{\mathrm{t}}\cdot T}{\gamma}
\end{aligned} \qquad \text{(C8)}$$

Given constant output to the production function Eq. (C4), total cost (C) is obtained by minimizing the cost under constant price of production factors:

$$C=V^{\frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}(\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma)\left(\frac{1}{Ae^{\lambda t}}\right)^{\frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}\left(\frac{P_{\mathrm{l}}}{\alpha_1}\right)^{\frac{\alpha_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}} \qquad \text{(C9)}$$

$$\left(\frac{P_{\mathrm{il}}}{\alpha_2}\right)^{\frac{\alpha_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}\left(\frac{P_{\mathrm{k}}}{\beta}\right)^{\frac{\beta}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}\left(\frac{P_{\mathrm{ik}}}{\beta_2}\right)^{\frac{\beta_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}\left(\frac{P_{\mathrm{t}}}{\gamma_2}\right)^{\frac{\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}}$$

Eq. (C9) is obtained by substitution Eq. (C8) into Eq. (C10).

$$\begin{aligned}
\ln C&=\ln\{C(V,P_{\mathrm{l}},P_{\mathrm{il}},P_{\mathrm{k}},P_{\mathrm{ik}},P_{\mathrm{t}})\}\\
&=\frac{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP} \qquad \text{(C10)}\\
&=\frac{\alpha_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP}+\frac{\alpha_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP}\\
&\quad+\frac{\beta_1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP}+\frac{\beta_2}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP}\\
&\quad+\frac{\gamma}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma}\ln\mathrm{GDP}+\ln(\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma)
\end{aligned}$$

SCE, defined by Eq. (C5) can be obtained from Eq. (C9):

$$\mathrm{SCE}=1-\frac{1}{\alpha_1+\alpha_2+\beta_1+\beta_2+\gamma} \qquad \text{(C11)}$$

Accordingly, coefficients α_1, α_2, β_1, β_2 and γ are estimated from Eq. (C6) as follows under the assumption of cost minimization:

$$\frac{\alpha_1}{\beta_2}=\frac{\mathrm{GLC}}{\mathrm{GICC}},\quad \frac{\alpha_2}{\beta_2}=\frac{\mathrm{GILC}}{\mathrm{GICC}},\quad \frac{\beta_1}{\beta_2}=\frac{\mathrm{GCC}}{\mathrm{GICC}},\quad \frac{\gamma}{\beta_2}=\frac{\mathrm{GTC}}{\mathrm{GICC}} \qquad \text{(C12)}$$

Average of coefficients ratios are obtained from Eq. (C13) using Eq. (C12).

$$\left(\frac{\hat{\alpha}_1}{\beta_2}\right)=\exp\left[\frac{1}{n}\sum\frac{\mathrm{GLC}}{\mathrm{GICC}}\right],\quad \left(\frac{\hat{\alpha}_2}{\beta_2}\right)=\exp\left[\frac{1}{n}\sum\frac{\mathrm{GILC}}{\mathrm{GICC}}\right],\quad \left(\frac{\hat{\beta}_1}{\beta_2}\right)=\exp\left[\frac{1}{n}\sum\frac{\mathrm{GCC}}{\mathrm{GICC}}\right],\quad \left(\frac{\hat{\gamma}}{\beta_2}\right)=\exp\left[\frac{1}{n}\sum\frac{\mathrm{GTC}}{\mathrm{GICC}}\right] \qquad \text{(C13)}$$

where n denotes number of samples.

Eq. (C15), 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 Eq. (C13) as below:

$$\hat{Z}=\ln(I_{\mathrm{k}})+\left(\frac{\hat{\alpha}_1}{\beta_2}\right)\ln(L)+\left(\frac{\hat{\alpha}_2}{\beta_2}\right)\ln(I_{\mathrm{l}})+\left(\frac{\hat{\beta}_1}{\beta_2}\right)\ln(K) \qquad \text{(C14)}$$

$$+\left(\frac{\hat{\gamma}}{\beta_2}\right)\ln(T)$$

$$\ln(V)=\ln A+\hat{\beta}_2\cdot\hat{Z}+\lambda t \qquad \text{(C15)}$$

Since $\hat{\beta}$ is obtained by Eq. (C14), we can calculate the estimators of α_1, α_2, $\hat{\beta}_1$, γ by multiplying $(\alpha_1/\hat{\beta}_2)$,$(\alpha_2/\hat{\beta}_2)$,$(\beta_1/\hat{\beta}_2)$,$(\gamma/\hat{\beta}_2)$ by $\hat{\beta}_2$. Based on the results of α_1, α_2, β_1, β_2, γ we can measure SCE by Eq. (C11).

References

Aggarwal, R., 1996. The shape of post-bubble Japanese business: preparing for growth in the new millennium. International Executive 38 (1), 9–32.

Cairncross, F., 1997. The Death of Distance. Harvard Business School Press, Boston.

Christensen, L.R., Greene, W.H., 1976. Economies of scale in U.S. electric power generation. Journal of Political Eoconomy 84 (4), 655–676.

Coombs, R., Saviotti, P., Walsh, V., 1987. Economics and Technological Change. Macmillan, London.

Economic Planning Agency, 2000. White Paper on the Japanese Economy, Tokyo.

Griliches, Z., 1957. Hybrid corn: an explanation in the economics of technical change. Econometrica 25 (4), 501–522.

MacRae, H., 1995. The World in 2020: Power, Culture and Prosperity. Harvard Business School Press, Boston.

Mansfield, E., 1963. Intrafirm rates of diffusion of an innovation. The Review of Economics and Statistics 45 (4), 348–359.

Mansfield, E., 1969. Industrial Researh and Technological Innovation: An Econometric Analysis. Longman, London.

Marchetti, C., 1976. On strategies and fate. In: Hafele, W. et al. (Eds.), Second Status Report on the IIASA Project on Energy Systems 1975. IIASA, Laxenburg (Austria), pp. 203–217.

McMillan, C., 1996. The Japanese Industrial System. Walter de Gruyter and Co, Paris.

Metcalfe, J.S., 1970. The diffusion of innovation in the Lancashire textile industry. Manchester School of Economics and Social Studies 2, 145–162.

Meyer, P.S., 1994. Bi-logistic growth. Technological Forecasting and Social Change 47 (1), 89–102.

Meyer, P.S., Ausbel, J.H., 1999. Carrying capacity: a model with logistically varying limits. Technological Forecasting and Social Change 61 (3), 209–214.

Ministry of Posts and Telecommunications (MPT), 2000. White Paper 2000 on Communications in Japan, Tokyo.

Moschella, D.C., 1997. Waves of Power. AMACOM, New York.

Norris, K., Vaizey, J., 1973. The Economics of Research and Technology. George Allen and Unwin, London.

OECD, 1997. Special issue on information infrastructures. STI Review, Paris.

OECD, 2001. The new economy: beyond the hype. Final report on the OECD Growth Project, Paris.

Oster, S.M., 1994. Modern Competitive Analysis. Oxford University Press, New York.

Rogers, E.M., 1962. Diffusion of Innovations. The Free Press of Glencoe, New York.

Romer, P.M., 1994. Beyond classical and Keynesian macroeconomic policy. Policy Options (July–August) 15–21.

Ruttan, V.W., 2001. Technology, Growth, and Development—An Induced Innovation Perspective. Oxford University Press, New York.

Schelling, T.C., 1998. Social mechanisms and social dynamics. In: Hedstrom, P., Swedberg, R. (Eds.), Social Mechanisms: An Analytical Approach to Social Theory. Cambridge University Press, Cambridge, pp. 32–44.

Telecommunications Council, Japan, 2000. The info-communications vision for the 21st century. Telecommunications Council for the Minister of Posts and Telecommunications, Tokyo.

US DOC, 2000. Digital economy 2000. DOC, Washington, DC.

Watanabe, C., Zhu, B., Griffy-Brown, C., Asgari, B., 2001. Global technology spillover and its impact on industry's R&S strategies. Technovation 21 (5), 281–291.

Chihiro Watanabe graduated from Tokyo University with a Bachelor's Degree in Engineering (Urban Planning) in 1968 and received his Ph. D. (Arts and Sciences) in 1992, also from Tokyo University. He joined the Ministry of International Trade and Industry (MITI) in 1968 and is a former Deputy Director-General of Technology Development. He is currently a professor in the Department of Industrial Engineering & Management, Tokyo Institute of Technology (TIT), and also Senior Advisor to the Director on Technology at the international Institute for Applied Systems Analysis (IIASA).

Reiko Kondo graduated from Tokyo University with a Bachelor's Degree in Computer Science in 1991 and received a Master's Degree also from Tokyo University in the same field in 1993. Afterwards, she received a MBA Degree from the Stanford University Graduate School of Business in 1998. She is currently a deputy director, Broadcasting Technology Division, Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT).

Noritomo Ouchi graduated from Tokyo Institute of Technology with a bachelor's degree in Engineering (management engineering) in 2000. He is currently pursuing his Master's degree at the Department of Industrial Engineering and Management, Tokyo Institute of Technology.

Haihong Wei graduated from Tokyo Institute of Technology with a bachelor's degree in Engineering (management engineering) in 2001. He is currently pursuing his Master's degree at the Department of Industrial Engineering and Management, Tokyo Institute of Technology.