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Institutional elasticity as a significant driver of IT functionality development

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Abstract

Institutions drive innovation and stimulate broad diffusion. Not surprisingly, national systems of innovation are influenced by their institutional flexibility in response to changing market conditions. As nations move from industrial to information-based societies, a key factor governing institutional "elasticity" is how institutions integrate information technology (IT). Since IT functionality is intimately connected with institutional dynamics, unlike simple manufactured products such as refrigerators, IT's specific functionality is formed through dynamic interaction with institutional systems. Consequently, institutional elasticity is a critical factor in the functionality of IT and its subsequent self-propagating behavior. This paper analyzes the mechanism of IT functionality development, with special attention to the interaction of the technology with institutional systems.

Keywords: Information society; IT functionality; Epidemic behavior; Self-propagation; Institutional elasticity

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1. Introduction

The development of new technologies is undoubtedly recognized as a significant driving force in sustaining economic growth. However, as the OECD [1] shows, new technology itself represents only potential, and in order to exploit this potential, institutional change is necessary. Nelson et al. (2001) [2], in their recent work developed the notion of institutions useful for the analysis of economic performance, and economic growth in particular as standard "social technologies," and postulated that economic growth results from the *co-evolution of physical and social technologies*.

A rapid surge in information technology (IT) around the world is inevitably forcing traditional societies to transform their socioeconomic structures. As the Telecommunications Council [3] noted, IT is hastening Japan's 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 an organization, or a society, to have an impact on structure and behavior. More precisely, IT waves, most recently exemplified by the growing popularity of the Internet and mobile communications, are characterized by so-called network externalities[1] (e.g., Refs. [5,6]) that construct a self-propagating "virtuous cycle" between the expanding number of users and the rising value of networks, rapidly diffusing throughout the social infrastructure to support socioeconomic activities.

The OECD [1] 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 "communicate" option, it can become a learning institution with new sets of skills.

Accordingly, IT differs from other technologies since individuals, organizations and societies use it to interact, and its features are formed dynamically through this interaction. In other words, the unique features of IT are formed during the course of interaction with institutional systems [7]. Ruttan [5] and Binswanger and Ruttan [8], in their postulate of "institutional innovation," suggested that "institutions are the social rules that facilitate coordination among people by helping them form expectations for dealing with each other" and also that "they reflect the conventions that have evolved in different societies regarding the behavior of individuals and groups." Consequently, IT products develop functionality through the diffusion process in organizations and societies.

Research on the diffusion of innovation has been undertaken in broad fields and Rogers [9] 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

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[1] The value to a consumer of a product increases as the number of compatible users increases [4].

elements in the diffusion of innovations: *innovation features, communication channels, time and social system*. All of Rogers' postulates further support the contention that IT's unique functionality can be developed during this diffusion process.

This diffusion process is actually quite similar to the contagion process of an epidemic disease [10] and exhibits S-shaped growth. This process is well modeled by the *simple logistic growth function* (SLF), an epidemic function that was first introduced by Verhulst in 1845 [11]. Since the logistic growth function has proved useful in modeling a wide range of innovation processes, a number of studies applied this function in analyzing the diffusion process of innovations as well (e.g., Refs. [10,12–15]).

While the SLF treats the carrying capacity of a human system[2] as fixed, this capacity is actually subject to change [16,17]. Among varieties of innovations, certain innovations alter their carrying capacity in the process of their diffusion, which stimulates an increase in the number of potential users [18,19]. This increase, in turn, incorporates new features in the innovations. Meyer [11] extended the analysis of logistic functions to cases where dual processes operate by referring to an example when cars first replaced the population of horses but then took on a further growth trajectory of their own. He postulated *bi-logistic growth* in an attempt to deal with the fact that this diffusion process that contains complex growth processes not well modeled by the single logistic growth function.

In addition to the above diffusion processes exhibited by a single logistic growth and bi-logistic growth, in particular innovations, a correlation of the interaction between innovations and institutions displays systematic change in their process of the growth and maturity. This is typically the case of the diffusion process of IT in which *network externalities* [4] function 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 [20] portrays an array of logistically developing and diffusing social mechanisms stimulated by these efforts. Meyer and Ausbel [21] 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 the unique diffusion process of IT, which diffuses by altering the carrying capacity or creating a new carrying capacity in the process. Meyer and Ausbel proposed *logistic growth within a dynamic carrying capacity* to model this diffusion behavior.

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 the diffusion process, we can disrobe this by analyzing its diffusion trajectory using logistic growth within a dynamic carrying capacity and by comparing it with the diffusion processes of technology in general.

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

Building on this foundation, this paper analyzes one possible mechanism of IT functionality formation in Japan, with special attention given to the interaction of the technology with institutional systems. Furthermore, this analysis helps to explain differences in institutional elasticity in Japan and US, as well as the implications for policy reform.

Section 2 attempts a mathematical analysis of the diffusion of innovations with self-propagating behavior. Section 3 identifies specific features of IT by a comparative empirical analysis of epidemic behavior between IT and other technologies. Section 4 extracts implications with respect to the effectiveness of institutional systems for IT functionality formation. Section 5 briefly summarizes the key findings of the analysis and presents conclusions by discussing the significant role of institutional elasticity for the effective utilization of IT in techno-economic growth.

2. Diffusion of innovations with self-propagating behavior: mathematical analysis

2.1. The formation process of specific features of technology

As emphasized in numerous studies, IT is a driving force transforming the existing socioeconomic structure by permeating people's daily life, organizational activities and society as a whole (e.g., Refs. [3,6,22,23]).

Table 1 compares features of the core technologies in the 1980s and in the 1990s. During the 1980s, developing manufacturing technology was critical for firms to be successful in industrial production. Manufacturing technology was developed by the supply side to provide end-users (customers) with products and was introduced to factories to replace part of the workforce for improving productivity [24]. Like other technologies, the features of manufacturing technology are established or programmed at the beginning and once this technology leaves the supply side, it does not change its basic use substantially during its dissemination. That implies that customers do not participate in the production process. Instead, they either choose whether or not to buy the technology. In this case, individual firms are responsible for forming features of technology.

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

With IT development, customers are co-producers. This is because these technologies permeate socioeconomic activities as well as infrastructure. In addition, business transactions and information exchange easier and cheaper, leading to an expanding e-commerce market [6]. In this marketplace, where mass customization reigns, customers effectively participate in the production process by specifying the features they want.

In addition, suppliers of IT are very concerned about compatibility. This is because IT products are often utilized as a communication tool and exist in a complex technological 'web.' Fig. 1 illustrates the web enabled rapid emergence of Japan's mobile communication business.

On the other hand, home appliances such as refrigerators or TV sets generally can be purchased without tremendous consideration given to compatibility issues related to "accessories" or technologies people possess besides electricity. Certainly, consumers want these products to have inputs and outputs consistent with other devices (such as DVD, VCR, satellite receivers, sound equipment, etc.). However, these accessories are generally standardized around the inputs and outputs on the TV sets, whereas in IT products, the standards are still very fluid and accessories tend to be device specific (Palm, i-mode, etc.). In this context, IT products are highly subject to 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 becomes, thus, attracting more potential users [5]. In short, IT is strongly a self-propagating once it gains momentum in terms of market share [25,26]. Therefore, these technologies closely interact with individuals, organizations and society during the course of their diffusion and behaves differently depending on the institutions involved [27]. These observations suggest that functionality is formed dynamically during the course of interaction with institutions. Furthermore, whether the potential benefits of IT can be

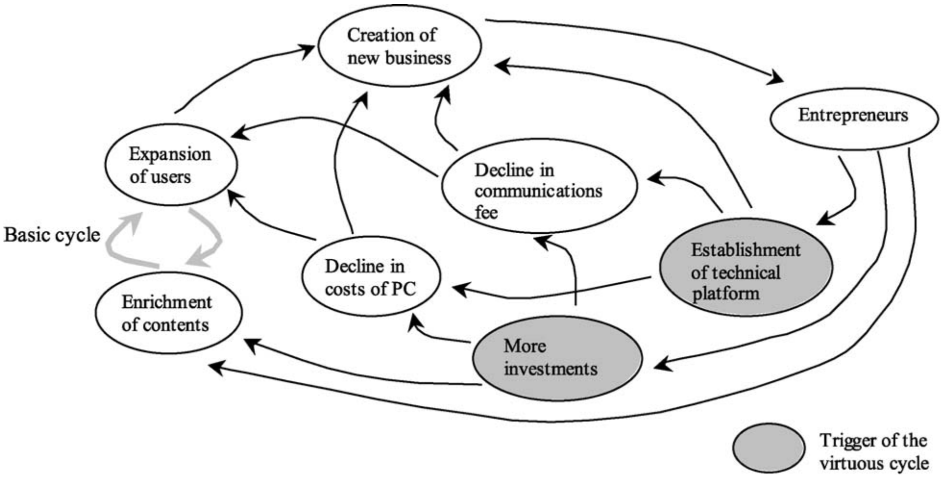

Fig. 1. Complex technological web emerging Japan's mobile communication business.

exploited greatly depends on the nature of these institutions, particularly on institutional flexibility or "elasticity."

This formation process of IT features is actually quite similar to the contagion process of an epidemic disease. Based on this similarity, the following analysis explains functionality development in the context of this self-propagating behavior.

2.2. Modeling of the diffusion of innovations with self-propagating behavior

There are a variety of efforts in modeling the diffusion of innovations [28] including the Bass model, the epidemic function (logistic growth function), the Gompertz curve, the Weibull curve and Lotka-Volterra model for competitive innovations. An epidemic function approach was used in line with the approaches introduced in Section 1 [11,21] in order to identify IT's self-propagation behavior. The following three epidemic functions (simple logistic growth function [SLF], bi-logistic growth function [BLF] and logistic growth function within a dynamic carrying capacity [LFDCC]) were used for a comparative analysis of epidemic behaviors between IT and other technologies.

2.2.1. Simple logistic growth function

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

where $f(t)$: number of adopters; a and b: coefficients; K: carrying capacity (ceiling of the adoptions of innovative goods); and t: time trend.

2.2.2. Bi-logistic growth function

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

where a_1, a_2, b_1 and b_2: coefficients; K_1 and K_2: carrying capacities; and t: time trend.

This function can be considered a variation of Eq. (i) as Eq. (ii) has the same structure as Eq. (i). Given $f_1(t)$, a parameter reflecting an influence that is independent of previous adoption ($f(t)$), Eq. (ii) is the Bass model.

2.2.3. Logistic growth function within a dynamic carrying capacity

The epidemic function expressed by Eq. (i) assumes that the level of carrying capacity (K in Eq. (i) as well as K_1 and K_2 in Eq. (ii)) is constant through the dissemination process of innovation. However, as reviewed in Section 1, in particular innovations, the correlation of the interaction between innovation and institutions displays a systematic change in the process of growth and maturity. This leads to the creation of a new carrying capacity in the process of its diffusion. In these innovations, the level of carrying capacity will be enhanced as their diffusion proceeds and carrying capacity K in Eq. (i) (similarly K_1 and K_2 in Eq. (ii)) should be treated as the following function:

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

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

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

where K_K indicates carrying capacity (the ultimate upper limit).

The solution of a differential Eq. (iii) under the condition (iv) can be obtained as an Eq. (v).

$$f(t) = \frac{K_K}{1 + a \exp(-bt) + \dfrac{ba_K}{b - b_K} \exp(-b_K t)} \tag{v}$$

where a, b, a_K and b_K: coefficients; K_K: carrying capacity; and t: time trend.

In case when $a_K = 0$, Eq. (v) is equivalent to Eq. (i). Thus, Eq. (v) is a general function of the epidemic behavior encompassing a SLF.

The dynamic carrying capacity $K(t)$ can be expressed by Eq. (vi) by transforming Eq. (iii).

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

Eq. (vi) demonstrates that $K(t)$ increases together with the increase of $f(t)$ as time goes by. This implies that Eq. (v) exhibits logistic growth within a dynamic carrying capacity, which is assumed to demonstrate functionality development in the context of the self-propagating behavior.

From Eq. (vi), the allowance between the diffusion level and its ceiling ($K(t)/f(t)$) can be enumerated by the following equation:

$$K(t)/f(t) = \left[1 - \frac{1}{b}\{(\mathrm{d}f(t)/\mathrm{d}t)/f(t)\}\right]^{-1} \tag{vii}$$

Eq. (vii) suggests that the allowance increases as the diffusion rate ($(\mathrm{d}f(t)/\mathrm{d}t)/f(t)$) increases and the value of coefficient b decreases.

3. Comparison of diffusion process between IT and other technologies: empirical analysis

3.1. Comparative analysis of epidemic behavior

The diffusion of innovations in this analysis, these processes were compared in terms of carrying capacity, by analyzing other diffusion patterns of (1) refrigerators, (2) fixed telephones, (3) Japanese word processors, (4) color TV sets, (5) personal computers and (6) cellular telephones.

These six products were chosen based on the dimensions illustrated in Fig. 2. As described previously, since IT's diffusion process is characterized by this self-propagating behavior creating new functionality through interactions with institutional systems, two dimensions were introduced in order to distinguish IT intensive products from other manufacturing products: the degree of multifunctionality and the user's manageability of the functionality.

Products positioned in the bottom-right in Fig. 2, such as personal computers and cellular telephones, are regarded as IT intensive products, while products with mono functionality and limited user customization such as refrigerators and fixed telephones are regarded as representative products of manufacturing technology. Fixed telephones are somewhat different from cellular telephones in that the hardware is mainly designed for voice communication only while cellular telephones enable both voice and data transmission. Color TV sets, which started with the monofunction of televising or pushing information to the viewer, have evolved since the introduction of BS digital broadcasting service in 2000. Color TVs gained additional functions such as permitting viewers broad options in accessing information and also participating in the contents of the programs. Thus, the

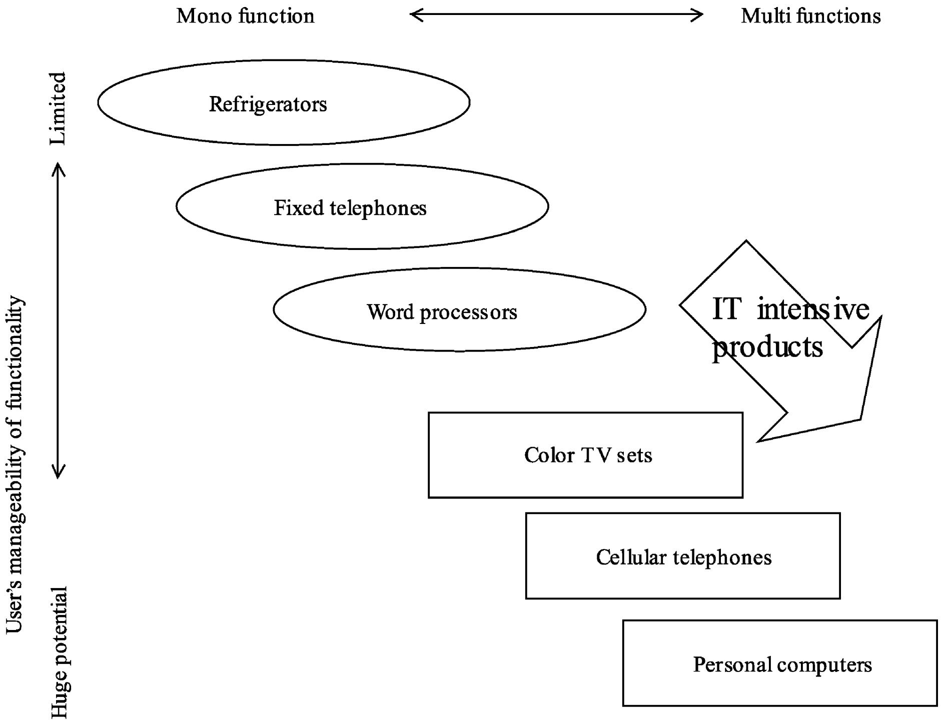

Fig. 2. Categorization of innovative goods.

technology in a limited way is shifting from monofunctionality to with multifunctionality and customization. Japanese word processors once proliferated as a substitute for typewriters and can now be considered as transitional products between typewriters and personal computers.

Similar analyses were attempted by Kodama [25] and Watanabe et al. [26]. Kodama compared the diffusion process of Japan's fax machines, liquid crystals and personal computers by comparing the fit to SLF and LFDCC. By examining the Akaike Information Criterion (AIC) value, he concluded that personal computers created a new business model according to the LFDCC fit, while fax machines fit SLF and liquid crystals demonstrate a similar fit to both SLF and LFDCC. Similarly, Watanabe et al. compared the diffusion process of Japan's refrigerators, color TV sets and cellular telephones by comparing the fit to SLF, BLF and LFDCC. They also examined AIC and concluded that given the strong LFDCC fit, cellular telephones, with the highest IT density, demonstrate a self-propagating. Contrary to cellular telephones, refrigerators exhibit a strong fit to SLF while color TV sets demonstrate fit well with the BLF followed by LFDCC rather to SLF. Therefore, while color TV sets demonstrate a transition from monochrome TV sets, they learn towards broad options

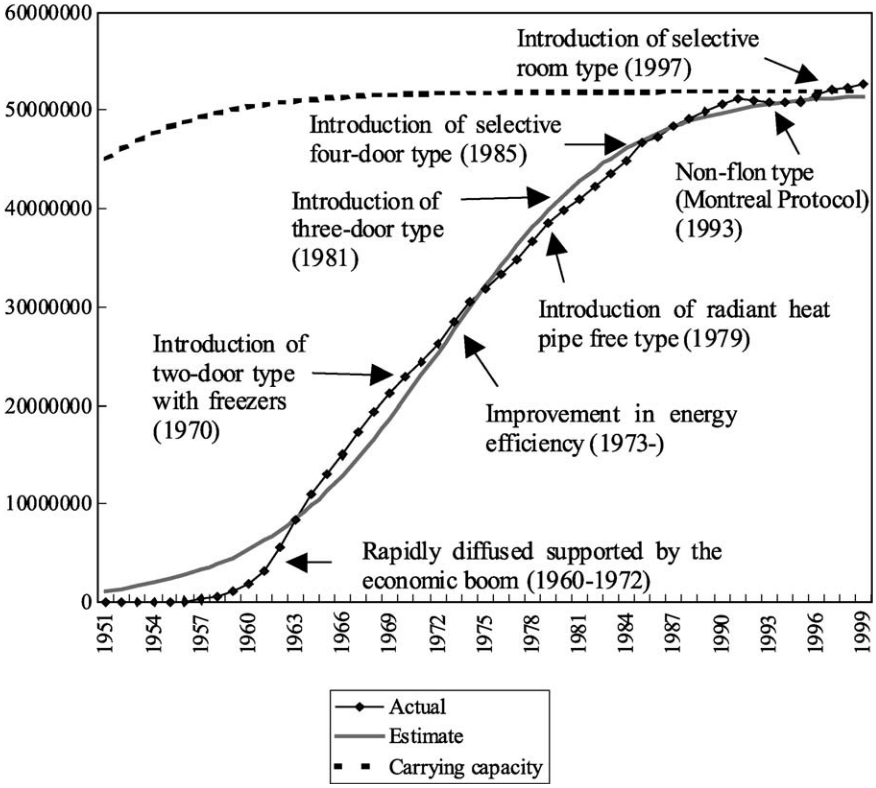

Fig. 3. Trends in the diffusion process of refrigerators in Japan (1951–1999).

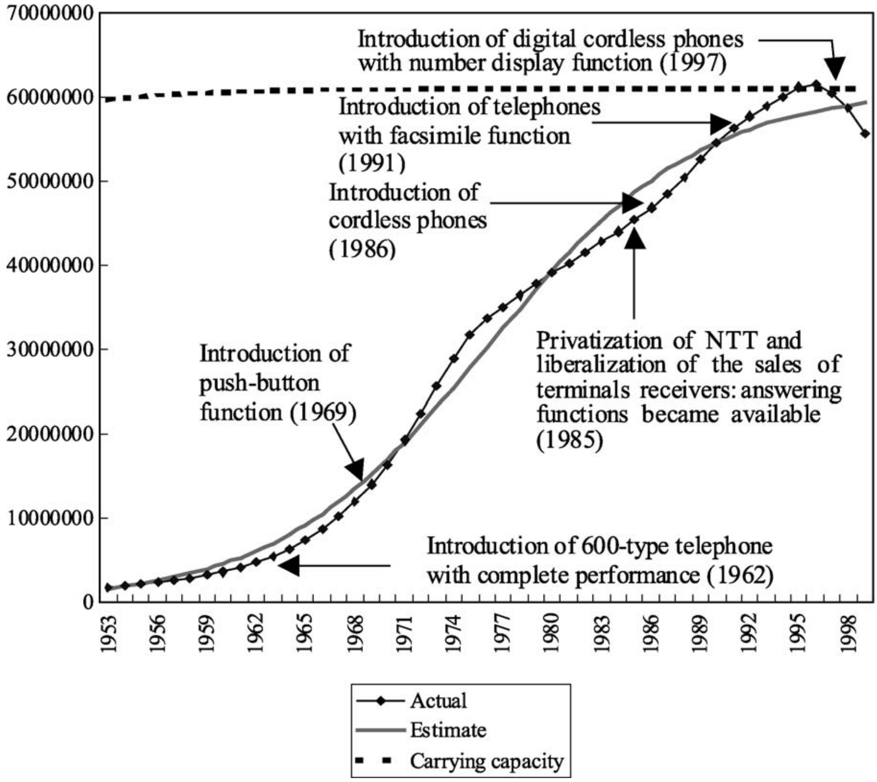

Fig. 4. Trends in the diffusion process of the fixed telephones in Japan (1953–1999).

leading to selectivity and interactiveness, a typical function of IT, has been increasing. Furthermore, this trend is increasing.

Their results correspond to our hypothesis that IT's specific functionality is formed in the diffusion process through dynamic interaction with institutional systems. However, their analyses depended on production or shipment of respective innovative goods not on cumulative volume. Given the interpretation of the results obtained from the logistic growth function, analyses should be based on the cumulative number of adopters.[3] Therefore, the cumulative number of respective innovative goods was used in analyzing the diffusion patterns of these goods in Japan.[4]

Looking at Figs. 3–8, we note the following findings with respect to trends in the carrying capacity of the respective innovative goods.

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[3] In our analysis, the cumulative shipment of goods is used as a first approximation. It is recognized that this may be an over estimate as the best measure would be the exact number of users of a new technology. However, this data is unavailable. To ensure the reliability of this data set, the authors performed a cross-evaluation analysis to ensure the data could be used as a reliable proxy.

[4] See Appendix A for data construction and sources.

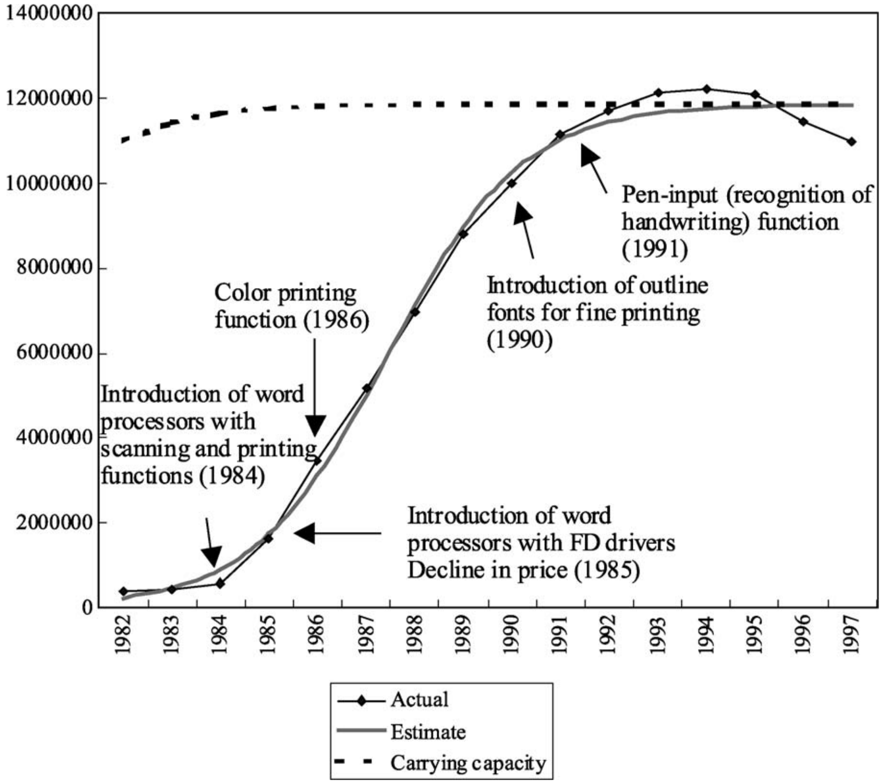

Fig. 5. Trends in the diffusion process of the Japanese word processors in Japan (1982–1997).

3.1.1. Refrigerators

The cumulative number of refrigerators shows a rapid increase in the beginning of the 1960s supported by the economic boom called the "Iwato Boom" and continued to increase over the 1970s. While slightly stagnating, the cumulative number still maintained its steady increase. This is probably due to the further development of freezers, a dramatic improvement in energy efficiency and the development of refrigerators with larger capacity. This level has been nearly constant except for an increase in the 1950s and early 1960s.

3.1.2. Fixed telephones

Similar to refrigerators, the cumulative number of fixed telephones shows a rapid increase from the middle of the 1960s (lasting two decades) up to the middle of the 1980s. While slightly stagnating, the cumulative number still maintained a steady increase. This is due to the privatization of NTT and the liberalization of the sales of terminal receivers that brought about nicely designed telephones with convenient functions such as message recording and facsimile transmission or receiving. This effectively created new demand. Similar to the case of refrigerators, since these innovations were in the scope of the same function, while fixed telephones maintained their carrying capacity, the level has

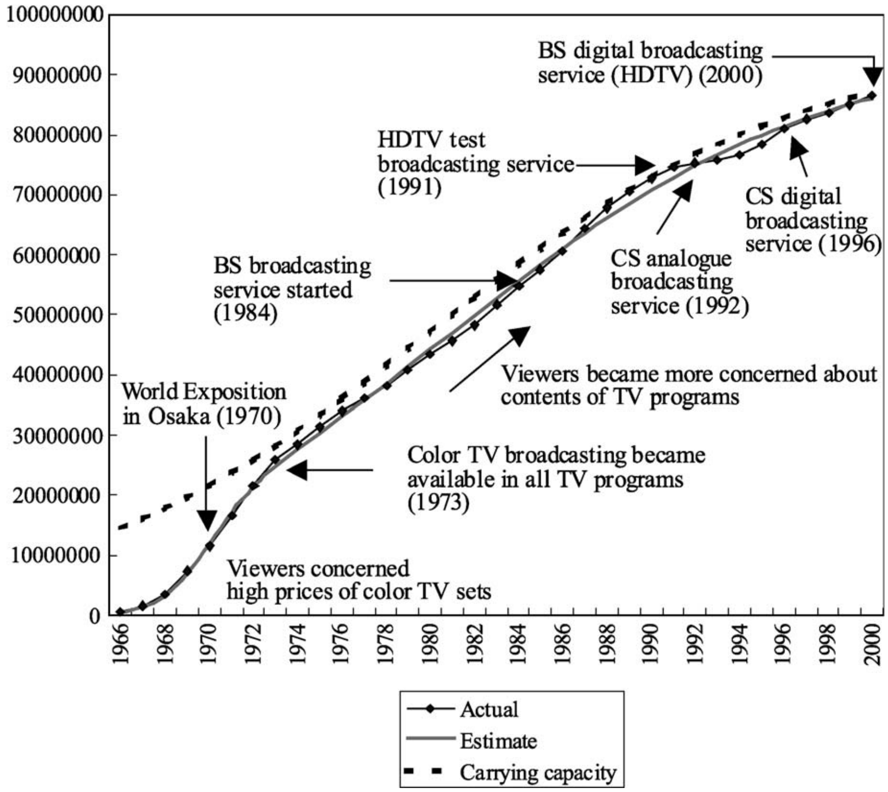

Fig. 6. Trends in the diffusion process of the color TV sets in Japan (1966–2000).

been nearly constant except for a slight increase in the 1950s and to the middle of the 1960s.

3.1.3. Japanese word processors

The cumulative number of Japanese word processors shows a rapid increase in the limited period of the last half of the 1980s when the price reached a reasonable level for personal users. While dramatically declining from the beginning of the 1990s, the cumulative number still maintained a consistent increase. This is due to innovations such as a memory function, graphic and color processing functions, downsizing and the fact that the technology maintained its niche function as a transitional product before being overtaken and substituted by personal computers. Although improved, the overall functionality has not made any substantial qualitative change. Thus, the carrying capacity level has been nearly constant except for a slight increase in the first half of the 1980s.

3.1.4. Color TV sets

The cumulative number of color TV sets rapidly increased before color TV broadcasting became widely available in 1973. While this trend subsequently declined, it also

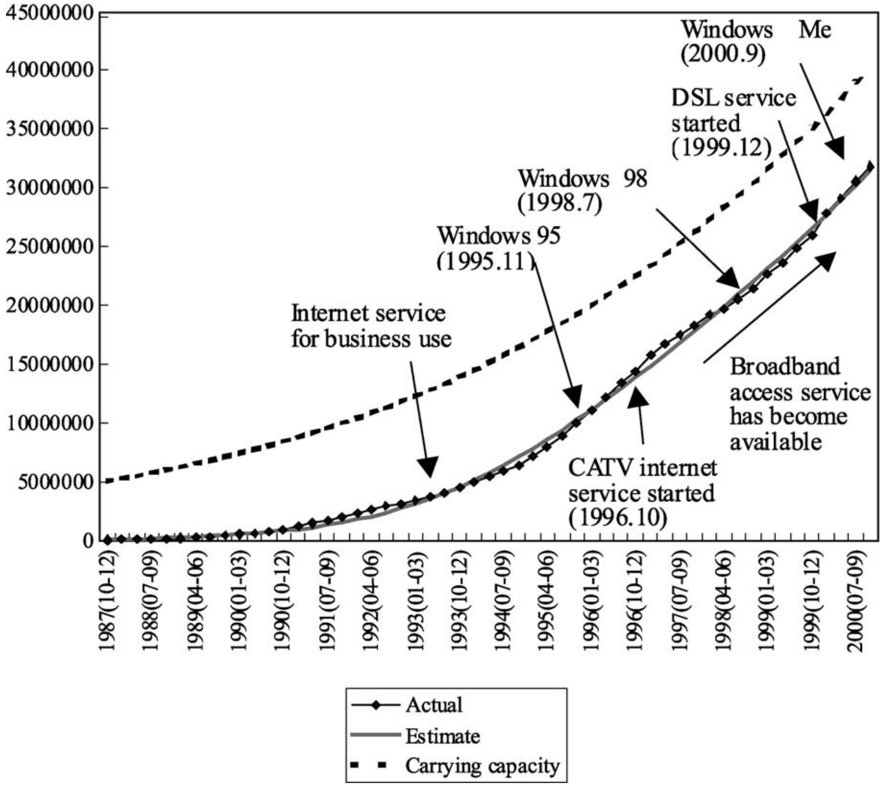

Fig. 7. Trends in the diffusion process of the personal computers in Japan (1987–2000).

maintained a consistent increase overall. This is due to successive innovations including the introduction of the BS broadcasting service in 1984 that afterwards started High Definition test TV broadcasting service in 1991 and the Communications Satellite (CS) broadcasting service in 1992. These new services provided viewers with new functionality including broad options in enjoying a variety of high-quality entertainment programs and clear HDTV images, accessing required information on demand and also interactively participating in TV programs. Therefore, the carrying capacity of color TV sets has increased as their cumulative number increased. However, the “allowance” between carrying capacity and cumulative number has been limited over the period except the period before color TV broadcasting became available in all TV programs in 1973. This is due to the limitations of the new functions, which were not necessarily evolutional.

3.1.5. Personal computers

The cumulative number of personal computers shows a constant increase with a higher increase from 1994 when advanced functions for both hardware and software were broadly introduced into personal computers and the Internet became widely

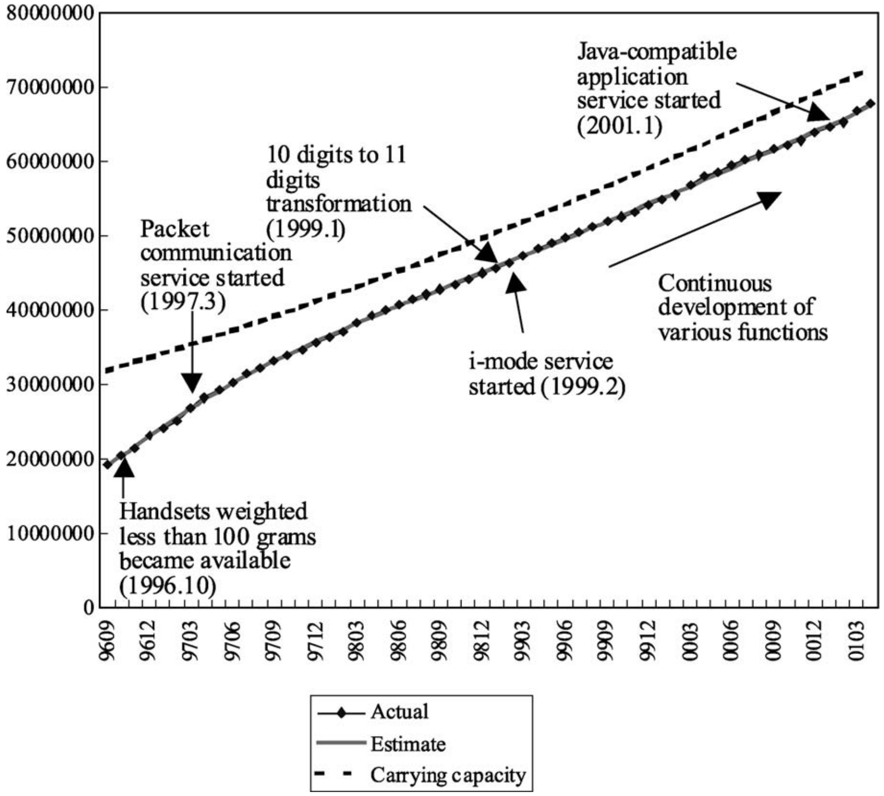

Fig. 8. Trends in the diffusion process of the cellular telephones in Japan (1996–2001).

available enhancing the network externalities of personal computers. Due to their self-propagating behavior with respect to substantially new functions, their carrying capacity demonstrated a parallel path with an increase in the cumulative number. The broad "allowance" or distance between these trend lines occurred over the period 1991–1994 corresponding to the initial stagnation in the cumulative number of Japanese word processors. This may suggest that personal computers have been developing in a "co-evolutionary" way with the same producers switching production from word processors to personal computers. The recent development of broadband network access services such as cable TV, Internet and DSL should further stimulate the diffusion of personal computers.

3.1.6. Cellular telephones[5]

Though cellular telephones have a relatively young history compared with that of the other products, the continuous development of smaller and lighter handsets with a variety of functions has made their diffusion process rather complicated and swift. One of the

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[5] Cellular telephones include personal handy-phone systems (PHS) and automobile phones.

Table 2
Comparison of the fit of logistic growth function within a dynamic carrying capacity for the diffusion process of six innovative goods

	K_K	a	b	a_K	b_K	Adj. R^2	DW
Refrigerators	51,884,200	31.793	0.177	0.181	0.175	.999	0.09
	(121.66)	(0.96)	(29.46)	(0.17)	(26.17)		
Fixed telephones	60,948,330	4.177	0.155	0.026	0.155	.997	0.18
	(56.85)	(12.60)	(23.14)	(10.41)	(23.11)		
Japanese word processors	11,849,440	1.207	0.722	0.163	0.721	.997	0.75
	(78.27)	(1.10)	(17.40)	(3.51)	(17.24)		
Color TV sets	94,780,600	470.330	1.011	6.203	0.121	.999	0.38
	(71.91)	(2.01)	(9.68)	(22.36)	(31.74)		
Personal computers	172,329,500	1947.517	0.180	34.996	0.045	1.000	0.20
	(5.88)	(7.27)	(49.33)	(7.06)	(17.93)		
Cellular telephones	157,768,400	3.371	0.182	4.038	0.022	1.000	0.80
	(8.70)	(7.49)	(19.71)	(8.13)	(15.50)		

Parameters are indicated in the following function:

$$f(t) = \frac{K_K}{1 + a\,\exp(-bt) + \frac{ba_K}{b-b_K}\exp(-b_K t)}$$

Figures in parentheses indicate t-value.

breakthroughs was NTT DoCoMo's introduction of *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.[6] Furthermore, Java-compatible handsets have been available since January 2001. They are expected to induce a further increase in carrying capacity. Reflecting this structure, the cumulative number of cellular telephones has maintained a constant increase and their carrying capacity has increased in parallel with the increase in the cumulative number keeping a certain-fixed distance between the two trends. In contrast to the distance between carrying capacity and cumulative number in personal computers, this "allowance" is fixed demonstrating a striking self-propagating feature with respect to functionality development.

3.2. Interpretation

Table 2 compares the fit of the logistic growth function within a dynamic carrying capacity for the diffusion process of six innovative goods: refrigerators, fixed telephones, Japanese word processors, color TV sets, personal computers and cellular telephones.

Looking at Table 2, we note the following findings with respect to the behavior of a dynamic carrying capacity of these innovative goods.

(i) Table 2 demonstrates all indicators are statistically significant for six products examined except refrigerators' t-values on a and a_K.

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

(ii) The adjusted R^2 demonstrates that the logistic growth function within a dynamic carrying capacity represents the actual diffusion behavior of six innovative goods in the market place.

(iii) Parameters a_K for refrigerators, fixed telephones and Japanese word processors are extremely small values in comparison to the values for color TV sets, personal computers and cellular telephones. This demonstrates that the epidemic behaviors of the first three innovative goods are similar to the behavior of simple logistic growth, while the epidemic behaviors of the latter three products are with a dynamic carrying capacity. In particular, a_K for refrigerators is statistically insignificant and the value of this coefficient for fixed telephones is extremely small. These further demonstrate that the epidemic behaviors of refrigerators and fixed telephones are similar to typical simple logistic growth.

(iv) Among the three innovative goods within a dynamic carrying capacity, the value of coefficient b for color TV sets is more than five times higher than personal computers and cellular telephones. This implies that, while the diffusion of color TV sets has developed with a dynamic carrying capacity, its level is approaching a ceiling or upper limit.

(v) In contrast to the diffusion of color TV sets, the allowances between the diffusion level and the ceiling for personal computers and cellular telephones are still unlimited as the values of coefficients b are small enough and also their diffusion rates are high enough.

(vi) All statistical interpretations correspond to the observations illustrated in Figs. 3–8.

In order to further demonstrate the significance of a dynamic carrying capacity for these three products, Table 3 compares the fit of the three epidemic functions for the diffusion process of these products. Table 3 also compares the AIC of the three functions for the respective innovative goods.

Looking at Table 3, we note the following with respect to the identification of epidemic behavior for color TV sets, personal computers and cellular telephones:

(i) The AIC demonstrates that the logistic growth function within a dynamic carrying capacity fits better than a SLF for these three innovative goods.

(ii) While the AIC suggests that the logistic growth function within a dynamic carrying capacity demonstrates a better fit than bi-logistic growth for cellular telephones, bi-logistic growth demonstrates a better fit than the logistic growth function within a dynamic carrying capacity for color TV sets and personal computers.

(iii) This implies that while color TV sets have provided viewers with new functionality, these new functions are limited, and personal computers have been developing in a co-

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Notes to Table 3:
Parameters are indicated in the following functions, respectively.

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

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

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

Figures in parentheses indicate t-value.

Table 3
Comparison of the fit of three epidemic functions for the diffusion process of six innovative goods

Color TV sets

(1)	K	a	b				Adj. R^2	DW	AIC
	86,976,510	11.398	0.161				.993	0.13	1.233E + 13
	(41.87)	(10.02)	(17.86)						

(2)	K_1	a_1	b_1	K_2	a_2	b_2	Adj. R^2	DW	AIC
	38,029,280	25.458	0.463	45,781,570	440.420	0.288	.999	0.29	1.165E + 12
	(72.59)	(4.76)	(13.73)	(143.25)	(3.50)	(18.84)			

(3)	K_K	a	b	a_K	b_K		Adj. R^2	DW	AIC
	94,780,600	470.330	1.011	6.203	0.121		.999	0.38	1.314E + 12
	(71.91)	(2.01)	(9.68)	(22.36)	(31.74)				

Personal computers

(1)	K	a	b				Adj. R^2	DW	AIC
	39,716,890	137.844	0.115				1.000	0.18	3.517E + 11
	(29.10)	(12.08)	(33.32)						

(2)	K_1	a_1	b_1	K_2	a_2	b_2	Adj. R^2	DW	AIC
	26,403,230	183.897	0.144	26,403,250	2,668,028	0.263	1.000	0.29	7.564E + 10
	(31.18)	(12.55)	(37.33)	(31.18)	(2.80)	(37.56)			

(3)	K_K	a	b	a_K	b_K		Adj. R^2	DW	AIC
	172,329,500	1947.517	0.180	34.996	0.045		1.000	0.20	1.250E + 11
	(5.88)	(7.27)	(49.33)	(7.06)	(17.93)				

Cellular telephones

(1)	K	a	b				Adj. R^2	DW	AIC
	80,824,020	2.743	0.044				1.000	0.08	1.241E + 12
	(36.69)	(37.18)	(24.71)						

(2)	K_1	a_1	b_1	K_2	a_2	b_2	Adj. R^2	DW	AIC
	39,420,150	1.278	0.114	39,420,160	41.825	0.082	1.000	0.62	6.140E + 10
	(78.66)	(53.53)	(31.65)	(79.41)	(19.94)	(55.48)			

(3)	K_K	a	b	a_K	b_K		Adj. R^2	DW	AIC
	157,768,400	3.371	0.182	4.038	0.022		1.000	0.80	6.007E + 10
	(8.70)	(7.49)	(19.71)	(8.13)	(15.50)				

evolutionary way with workstations and/or traditional technology primarily with the advanced type of word processors.

4. Identification of IT features with respect to institutions

4.1. Functionality development by self-propagating behavior

These analyses demonstrate that innovative goods such as personal computers and cellular telephones match the logistic growth function within a dynamic carrying capacity. This suggests that the behavior of a dynamic carrying capacity has some relevance in terms of IT functionality development.

Eq. (vi) in Section 2.2 demonstrates that the dynamic carrying capacity $K(t)$ increases together with the increase of the number of adopters (customers) $f(t)$ as time goes by. The increase in $K(t)$ induces $f(t)$, which in turn activates interactions with institutions leading to an increase in potential customers (carrying capacity) by increasing the value and function stimulated by network externalities. This dynamism can be depicted as a mechanism illustrated in Fig. 9. Thus, functionality is assumed to be formed in this interactive process.

Therefore, we postulate that IT creates new demand in the course of this development process. Specific functionality is formed in this interaction of users and this functionality is then found to be useful by other users. This results in continued use and further functionality develop. Thus, the behavior is self-propagation.

In order to demonstrate this postulate, we attempted to decompose the contribution factors of the total factor productivity (TFP) increase. Following Nadiri and Schankerman [29], and introducing technology stock as a source of the impact of direct and indirect technology change, the change rate of TFP was developed into the following equation [30]:

$$\dot{\mathrm{TFP}} = (1-k^{-1}\eta)\dot{F}_{\mathrm{d}} - (1-k^{-1}\eta)\psi\eta\sum_i s_i\dot{P}_i + (1-k^{-1}\eta)\eta^2(\psi-1)k^{-1}\frac{\partial V}{\partial T}\frac{T}{V}\dot{T} + k^{-1}\eta\frac{\partial V}{\partial T}\frac{T}{V}\dot{T} \qquad \text{(viii)}$$

where V: GDP; F_{d}: final demand; T: technology stock; P: factor's price; $S_i\frac{P_iX_i}{PV}$; X_i: factor i's quantity; η: production elasticity to cost; e: elasticity to production; $\psi = \frac{e}{1-e(1-\eta)}$; k: profit ratio $\left(=\frac{PV}{C}\right)$; and C: total cost.

The first term represents the impacts of an exogenous shift of product demand, the second term represents the impacts of change in factor prices, and the third and the fourth terms represent the impacts of indirect and direct technology change, respectively.

Fig. 10 illustrates the correlation between IT intensity[7] and the contribution of the exogenous shift of product demand increase to the TFP increase in major sectors of Japan's

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[7] See Appendix A for measurement of IT intensity.

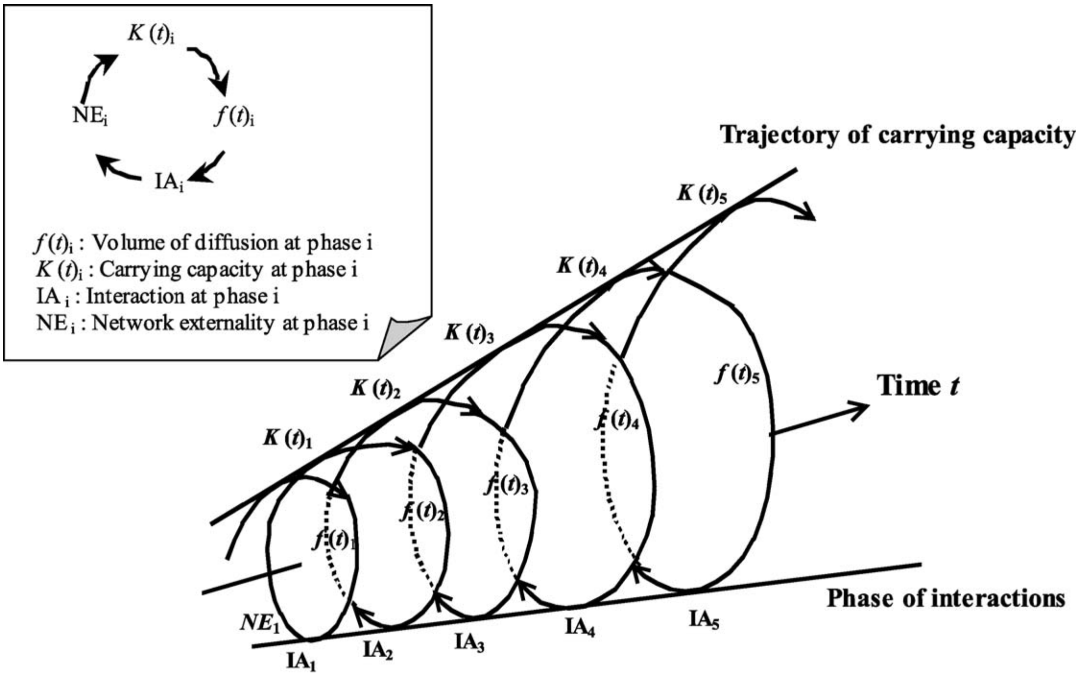

Fig. 9. Mechanism in creating a new carrying capacity in the process of IT diffusion.

manufacturing industry over the period 1995–1998. Fig. 10 demonstrates a significant correlation between them.

Therefore, this analysis indicates that IT creates new demand, which induces a TFP increase leading to a spiral development as illustrated in Fig. 11.

Under the condition of a profit ratio = 1 ($PV = C$), the first term of Eq. (viii), the impacts of an exogenous shift of product demand can be expressed by the product of production[8] elasticity to price and the change rate of final demand as follows:

$$(1 - k^{-1}\eta)\dot{F}d = -(\partial P/\partial V)/(V/P)\dot{F}d \tag{ix}$$

Provided that both production elasticity to price and the change rate of final demand are subject to the flexibility of institutions, Eq. (ix) suggests that the impacts of an exogenous shift of product demand are subject to institutional elasticity as well. Table 4 indicates a strong correlation between the two factors examined. All these analyses demonstrate that institutional elasticity plays a significant role in the creating of demand through IT's development process. This leads to a new carrying capacity and the subsequent self-propagating behavior.

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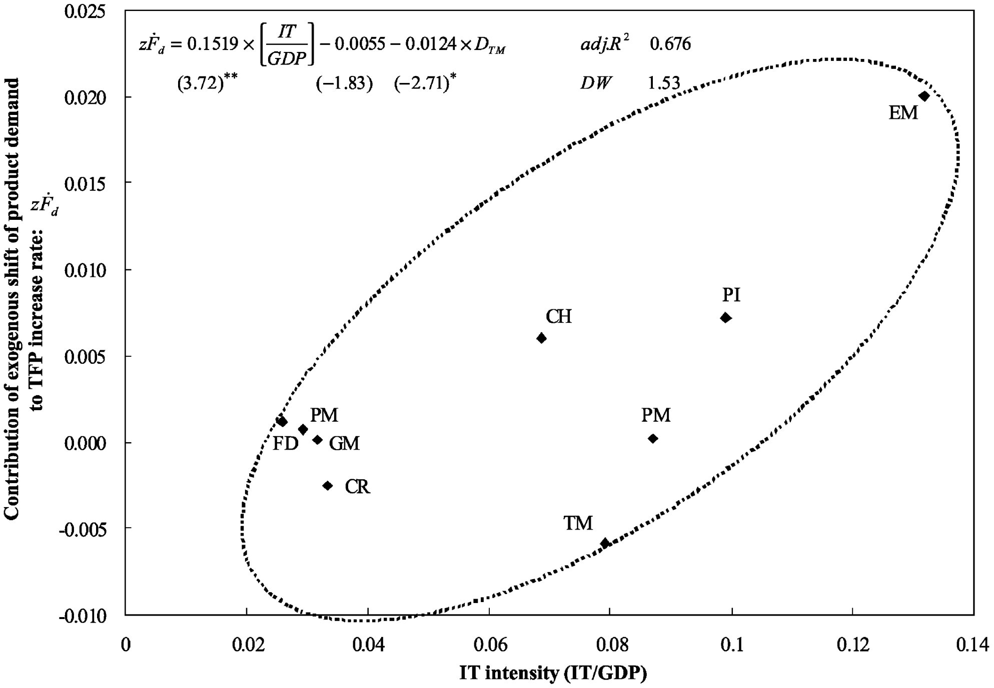
[8] The "productivity standard principle" introduced in 1969 made significant contribution to Japan's success in attaining sustainable growth without inflation by controlling the wage increase not higher the level of productivity increase. This success can be attributed to Japan's elastic relation between wages increase and productivity increase.



a $z \equiv 1 - k^{-1}\eta$ where k: profit ratio; and η: production elasticity to cost.

b ** and * indicate statistically significant at 1% and 5%, respectively

c EM: electrical machinery; PI: precision instruments; CH: chemicals; PM: primary metals; TM: transportation equipment; GM: general machinery; CR: ceramics; PP: pulp and paper; and FD: food.

d D_{TM} : dummy variable

Fig. 10. Correlation between IT intensity and TFP increase through creation of final demand in Japan's manufacturing industry (1995–1998).

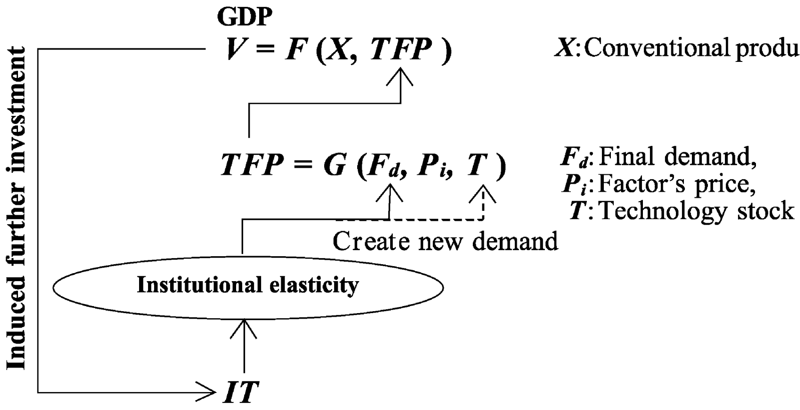


Fig. 11. Self-propagating structure of IT.

Table 4
Comparison between "TFP increase through creation of final demand" and "institutional elasticity" in Japan's electrical machinery (1975–1996)

	1975–1986	1987–1990	1991–1996
TFP increase through creation of final demand (% p.a.)	5.49	6.05	2.99
Institutional elasticity	0.55	0.67	0.21

TFP increase through creation of final demand is measured by contribution of exogenous shift of product demand to TFP increase rate.
Institutional elasticity is measured by institutional elasticity indicator in terms of wage elasticity to labor productivity.

4.2. Features of IT

As explored in Section 2.2, personal computers and cellular telephones are technologies that matched the logistic growth function within a dynamic carrying capacity. This supports the contention that these technologies are self-propagating because of the nature of their interactivity. Consequently, IT's epidemic behavior closely interrelates with the continuous increase in the number of potential users. This means that during the course of diffusion, IT interacts with individuals, organizations and society as a whole, dynamically transforming its functionality and extending potential users in line with these newly acquired features. Furthermore, this characterizes the unique diffusion process of IT in that it alters the carrying capacity or creates a new carrying capacity in the process of its diffusion, thereby acquiring new specific features.

As Fig. 12 shows, IT's diffusion process is stimulated by an interaction with institutions and institutional change is also stimulated by an interaction with IT, leading to a co-evolution of the technology itself and institutions. In this process, rising technology value increases the number of potential users and a "virtuous cycle" results.

This behavior indicates that IT behaves differently because of some unique features facilitated by the institutions involved in the innovation process. Whether a nation can fully exploit the benefits of IT greatly depends on the nation's institutional ability to flexibly respond and adopt this technology given its unique features. In other words, "institutional elasticity"[9] affects the nation's ability to reap the benefits of IT creating, competitive advantage [27]. This is due to the following characteristics of IT.

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[9] Institutional elasticity in terms of wage elasticity to labor productivity ($\Phi_{\mathrm{pl},V/L}$) is measured by developing the following technology incorporated constant elasticity of substitution (CES) type production function (see details in Ref. [27]):

$$V = F(t, L(T), K(T))$$

where V: GPD, t: time trend, L: labor, K: capital and T: technology stock.

$$\Phi_{\mathrm{pl},V/L} = \frac{\partial(V/L(T))}{\partial P_{\mathrm{l}}}\frac{P_{\mathrm{l}}}{V/L(T)} = \frac{\partial \ln(V/L(T))}{\partial \ln P_{\mathrm{l}}} = \sigma\frac{1}{\left[\frac{1-\delta}{\delta}\right]^{\sigma}\left[\frac{P_{\mathrm{l}}}{P_{\mathrm{k}}}\right]^{1-\sigma}+1}$$

where P_{l}: labor prices (wages), P_{k}: capital prices, σ: elasticity of $K(T)$ substitution for $L(T)$ and δ: capital distribution.

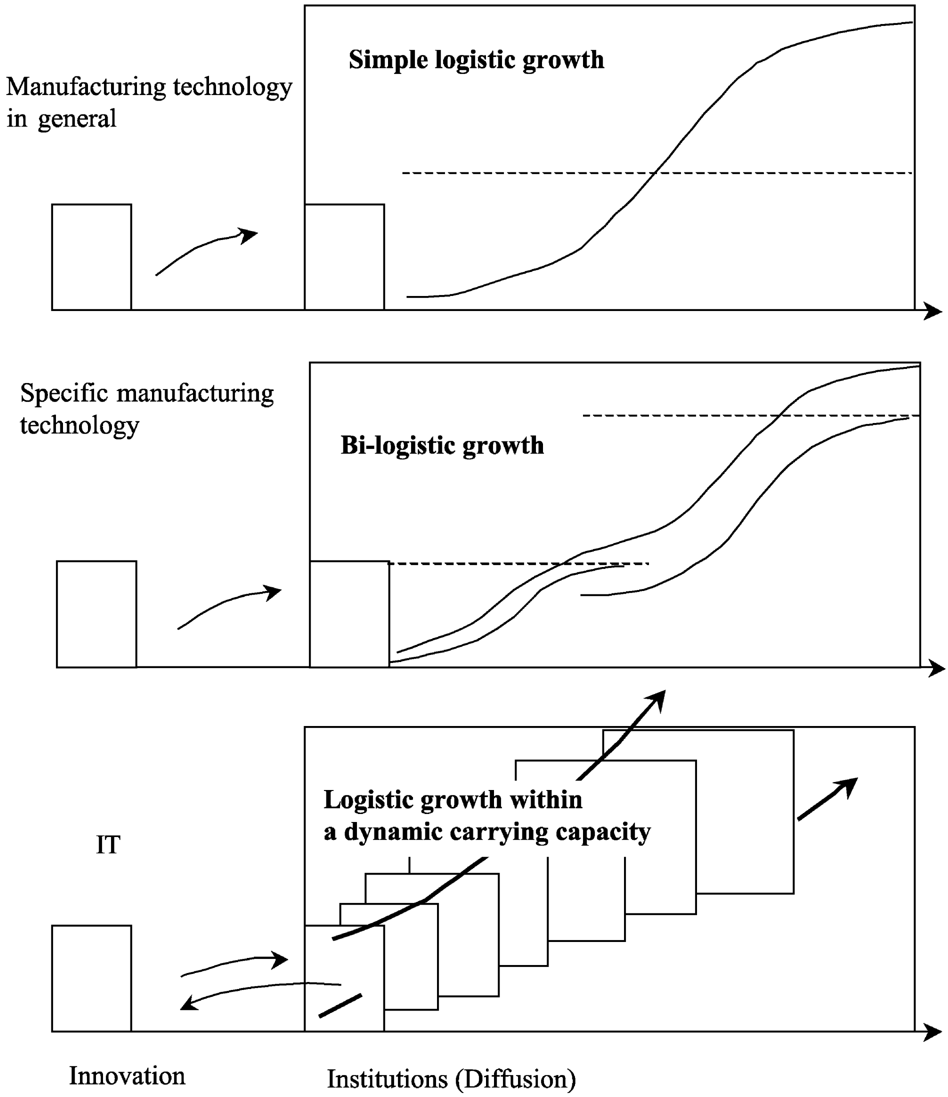

Fig. 12. General concept of technology diffusion process—comparison between manufacturing technologies and IT.

4.2.1. Disseminative

This is represented by the logistic growth function within a dynamic carrying capacity. The dynamic evolution of a carrying capacity can be directly connected to a disseminative feature of IT. The rapid development of IT together with network externalities enable IT-related products and services to disseminate rapidly. In this context, appropriately judging the surrounding environment and quickly commercializing new products and services are crucial for survival in an information society [31]. The increasing significance of global technology spillover is important in this context [32].

4.2.2. Interactive

The leading product in the IT industry is now shifting from personal computers to networks [33]. Each time people use networks to communicate or exchange information, they actually interact with IT and the phenomena of network externalities pushes up the carrying capacity raising the value of networks through the interaction between people and IT. Accordingly, the interactiveness of IT is an important feature explaining this unique behavior.

Inside organizations, the interactive nature of IT improves the efficiency of the decision making process and induces the structural transformation of organizations from hierarchical to networked [3]. In order to exploit the potential benefits of IT, a reorganization of work that introduces new work practices is required [34].

4.2.3. Co-evolutional

As Figs. 9 and 12 illustrate, IT and institutions evolve together during the course of their interaction. IT diffuses throughout the society as a type of social infrastructure and transforms the economic, 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 [34]. In this context, the most effective way to maximize the benefits of IT should be the evolution of the society itself as technological development proceeds. Institutional elasticity enables these features to continually transform business practice.

4.3. Implications

The above analyses indicate that IT stimulates interactivity, which increases its own carrying capacity during the diffusion process. In other words, if a nation's indigenous institutions can react flexibly to incorporate IT, the diffusion process of IT is accelerated and the nation can exploit the potential benefits of IT, resulting in enhanced international competitiveness. Thus, institutional elasticity and the self-propagating native of IT construct a subtle cycle increasing a nation's ability to compete and thus creating a more competitive position in the world.

Although Japan's institutional system has lost its elasticity in the shift from an industrial society to an information society [27], its potential for change remains.

A good example can be found in the case of the mobile Internet access service represented by NTT DoCoMo's i-mode, which achieved remarkably rapid diffusion within just a few years after its inauguration as described in Section 3. Under the condition that Japanese indigenous characteristics such as tend to react solidly to accepting unknown systems, the exceptional diffusion of the mobile Internet access service demonstrates the potential flexibility in despite homogeneity and a preference for stability [35–37] Japanese institutions. This product was successful because of the following institutional factors.

4.3.1. Prior experience in similar services

When i-mode service was started in February 1999, the Internet was already popular in Japan.[10] People recognized the convenience of exchanging e-mail and obtaining the information via the Internet. That is, the mobile Internet access service itself was not a completely unknown system and people were less reluctant to accept it. Increased convenience brought by the "anytime, anywhere" feature of mobile communications seemed to further expanded the diffusion.

4.3.2. Familiarity with the equipment

There were already 40.5 million cellular telephone users when i-mode service was inaugurated. Since the i-mode service was provided as an optional service to the cellular telephone, people could enjoy the service through cellular handsets with simple and familiar operations as they in addition to making calls.

The feeling of "being the same" as others seemed to accelerate the diffusion of i-mode and further enhanced the value of the service. One implication is that if some familiarity is provided, institutional elasticity in Japan can stimulate the self-propagating features of.

5. Conclusion

The effective utilization of IT in an information society will differ greatly depending on structural differences in different countries. In particular, the elasticity or flexibility of institutions in the national innovation system is critical. Furthermore, the specific functionality of IT is developed through interactions with flexible institutional systems. This paper attempts to explain this process by focusing on the unique diffusion process, or epidemic behavior of IT.

First, through the mathematical analysis of the diffusion process of innovations with self-propagating behavior, the mechanism in creating a new carrying capacity in the process of IT diffusion was conceptualized.

Second, using this conceptualized mathematical model, an empirical analysis of the diffusion process of innovative goods in Japan was conducted using refrigerators, fixed telephones, Japanese word processors, color TV sets, personal computers and cellular telephones, which represent innovative goods across a spectrum from monofunction to multifunction products. Through a comparative analysis of epidemic behavior between these technologies, it was demonstrated that innovative goods with higher "IT density" matched the logistic growth function within a dynamic carrying capacity. These analyses demonstrated that the specific functionality of IT is formed through dynamic interaction with an institutional system.

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[10] Internet penetration rate in enterprises was 80.0% and in households was 11.0%, respectively, in Japan as of 1998 [23].

Third, on the basis of the framework on IT functionality development, an empirical analysis of Japan's manufacturing industry using a new approach to decomposing the factors of TFP was developed. This postulated that IT creates new demand in its development process and specific functionality is formed in this interactive system. In addition, an empirical analysis of the correlation between this new demand creation and institutional elasticity showed a strong correlation and demonstrated that institutional elasticity plays a significant role in IT functionality development. Furthermore, on the basis of these analyses, certain IT qualities enabling this self-propagating behavior were identified and discussed. These unique qualities critical to enhancing the epidemic behavior observed depend on institutional flexibility to "capture" the potential of IT.

These findings remind us of the significance of the role of institutional elasticity in making full utilization of IT and also the urgency of recreating institutional elasticity in Japan. Further analysis is required to fully elucidate critical success factors in US and Japanese businesses by contrasting the institutional systems of the two nations.

Appendix A. Data construction and sources

A.1. TFP and IT intensity

In order to measure TFP and IT intensity, the following production function was used:

$$V = F(L, K, I, T, t)$$

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.[11]

IT production factor was constructed using the data from the Ministry of International Trade and Industry's (MITI)[12] "Current Status of Japanese Information Processing," which referred the "Survey on Information Processing in Japan" by Japan Information Processing Development Center. "Capital Matrix of the Input–Output Tables" was also used to supplement the IT-related investment that is not covered by the Survey. The resultant IT production factor is explained by the IT-related investment listed in Table A1-1.

A.2. Epidemic behavior

In the analysis of the epidemic behavior of six innovative goods, trends in the cumulative number of adopters were analyzed using an epidemic function.

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[11] See Ref. [38] for data construction and sources for L, K and T.

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

Table A1-1
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

Provided that the ’pregnancy’ period is short enough to neglect this timing and the depreciation rate can be treated as a reverse of the lifetime, the cumulative number is measured by the following equation:

$$N_t = P_t + (1 - \rho)N_{t-1}$$

$$N_0 = \frac{P_1}{g + \rho}$$

$$\rho = \frac{1}{\mathrm{LT}}$$

where N_t: cumulative number of adopters at time t; P_t: number of shipment for domestic use at time t; g: increase rate of production in the initial period; ρ: depreciation rate; and LT: life time (average years in use).

A.2.1. Refrigerators (1951–1999)

The annual shipment volume of refrigerators from the year 1951 to 1999 was obtained from the “Report on Machinery Statistics” (MITI, annual issues). Since the ratio of imports and exports of refrigerators to their shipment as a whole has not been changing greatly, the annual shipment volume was used for the analysis.

The depreciation rate was measured by multiplying the rate of obsolescence of technology in the electrical machinery industry [38] and the ratio of depreciation rate of refrigerators (“Consumer Confidence Survey” (Cabinet Office, 1998–2001)) and electrical machinery industry in 1998.

A.2.2. Fixed telephones (1953–1999)

The cumulative number of fixed telephones subscribers from 1953 to 1999 was obtained from NTT’s annual reports.

A.2.3. Japanese word processors (1982–1997)

The annual domestic production volume of Japanese word processors from the year 1982 to 1997 was obtained from “Industry in Japan: A Graphical Look at 1626 Goods and Services” (Development Bank of Japan, Economic and Industrial Research Department, 1999).

The depreciation rate was measured by multiplying the rate of obsolescence of technology in the electrical machinery industry [38] and the ratio of depreciation rate of Japanese word processors ("Consumer Confidence Survey" (Cabinet Office, 1998–2001)) and the electrical machinery industry in 1998.

A.2.4. Color TV sets (1966–2000)

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

The depreciation rate was measured by multiplying the rate of obsolescence of technology in electrical machinery industry [38] and the ratio of depreciation rate of color TV sets ("Consumer Confidence Survey" (Cabinet office government of Japan, 1998–2001)) and electrical machinery industry in 1998.

A.2.5. Personal computers (1987–2000)

The 32-bit personal computer was analyzed as the PC. The quarterly shipment of the 32-bit PC for domestic use from 1987 to 2000 was obtained from the "Personal Computers Statistics" (JEITA, annual issues).

The depreciation rate from 1998 to 2000 was estimated 20% p.a. by using the reverse of legal life time defined by the Corporate Tax law. The rate before 1998 was measured by multiplying the rate of obsolescence of technology in electrical machinery industry [38] and the ratio of depreciation rate of PC and electrical machinery industry in 1998.

A.2.6. Cellular telephones (1996–2001)

The cumulative number of cellular telephones contracts from September 1996 to March 2001 (monthly statistics) was obtained from monthly reports issued by Telecommunications Carriers Association (TCA).

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