Mechanism of Diffusion of Fixed-Line Broadband Access Services in Japan and its Application to Long-Term Growth Prediction - Rapid Diffusion in Urban Areas -

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Abstract

This paper studies the diffusion of broadband access services in Japan. The long-term prediction results of ordinary growth curve models are not so robust. This seems due to the singularity, in the sense of analytic function theory, of the infection point of the growth curve. The growth curve is downward convex in the early adopter phase whereas the growth curve is a logarithmic function in the late-comer phase. To develop a new model, this paper focuses on the urban/rural prevalency gap. We show that the shapes of the growth curves among the prefectures are similar whereas the urban/rural prevalency (the prevalence ratio) gaps for late comers are stronger than for early adopters. The behaviors of early adopters and late comers are modeled on basic antisymmetric characteristics of interactions. Early adopters' behaviors are characterized as going to search for information whereas late comers' behaviors are characterized as pulling information from their neighborhood. The downward convexity of the growth in the early adopter phase is deduced from the branching characteristics of the information flow associated with the searching. The logarithmic growth in the late-comer phase is deduced from the modeling of the accumulation of experience, which is the accumulation of the information pulled from the neighborhood. Here, the channel size of the information flow is characterized by the overlap density of the neighborhoods. Using the well-known city-size statistics, the channel size statistics and then the logarithmic growth curve are derived. Through the analyses, we show the mechanism of how urbanizations accelerate the diffusion in the late comer phase. That is, urbanizations cause densely overlapped neighborhoods, which increase the channel size of the information flow. These results indicate that the actions for fostering subscriptions in the early adopter phase may increase the long-term prevalency efficiently.

Keywords: Broadband Access Service, Service Diffusion, Growth Curve, Bass Model, Robustness, Inflection Point, Early Adopter, Late Comer, Urban/Rural Gap, Experience, Interaction, Antisymmetricity, Reversibility, Branching Process, Zipf's Law.

1. Introduction

Factors in the adoption of broadband access services have been given much attention by a number of authors (Aron and Burnstein, 2003; Savage and Waldman, 2004; Nishimatsu et. al., 2005; Clements

and Abramowitz, 2006). On the other hand, the status of the market changes dynamically. Efficient actions should be consistent with these changes, so the understanding of the diffusion mechanism as well as demand prediction (Fildes and Kumar 2002) is important. The diffusion mechanisms of telecommunication services have not yet been elucidated as much as predicting their growth in the long term. That is, the ordinary prediction method for their long-term growths is to apply such growth curves as the logistic model (Verhulst, 1838), the Lotka-Volterra model (Volterra, 1928), the Bass model (Bass, 1969) and their followers' (see, Eliashberg and Lilien, 1993). These applications often provide us with unstable long-term predictions, which Section 2 discusses in detail.

This difficulty in predicting long-term growths seems related to significant urban/rural gaps in the growths of telecommunication services, which are hardly taken into account in those growth-curve models. This paper analyzes the diffusion of the fixed-line broadband access service in Japan by comparing the growths of 47 prefectures in terms of curves' shape and the market phases of early adopters and late comers. The diffusion mechanism is extracted as two models of inter-personal behaviors resulting in subscriptions, which correspond to the two market phases. This modeling enables us to explain the urban/rural gap. This modeling is done with the aide of a basic model describing personal interaction with her/his environment, which is related with the reversibility in the phenomenology (Merleau-Ponty, 1968). A very robust long-term prediction is deduced from the inter-personal behavioral model of late comers and the well-known general characteristics in city-size statistics (Zipf, 1949). These analyses indicate that the actions for fostering the subscriptions in the early adopter phase may increase the long-term prevalence efficiently.

Let us briefly describe the analysis and modeling. Section 2 analyzes the national growth curve. The cause of the lack of robustness for ordinary models is discussed. We show that the inflection point of the growth curve seems singular, which implies that the growth curve cannot be easily expressed by one analytic function. The singularity indicates the level of behavioral difference between two groups of people, which we call early adopters and late comers. We also show that the growth curve is downward convex before the singular point and it can be expressed by a logarithmic function after the singular point. Section 3 analyzes urban/rural gaps among the prefectural growth curves. We show that the increasing rates of the prevalency (the ratio of the prevalence to the number of householders) are larger for prefectures with higher prevalencies. This suggests the large regional gaps among the long-term prefectural prevalencies because the increasing rates of the prevalency have been decreasing since 2003. It is also found that the shapes of the growth curves among the prefectures are quite similar and the prevalency ranks among the prefectures are quite stable. These results indicate that the urban/rural gap in the diffusion is

significant for the latecomers rather than the early adopters. In order to represents these analytical results, the following model of diffusion is constructed. Section 4 discusses personal behavior resulting subscriptions and its relationship to the growth curve. Due to an experience-based hypothesis of subscription behavior, the shape of the growth curve $N(t)$ is modeled with respect to the time T to perform a basis resulting in the subscription by the accumulation of the experiences. Section 5 discusses the behaviors of early adopters and late comers in terms of basic antisymmetric characteristics of personal interactions with her/his environment. Early adopters' behaviors are characterized as "going to" search information whereas late-comer behaviors are characterized as "pulling" information from their neighborhood. Based on this, Section 6 considers the interpersonal mechanism of the experience accumulations and deduces the convexity and logarithmic growth. The downward convexity of the growth in the early adopter phase is deduced from the branching characteristics of the information flow. The logarithmic growth in the late-comer phase is deduced from the modeling of the experience growth $E(t)$ as the accumulation of information $E(t) = Ct$. Here the channel size C is determined by the overlap density of the neighborhoods. Then, the channel size C is calculated by the interpersonal mechanism of late-comer behaviors. That is, the channel size C is proportional to the number of people whose neighborhoods overlap each other, the statistical characteristics of which seem to be the same as those of the population size of cities. Finally, using well-known city-size statistics (Zipf, 1949), the channel-size statistics and then the logarithmic growth curve are derived. Through the analyses, we show that the urbanizations cause the neighborhoods of the habitants to become densely overlapped, which increase the efficiency of accumulating experiences in the neighborhoods. This explains the mechanism of how the urbanizations more accelerate the prevalency in the latecomer phase than in the early adopter phase. Section 7 concludes this paper.

2. Singularity in Growth Curve

We begin the analyses from a macroscopic viewpoint. The fixed-line broadband access service in Japan started in 1999, where the major service types are CATV cable, ADSL, and FTTH. We consider the robustness of an ordinary growth-curve model. The well-known Bass diffusion model (Bass, 1969) is applied to subsets of the data consisting of the number of broadband-access service subscribers in Japan during 2000.3- 2006.12 (MIAC, 2007). As shown in Fig. 1, unfortunately, the fitted curve varies significantly if a data subset is replaced by other data subsets. Thus, the model is not robust and then the Bass model cannot be applied to the long-term prediction of the market growth.

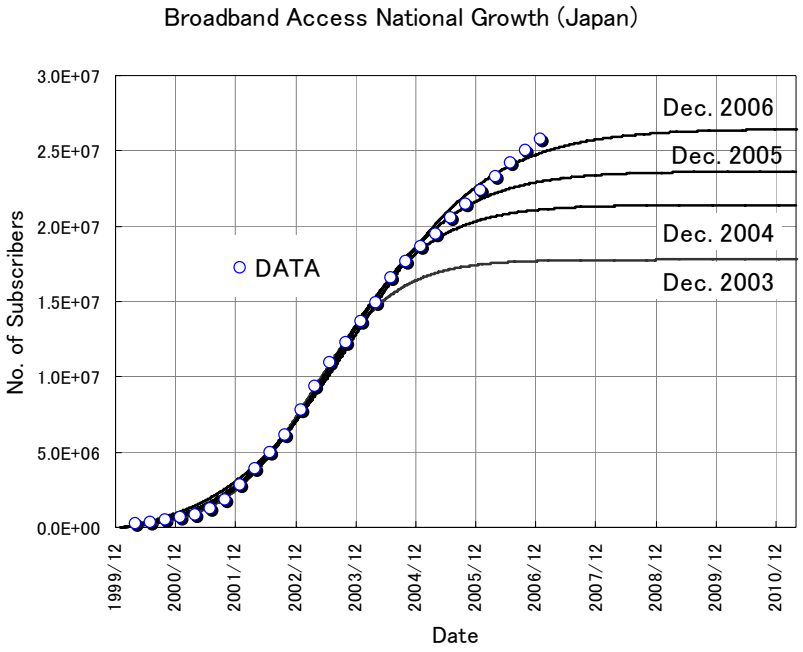


Fig. 1 Long-term prediction by Bass model.

The tags of the curves represent the last point of data used in the fitting

By changing the functions for fitting, we found that, a logarithmic function robustly fits the data after the peak of the growth rates (Shimogawa and Iwashita, 2007), as shown in Fig. 2, where logarithmic functions are fit for subsets of the data after the inflection point, i.e., the peak point of the growth rate curve. Moreover, as shown in Fig. 3, when the logarithmic time axis is taken, the entire growth curve seems strictly convex downward before the peak of the growth rate and highly linear for approximately 5 years after the peak until now.

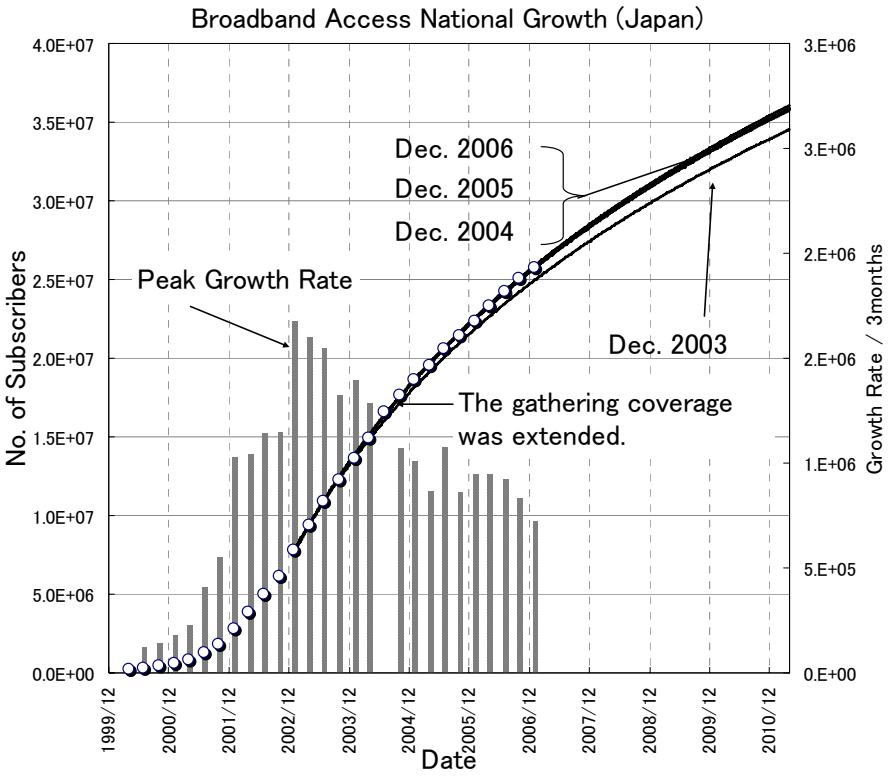


Fig. 2 Long-term prediction by logarithmic function.

The tags of the curves represent the last point of data used in the fitting. Vertical lines express growth rates per 3 months. Because the coverage of gathering has been extended since Dec. 2003, the fit curves shift upward

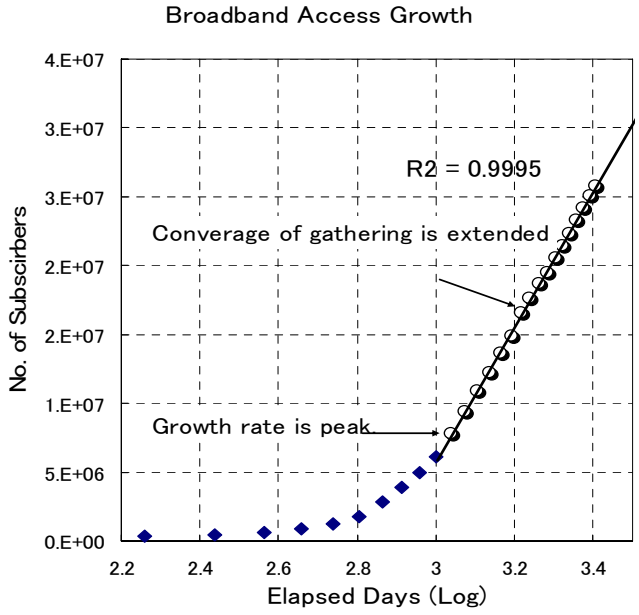


Fig. 3 Shape of growth data in logarithmic time scale.

Fitting by a line is given for the data after the growth rate peak

This result indicates that the peak of the growth rate seems to be not only an inflection point, which means the point of the convexity change, but also a singular point. Here a singular point of a curve means there is no such analytic function defined around the point that represents the curve. It should be noted that a mathematical function is called analytic if it can be represented by a power series at any point of the domain of the function. The singularity of the growth curve at the peak follows from the identity theorem of analytic functions (Ahlfors, 1979). Namely, the identity theorem asserts that an analytic function cannot be strictly convex downward before the peak and linear after the peak.

Because of this singularity of the growth curve, such ordinary growth curve models as those listed in Eliashberg and Lilien (1993) cannot fit the data robustly anymore. This is because ordinary growth curves are analytic on their domain (the time axis half-line). This result indicates that the mechanism of service diffusions has not been revealed yet so that one can explain the growth curve. The following part of this paper tries to make progress in understanding the mechanism.

Here, we note the implications of the analysis above. First, there are two groups of people. Subscriptions of people in one group dominate the growth before the peak whereas those in the other group dominate the growth before the peak. Then, we call these two groups of people early adopters and late comers, although Bass (1969) called them innovators and imitators. There seems to be two different market phases associated with early adopters and late comers. Second, the processes and their interactions resulting in subscriptions must be significantly different between these two groups so that they generate the singularity of the growth curve. Third, the notion of final demand, i.e., the long-term limit of the growth, can hardly play a role because the growth curve of the late-comer phase is a logarithmic function.

A model of the growth curve in Japan is given as follows.

Model of national growth curve

The curve consists of two phases: the early adopter phase and the late-comer phase. The curve grows along a downward convex function $f(t)$ in the early adopter phase and along a logarithmic function $p\log t + q$ in the late-comer phase. The market phase transits from that of early adopters to that of late comers. These two curves are connected by $f(\tau) = p\log\tau + q$.

3. Urban/Rural Gaps in Diffusion of Broadband Access Service

We analyze the diffusion of broadband access service at the prefectural level. If one observes the diffusion of new telecommunication services or media, significant prevalency gaps between urban

areas and rural areas, which can be hardly explained in terms of deployment factors, are easily found. For example, in 1998, high school girls in Osaka, the second largest city in Japan, were quite active in using pagers whereas those in Tokyo (the largest) had moved to PHS already (Shimogawa et. al., 1998). The new media seems to diffuse from metropolitan areas to the provinces. One of the old examples is the diffusion of words (Yanagida, 1943). From this point of view, we investigate regional differences of the diffusion, which we may call a sub-macroscopic (or social) level study.

Let us see how the recent prevalence depends on urbanization. Japan consists of 47 prefectures. In Fig. 4, the prefectures are plotted by the prevalency and concentricity of inhabitants to the urban area of the prefecture, where the prefectural prevalence per the number of families (households) is normalized by the mean size of a household in the prefecture.

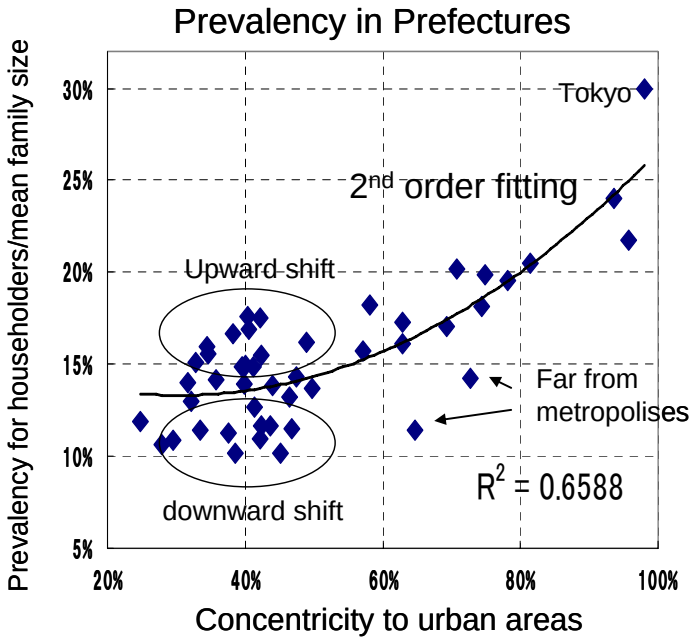


Fig. 4 Dependence of prevalency on concentricity of inhabitants.
The concentricity of a prefecture is defined as the ratio of the population in the urban area to the population of the prefecture (MIAC, 2005). The urban area is defined by the population density as it is larger than 4000/km^2

The prevalence in a prefecture strongly depends on how highly urbanized the prefecture is. In fact, the prevalence in a prefecture strongly depends on the concentricity of habitants to the urban area of the prefecture. In addition, the prevalence of a prefecture shifts upward if the prefecture is closer to the capital (Tokyo) and other metropolises (Osaka and Nagoya). Moreover, upward shifts can be seen with such prefectures in provinces that may maintain the shape of their population pyramids by their industries, jobs, and education, etc. in resistance to the drain of young men to prefectures nearby or inside of metropolitan areas. In this connection, see Fig 5.

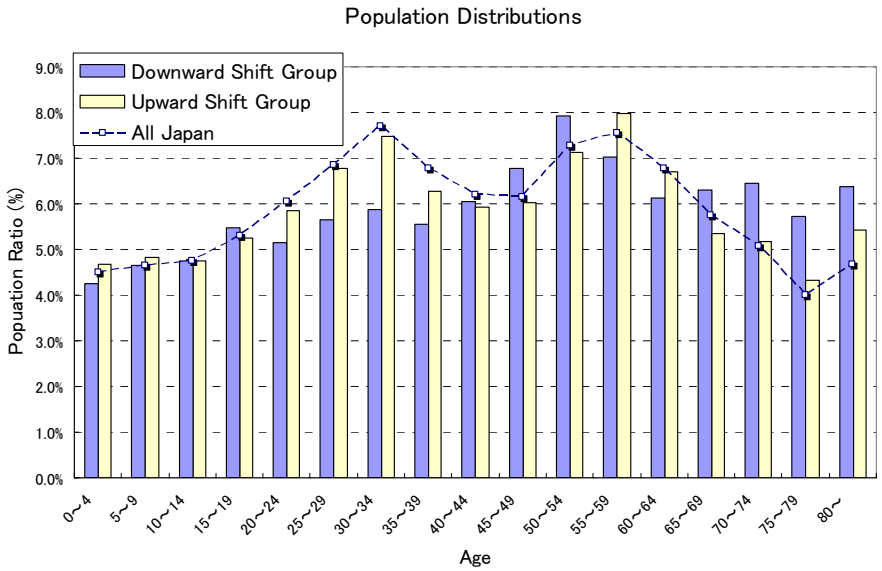


Fig. 5 Population distributions of the prefectures with the upward /downward shift.
Downward shift group represents the distribution of a typical prefecture in the group of downward shift shown in Fig 4 whereas upward shift group represents that of upward shift group

Now let us consider the urban/rural gaps of prevalency from dynamical point of view. For this we compare the growth curves among prefectures. The data of the number of subscribers living in prefectures have been gathered and published on the web by regional government offices (LBT, 2007). However, the gathered data do not cover all subscribers. Because of this, we can analyze the growth curves for a number of prefectures but not all of them. The growth curves for the prefectures that do not lack data points and that have data with a smaller number of missing new subscribers are shown in Fig 6, where the prevalency is measured as the percentage of subscribing householders (families).

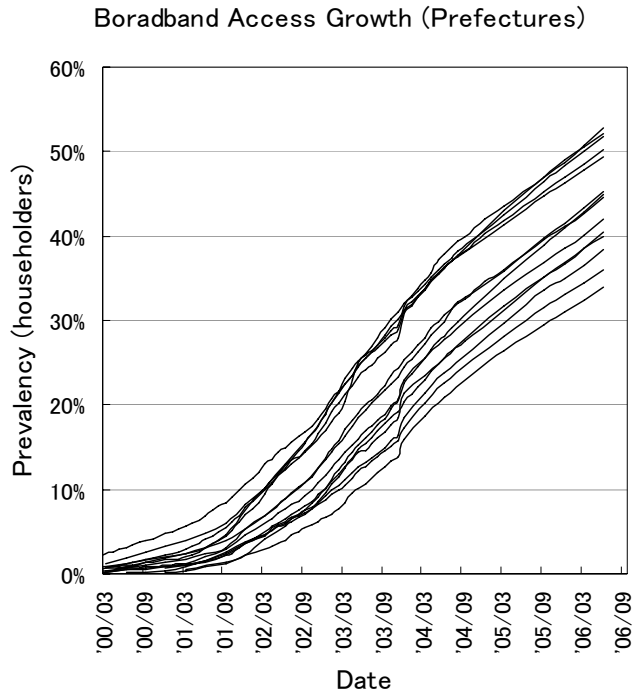


Fig. 6 Growth curves of prefectural prevalency

Let us note observations from the comparisons of these prefectural growth curves. First, the shapes of the prefectural growth curves are very similar. Second, the prevalence ranks of prefectures are quite stable. Third, the prevalence gaps among the prefectures monotonically increase. The last observation is shown in Fig. 7 more clearly, where the prevalency and its growth rate are positively correlated among the prefectures. Fourth, the inflection point seems to occur earlier for prefectures with larger prevalency, which is explicitly shown in Fig. 8.

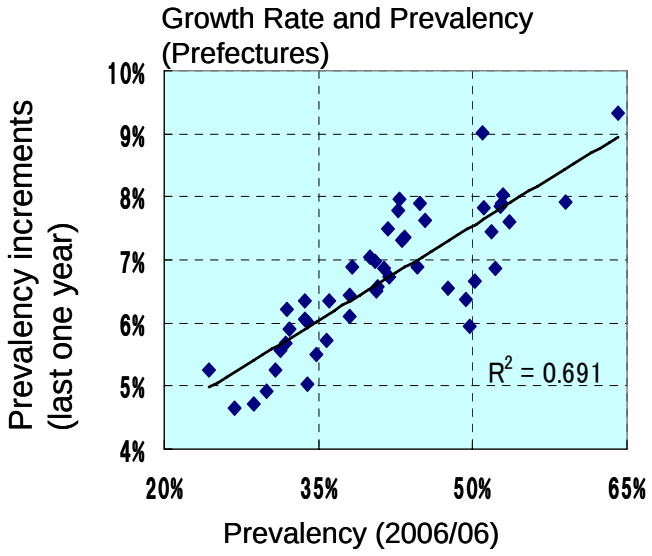


Fig. 7 Dependence of growth rate on prevalency

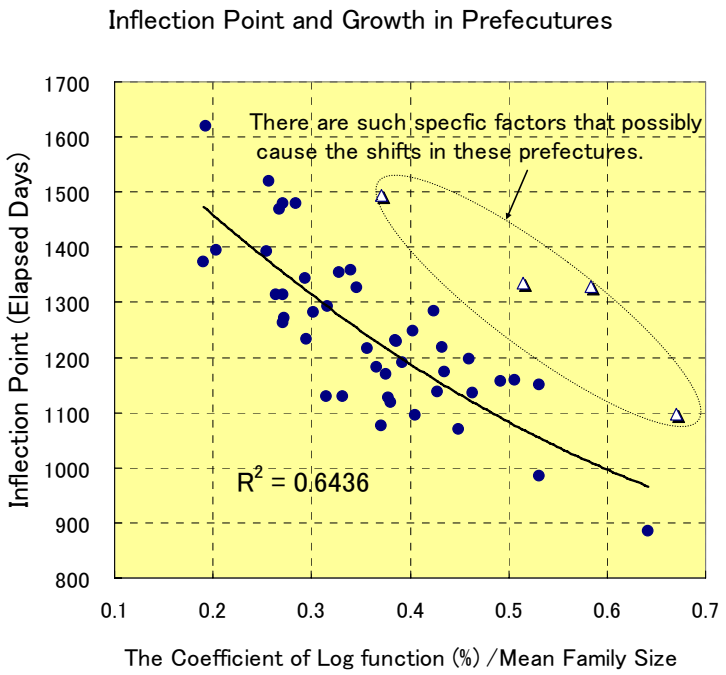


Fig. 8 Dependence of inflection (singular) point on prevalency

Based on the above observations and the national growth curve described in Section 2, let us present a model of the prefectural growth curves.

Model of prefectural growth curves

An individual prefectural growth curve is similar to the national growth curve model, which consists of downward convex function $f_i(t)$ of an early adopter phase and a logarithmic function $p_i \log t + q_i$ of a late-comer phase. Prevalency growth curves $f_i(t)$ are order preserving in the sense that $f_i(s) < f_{j(}s)$ implies $f_i(t) < f_j(t)$ for $s<t$ and that the market phase transition points τ_i come earlier and the coefficients p_i of logarithmic function are larger for the larger growth curves i.e., $\tau_i > \tau_j$ and $p_i < p_j$ if $f_i(t) < f_j(t)$. This model is illustrated in Fig. 9.

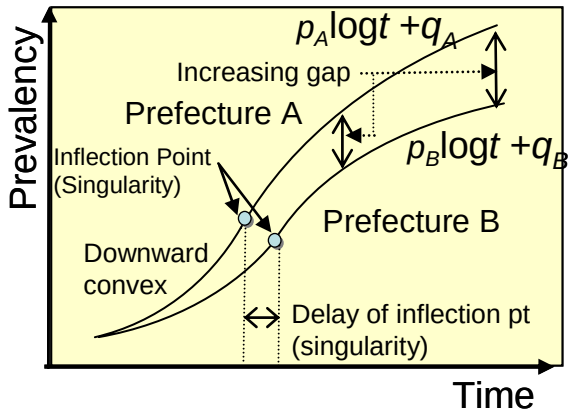
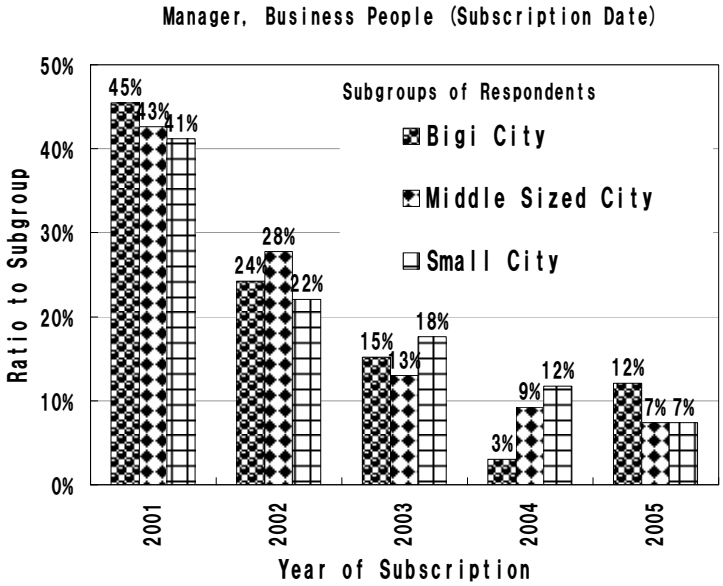


Fig. 9 Prefectural growth curves (model)

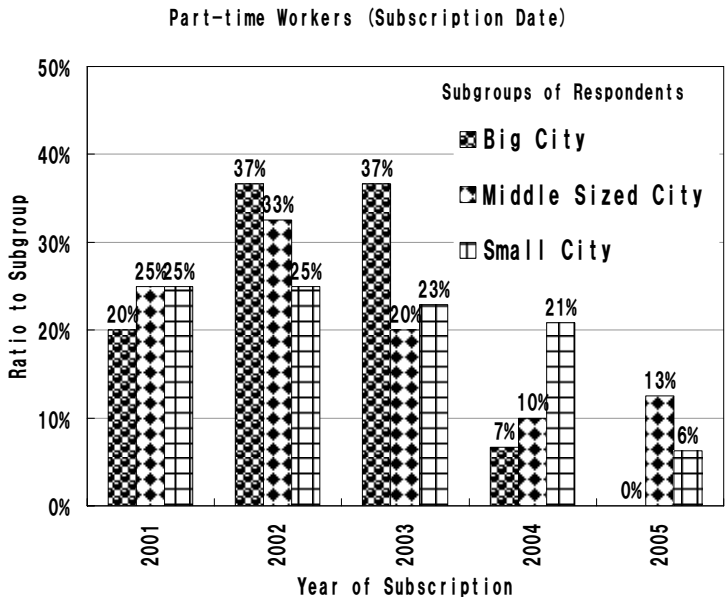
Characteristics of urban/rural gaps in diffusion

On the basis of the characteristics and model of the prefectural growth curves, let us discuss the characteristics of urban/rural gaps in the service diffusion from the viewpoint of its dynamics. First, the urban/rural gap of the prevalence monotonically increases with time. In addition, the start of early adopter phase is not significantly different between metropolises and the provinces whereas the start of the late-comer phase is evidently delayed in provinces. Therefore, the urban/rural gap is more significant for late comers than for early adopters. In other words, the speed of diffusion depends on both the type of people and on the urbanization. For people that adopt new service more slowly, urbanization more accelerates the diffusion.

The faster acceleration by urbanization for late comers can be seen in a questionnaire survey. The results of a questionnaire survey conducted in 2006 are shown in Fig. 10. Two groups of users are chosen in the aggregation. The first group consists of managers and business persons whereas the second group consists of part-time workers. Three types of the cities where the respondents live are considered, i.e., big, medium, and small cities. For the first group, the subscription-time distributions are similar among these types of the cities. On the other hand, for the second group, the time distribution is delayed if the type of city is changed along the direction from big to small.



(a) Manager and business people



(b) Part-time workers

Fig. 10 Urban/rural gaps according to user types (questionnaire survey).

First, the two groups of the respondents of the questionnaire survey are chosen. The group (a) consists of managers and business people and group (b) consists of part-time workers. Then, each group is decomposed into three subgroups by the city size. These graphs show the distribution of the time (date) when the respondents in a subgroup subscribe a broadband access service

4. Hypothesis Bridging Personal Behavior and Prevalency Growth

We shall study personal-level behaviors resulting in subscriptions with the aid of the

macroscopic-level results in Sections 2 and 3. Sections 2 and 3 provide the following questions, which guides our analyses.

Guiding Questions:

- Why are there such singular points in the growth curves dividing subscribers into two groups?
- Why do urbanizations very accelerate late comers' subscriptions?

In order to solve these questions, we should consider basic characteristics of subscription behaviors and its relationship to the shape of growth curves, which is stable among prefectures.

We start with a basic but quite natural hypothesis based on experience.

Personal-level hypothesis: Experience that form basis of subscription

When a person subscribes to (starts to use) a broadband access service, she/he expects benefits or merits of using the service. Her/his expectation should be strong enough to decide her/his subscription. Her/his expectation as well as its intensity is based on the experiences that she/he has had already. This is the experience basis of subscription.

For example, the prevalency of Japanese ADSL access service very rapidly increased in an early stage, as seen in Fig. 11. This rapid increase indicates strong expectations of people of the ADSL service. We guess that these strong expectations seem based on such dial-up users' experiences that they had been frustrated by low speeds, charges by time, and telephone-level-prices, for example. In fact, the characteristics of broadband access services such as high speed, flat-rate charges, and low prices, for example, can be easily understood based on those frustrating dial-up experiences. This guess can be seen in Fig. 12, which is a result of the questionnaire survey conducted in Feb. 2005. On the other hand, the FTTH (fiber-to-the-home) characteristics seem quite different from the experiences of dial-up accesses but similar to those of ADSL accesses. This is consistent with the delayed growth of FTTH, as seen in Fig. 11.

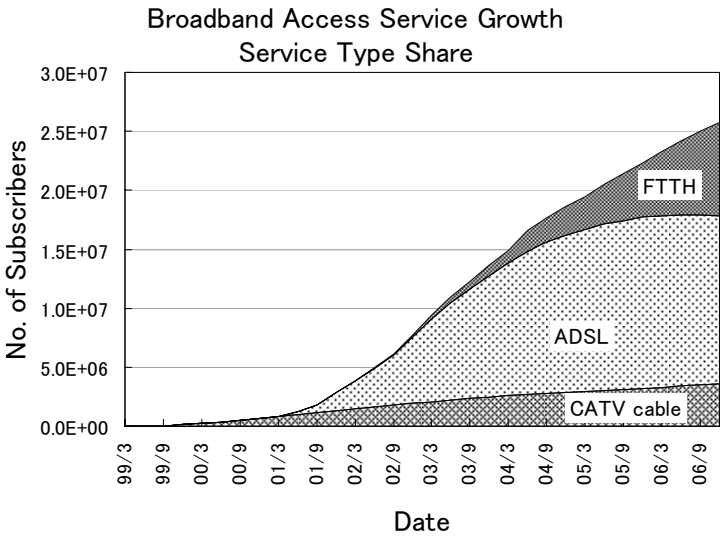
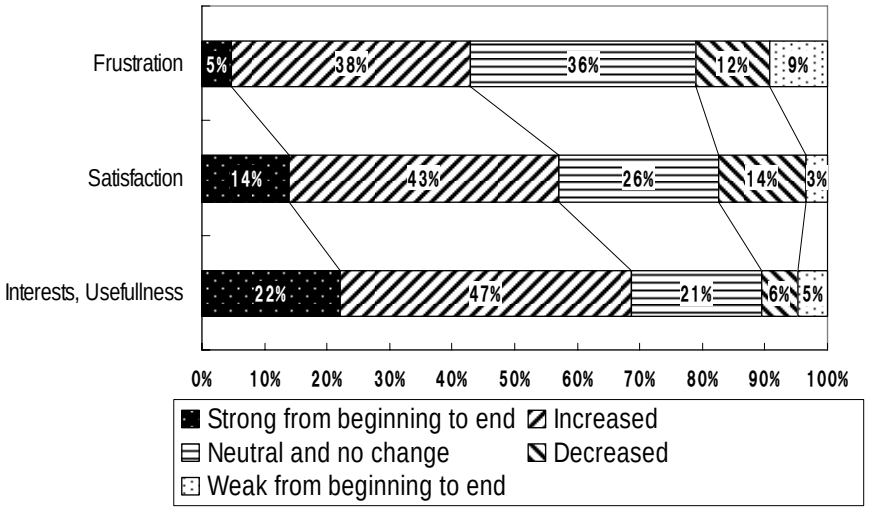
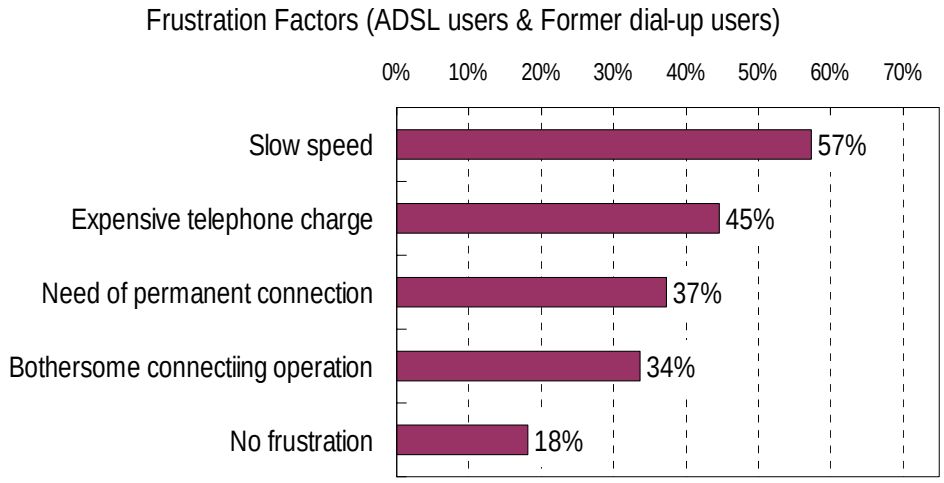


Fig. 11 Market share of individual types of services in growth curve



(a) Changes of frustration, satisfaction, and usefulness through use of dial-up access



(b) Factors of frustration in using dial-up access

Fig. 12 Accumulation of experiences through the use of dial-up internet access (ADSL user & former dial-up user)

As above, a person understands the benefits of a new service as the differences between the new characteristics and the ordinary characteristics that she/he experienced before. We should note that experiences are not only gained by using the Internet. She/he expects her/his benefits based on the experiences gained by various types of behaviors such as communicating with friends, reading books, and studying, for example. In addition, the experiences are also based on previous related experiences, which may be very general.

Time to perform experiential basis of subscription

It takes time for a person to perform the basis of subscription, i.e., to accumulate experiences enough so that the person subscribes (start to use) a new service. This time T to perform the experiential basis seems to characterize the shape of the prevalence growth curves discussed in previous sections. In fact, factors that cause a person to subscribe are possibly divided into two groups. One group of factors consists of changes in herself/himself, which are nothing else but experiences. The other group of factors consists of changes in her/his environment such as price changes, marketing campaign, extensions of coverage, and so on. These environmental factors of course accelerate the service diffusion. However, they can hardly change the shape of growth. The environmental factors are specific to the regions and the time. For example, competitions among companies are quite different among the regions. If company actions change the growth shapes, the shape is not stable among the regions. Now we present an inter-level hypothesis:

Bridging hypothesis:

The shape of the growth curve $N(t)$ of prevalence is characterized by the statistics of the time $T(p)$ according to the equality

$$N(t) \sim \mathrm{Nr}\{p|T(p)>t\},$$

where $T(p)$ denotes the time spent by a person p for accumulating p's experiences enough to perform the basis resulting in p's subscription.

This hypothesis looks like a representation of the growth curve given by Bass (1969) but the meaning is different. Bass's representation is not a hypothesis but a logically deduced equality. On the other hand, this hypothesis specifies the experiences and their accumulation of a person. This is based on the personal-level hypothesis presented above.

5. Antisymmetricity in Interactions and Early Adopters / Late Comers

Let us discuss characteristics in accumulating experiences to perform the basis of subscription with the aid of general characteristics of interactions.

As discussed in Section 2, the prevalency growth curves of early adopters and late comers are significantly different. This significant difference and the shapes of growth curves are stable among prefectures. Moreover, at least two groups of consumers can be seen in various markets. This suggests that the mechanism of generating significant differences may be primitive, which can be described in simple general terms. Let us consider generation of experiences from this point of view.

Two alternative interactions (go/pull-type)

One's experience is generated by her/his interactions with her/his environment. We shall discuss basic characteristics of interactions. Consider that a person is in a place. She/he has generated complex relationships with her/his surroundings, which performs her/his current neighborhood. Now, consider the situation in which an entity (e.g., item) is placed near but outside of the neighborhood, and then, she/he starts to interact with the entity. See Fig. 13. There are only two alternative cases. In one case, she/he exits from her/his neighborhood and goes to interact with the entity (the *go-type* interaction). In the other case, she/he reaches out and pulls the entity into her/his neighborhood (the *pull-type* interaction).

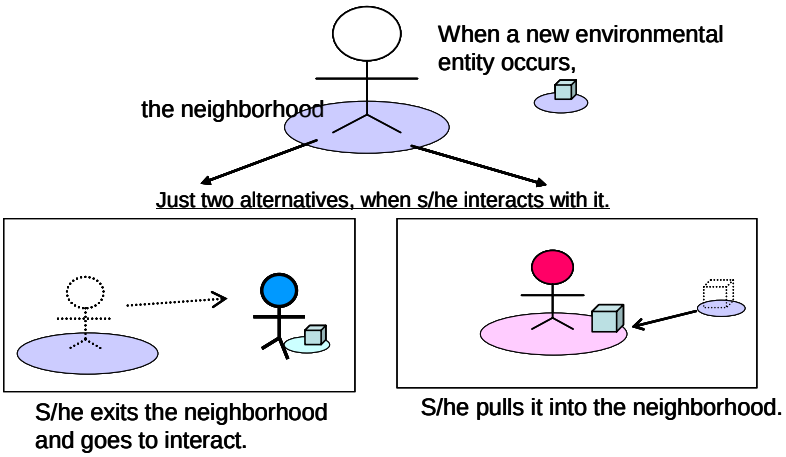
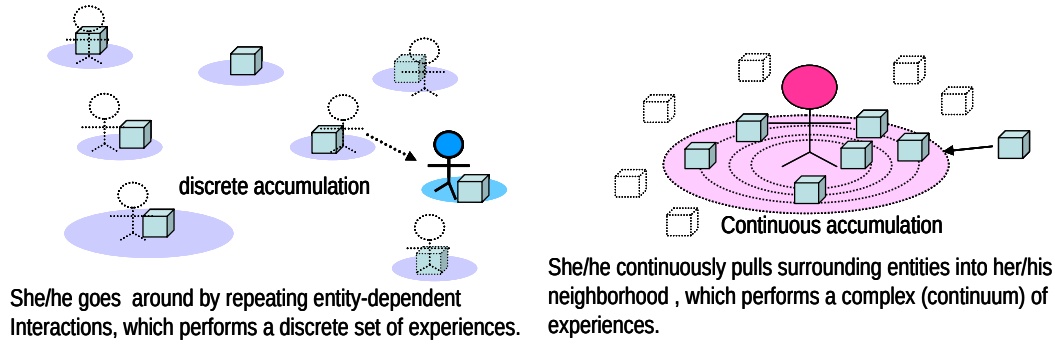


Fig. 13 Two alternative interactions (left: go-type, right: pull-type)

These two alternatives seem consistent with the two groups of people, i.e., early adopters and late comers. In fact, early adopters seem more interested in or have to search for new things than the ordinary things surrounding her/him. Because of this, we have argued that these two alternative interactions cause two groups of people to form as below.

Antisymmetrically different experiences：their accumulations and relationships

These two alternative interactions are associated with each other because they can be converted by the reverse of the actions. Although there is the reversibility, experiences are antisymmetrically different and behaviors are often biased to one type. In fact, experiences of go-type interactions strongly depend on the entity and scarcely depend on her/his neighborhood. Because of the poor relationships with the current neighborhood, she/he tends to repeat go-type interactions. Conversely, experiences of pull-type interactions weakly depend on the entity and widely depend on her/his neighborhood, which may cause complex relationships among the entity, her/his neighborhood, and her/him. Because of the increased relationships with the current neighborhood, she/he tends to repeat pull-type interactions. As a result, two alternative interactions accumulate experiences quite differently as illustrated in Fig. 14. Repeats of go-type interactions accumulate experiences separately whereas those of pull-type interactions accumulate them without separation.



(a) Repeats of go-type interactions (b) Repeats of pull-type interactions

Fig. 14 Characteristics of experience accumulations by the repeats of go/pull-type interactions.

The reversibility in interactions seems to be considered in phenomenology by Merleau-Ponty (1968), whereas the antisymmetricity between reversed actions and its consequences discussed here seem to be overlooked.

As noted above, there is a tendency of repeating one type of interactions, so her/his experience accumulation is biased to one type. That is, one's experiences (related to the service) consists of both (a) and (b) in Fig. 14 but one type of experiences is richer than the other type depending on the individual. This personal bias may cause two groups of people, which are early adopters and late comers. Early adopters' experiences that form basis of subscription seem accumulated by go-type interactions. Namely, early adopters' interests in subscribing new services are fairly simple. They are interested in such functions of services as bandwidth, price, and permanent connectivity, for example, which are separable factors. The experiences understanding these factors strongly depend on the characteristics of service. Alternatively, late comers' experiences that form the basis of subscription seem to accumulated by pull-type interactions. That is, late comers' interests in subscribing new services are much complex. They are interested not only in those simple functions of service but also in such benefits of using the Internet as reading web-pages, information searches, communications with friends, shopping, etc, which are hardly separable from each other. The experiences of understanding these benefits of using the Internet widely depend on ordinary things and events surrounding her/him.

The result of the questionnaire survey conducted in Feb. 2006 is shown in Fig. 15. The figure shows the way of how broadband users knew the benefits or merits of broadband services. The ratio of the users who knew them by her/his search decrease along the date (year) when she/he started to subscribe.

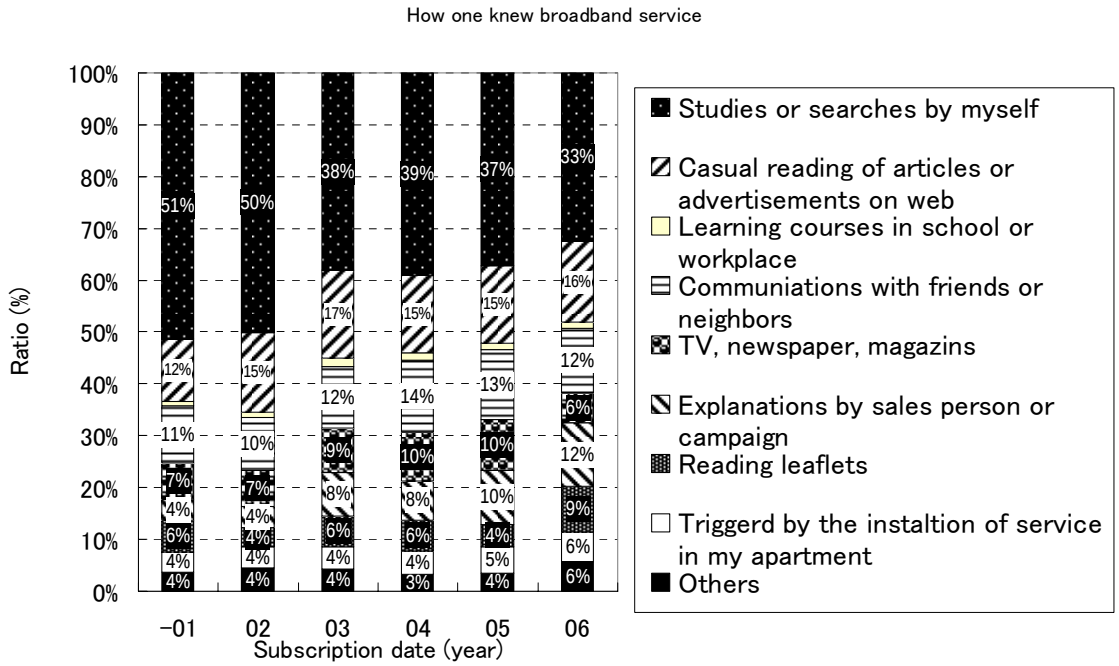


Fig. 15 Shift of the way of knowing the benefits or merits of broadband services

Let us illustrate typical processes resulting in subscriptions for early adopters and late comers. Following the basic hypothesis in Section 3, we describe here the accumulation of experiences.

Early adopters (Fig. 16)

To use the Internet satisfactory, an early adopter searches around by checking new things, events, and news, for example. She/he is or becomes interested in separate factors such as bandwidth, price, charging system, connectivity, and IP-phone, for example. The probability of subscription becomes high when she/he knows some characteristics of broadband access services such as high speed, fixed and time-independent charge, low price, permanent connectivity, and cheap charge of IP-phone, for example.

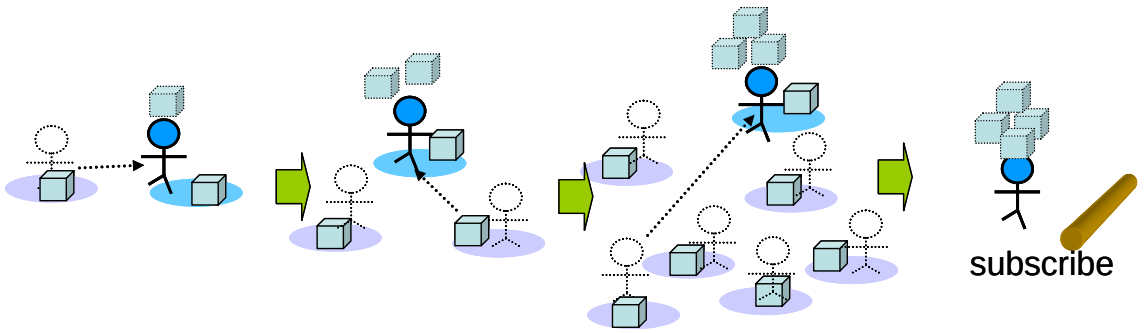


Fig. 16 Experience accumulation in an early adopter

Late comers (Fig. 17)

She/he might not know much about the Internet in the beginning. She/he learns the benefits or merits of using the Internet as well as broadband access services from people, events, and things surrounding her/his daily life. It takes time for her/him to accumulate such experiences as feeling, recognizing, knowing, or understanding the benefits of reading web-pages, information searches, communications with friends, and shopping, for example, which she/he may not distinguish clearly from the benefits of broadband access services.

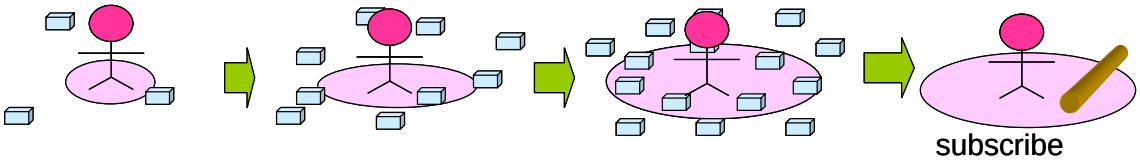


Fig. 17 Experience accumulation in a late comer

It should be noted that the benefit of using IP-phone can be easily understood without understanding the Internet. IP-phone may accelerate the prevalency growth of broadband access services. On the other hand, IP-phone cannot be the single reason for subscription. Thus, for late comers, accumulating the experiences resulting in subscriptions takes time.

These go-type and pull-type interactions were firstly considered in order to interpret gender gaps in the questionnaire survey on the uses of telecommunication tools (Shimogawa et. al., 1998). Because of the generality, it may be possible to apply wide variety of fields. For example, antisymmetric characteristics between the Internet and mobile phone were discussed with the model (Shimogawa et. al., 2003).

6. Inter-personal Behaviors and Deduction for Growth Curve Characteristics

Let us deduce the shape of the prevalence growth curve from the two alternative interactions and their personal bias by changing the viewpoint of analysis from the personal level to groups of people.

Essence of inter-personal mechanism

Let us note the essence of the inter-personal mechanism of accumulating experiences of subscription. The mechanism can be given as in Fig. 18 for go-type interactions by early adopters whereas given as in Fig. 19 for pull-type interactions by late comers. The accumulations of experience are essentially characterized by the flow of the entities to interact. Because of the go-type interactions, an entity can be shared by a number of early adopters whose search areas contain the entity, which is represented in Fig. 18. On the other hand, because of the pull-type interactions, an entity can be

shared by a number of late comers whose neighborhoods contain or are close to the entity, which is represented in Fig. 19.

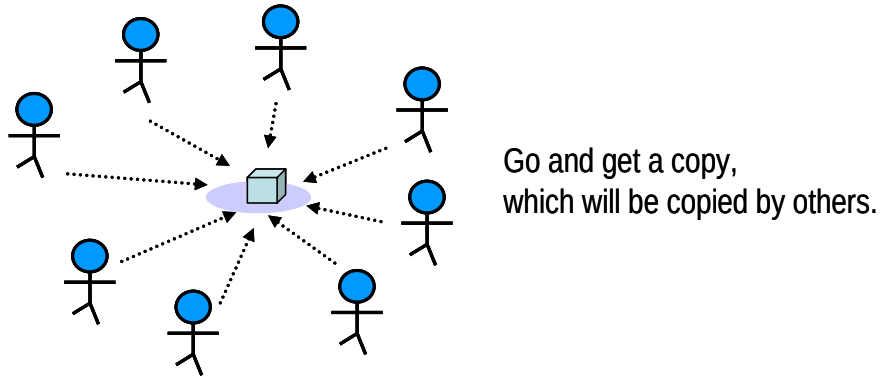


Fig. 18 Inter-personal mechanism of go-type interactions

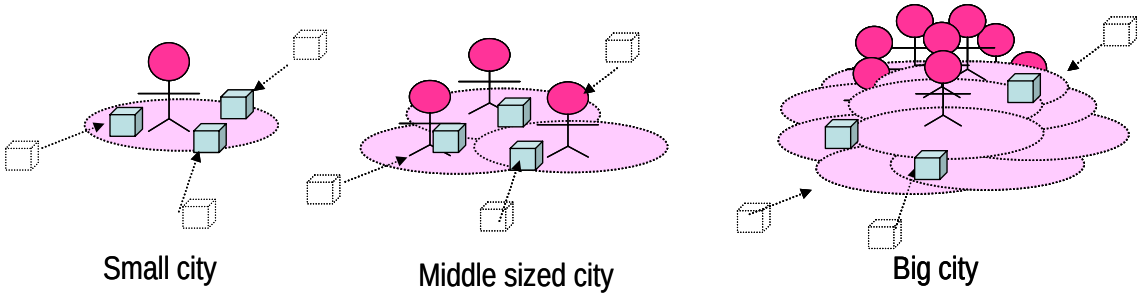


Fig. 19 Inter-personal mechanism of pull-type interactions

Downward convexity in early adopter phase

In the early adopter phase, the prevalency grows along a downward convex curve. This is essentially deduced from the separate (discrete) structure ((a) in Fig 14) of the experiential basis that results in subscription, the branching mechanism of the information flow as shown in Fig. 18, and a natural assumption that the number of people decreases in the size of the search area (see Fig. 20).

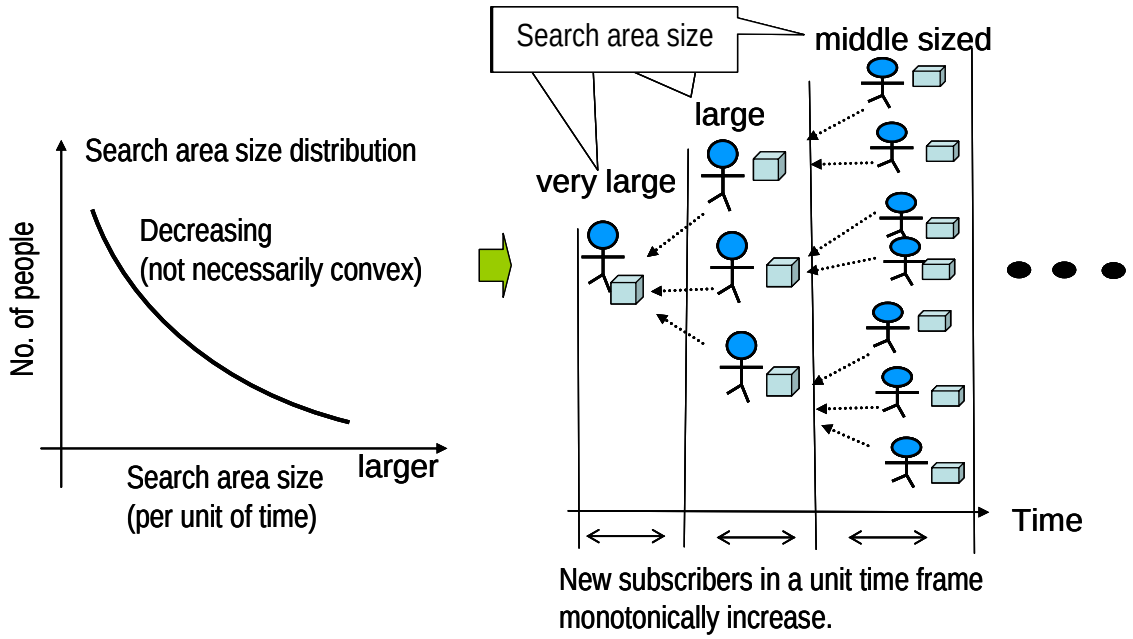


Fig. 20 Assumption on statistics of search area sizes and monotonic increase of new subscribers in early adopter phase

Let us present this deduction (see Fig 20). These separate experiences for subscriptions are some of the understandings about bandwidth, price, charging system, connectivity, and IP-phone, for example. These separable experiences strongly depend on the entities that one interacts with. Therefore, the flow can be seen as the networking where these entities are copied at the branching nodes, as shown in Fig. 18, which is the similar situation of branching models (Grimmett and Stirzaker, 1992; Bulmer, 2003). The search area size performs the stages of this networking, where the people with the larger search area sizes are in the higher (earlier) stages. The assumption of the area-size distribution (Fig. 20) implies that the numbers of people in the lower (later) stages are larger than those in the higher (earlier) stages. The number of people in the same stage approximates the increment of the prevalence. Thus, the increments of the prevalence increase in time. From this result, we deduce the downward convexity of the prevalence growth in the early adopter phase.

Logarithmic curve in late comer phase

In the late-comer phase, the prevalence grows along an upward convex curve, i.e., a logarithmic function. This is deduced from the inter-personal structure (Fig. 19), the nonseparable (continuous) structure ((b) in Fig 14) of the experiential basis that result in subscriptions, and a natural assumption that the statistical characteristics of the number of people who share their neighborhood can be the same as that of the population of the cities.

Let us present this deduction. For late comers, the experiences for subscriptions are the understanding of the benefit of using the Internet in connections to such ordinary things and events surrounding them that constitute their neighborhoods. In addition the information flow is caused by the pulling interaction that can take new entities surrounding the neighborhood. Therefore, such copying flow of separable (discrete) experiences does not play essential roles in the growths of late-comer experiences for subscriptions. On the other hand, because of nonseparability (continuity), modeling the accumulation of experiences in a quantitative manner may be possible. Namely, let us introduce the notion of the amount of experiences generated in person p until time t, which is denoted by $E(p,t)$. Now, the time $T(p)$ to perform the experiential basis in a person p resulting in subscription is modeled as

"$T(p)<t$ " is equivalent to "$E(p,t) > e_{0,}$" with a constant $e_{0,}$

Let us approximate $E(p,t)$ by a linear function $C(p)t$ with the rate $C(p)$ of incoming flow by the pull-type interactions. The flow rate $C(p)$ represents the efficiency of p's neighborhood in capturing new things for person p to understand the benefits of using the Internet and broadband access services. As described in Fig. 19, this efficiency of the neighborhood seems proportional to the number of people who share their neighborhood, which can be approximated by the population of their cities or towns, i.e., $C(p) \sim c_0 n(p)$ for a person p, where c_0 is a constant and $n(p)$ denotes the population of the neighboring people of p. The bridging hypothesis asserts that the growth curve $N(t)$ is given as $N(t) \sim \mathrm{Nr}\{p|T(p)<t\}$. Now let us start to calculate for deriving the logarithmic growth in the late-comer phase as follows:

$$N(t) - N(\tau) = \quad \mathrm{Nr}\{p|E(p,t) > e_0\} \sim \mathrm{Nr}\{p|C(p)t > e_0\} \sim \mathrm{Nr}\{\, p|c_0 n(p)t > e_0 \,\},$$

where τ denotes the singular point. We apply a basic law in the geography on the city-size distribution, known as Zipf's law (Auerbach, 1913; Zipf, 1949). That is, the population of the k-th largest city is proportional to $1/k$. Let M_k denote the set of all people living in the k-th largest area where people share their neighborhoods. Here we apply the last assumption that statistical characteristics of the number of people who shares their neighborhoods are the same as that of city sizes. Now, from the Zipf law, we have $\mathrm{Nr}M_k \sim z_0/k$ where z_0 denotes a constant. We should note that $n(p)=\mathrm{Nr}M_k$ if $p \in M_k$. Now we have

$$\begin{aligned} N(t) - N(\tau) &\sim \mathrm{Nr}\{\, p|\ p \in M_k \quad \text{for some } k,\ c_0 n(p)t > e_0 \,\} \\ &\sim \mathrm{Nr}\{\, p|\ p \in M_k \quad \text{for some } k,\ c_0 (z_0/k)t > e_0 \,\} \\ &\sim \sum_{z_0 c_0 t / e_0 > k} \mathrm{Nr}\{p \mid p \in M_k\} \ \sim \sum_{z_0 c_0 t / e_0 > k} l_0 \,\mathrm{Nr}\, M_k = \sum_{z_0 c_0 t / e_0 > k} l_0 z_0 / k \\ &\sim\ l_0 z_0 \log z_0 c_0 t / e_0 \,, \end{aligned}$$

where the population ratios of late comers in M_k are approximated by a constant l_0. This completes the deduction.

It should be noted the approximation of $E(p,t)$ can be generalized to a power function $E(p,t)$~C$(p)t^{\alpha}$ for some positive constant α. In this case $N(t) - N(\tau) \sim \alpha l_0 z_0 \log z_0 c_0 t / e_0$. This suggests the possibility of increasing the coefficient of logarithmic growth by the enrichment of user's benefits.

Answers to the guiding questions

Let us summarize here the answers to the guiding questions noted in Section 4. That is, the question of why there are such singular points in the growth curves dividing subscribers into two groups and that of why urbanizations strongly accelerate late comers' subscriptions. Our analyses have shown that the genesis of both the growth curve singularity and the urban/rural gaps of the service diffusion seems the reversible dual interactions and their anti-symmetricity as discussed in Section 5. On the other hand, the mechanism of generating the growth curve singularity and the urban/rural gaps is essentially shown in Figs. 18-19. The relationships in these two types of inter-personal dynamics are quite (anti-symmetrically) different. It is natural that two very different higher dimensional dynamics are associated with very different analytic functions. As for the urban/rural gaps, the late comers' adaptations (experience accumulations) are dominated by their neighborhoods. Urbanizations are characterized as the magnitudes of the neighborhood overlaps. The inter-personal structure Fig. 19 shows how the urbanizations accelerate the efficiencies of the neighborhoods.

7. Discussion: How can we foster the prevalence of broadband access services?

Let us discuss the ways for accelerating the diffusion of broadband services.

First, due to the personal level hypothesis, understanding the level of experiences of people is quite important. Depending on the levels of their experiences, the appropriate type of services should be offered or demonstrated with appropriate benefits.

Second, as long as the inter-personal mechanism Figs. 18-19 are accurate, actions that cause acceleration are effective in the earlier periods of the growth. Because of the branching structure and separable experiences, the cost of acceleration is smaller in the earlier stage. Moreover, these actions can raise the growth curve not only in the early adopter phase but also late comer phase. This is because the number of early adopters in the neighborhoods of the late comers becomes larger, and then, the efficiency of accumulating experiences characterized by the neighborhoods may become greater.

Third, the efficiency characterized by the neighborhoods may be changed physically. In fact, if there is such physical entity placed one's neighborhood that indicates the benefits, her/his experiences may increase rapidly. A well-known example is the apartment houses with a LAN where a broadband access service appears to be available but actually is not. Another example is the case when PC becomes available.

8. Conclusion

This paper analyzed the diffusion mechanism of broadband access service in Japan. We started with national and prefectural growth curves. We analyzed these curves and we showed such properties as

- lack of robustness in the predictions of ordinary methods,
- singularity of the inflection point,
- robustness of logarithmic function fitting after the singularity,
- stability of the shape of the prefectural growth curves,
- stronger urban/rural gaps of the prevalence in the late comer phase.

To search for the reasons for the occurrences of these properties in the growth curves, we consider personal level behavior resulting in subscriptions. We proposed the following hypotheses.

- Subscriptions are based on experiences.
- The shape of the growth curve is characterized by the time to perform experiential basis of subscription.
- There is an antisymmetric reversible dual interactions: go-type and pull-type.

On the basis of these hypotheses and deductions from them, we obtained the inter-personal mechanism of generating information flow as described in Figs. 18-19. This mechanism enabled us to deduce the convexities of growth curves and the logarithmic growth in the late-comer phase, where the Zipf law on the city-size distribution is applied. The stronger urbanism in the late comer phase is also explained in terms of the inter-personal mechanism shown in Fig. 19.

We also discussed the ways of fostering the prevalence of broadband access services. We claimed that actions that cause acceleration are effective in the earlier periods of the growth.

Limitation

Apparently, the theory of this paper may not depend on something special to Japan. On the other hand, our analyses wholly depend on the observations of Japanese case. This paper's theory may not be applied to some other countries.

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