

**Network Topology and Standards War:
When Does a New Technology Survive in the Network Economy?**

Jeho Lee

Korea Advanced Institute of Science & Technology 207-43 Cheongryangri-dong,

Dongdaemun-gu,

Seoul 130-012, Korea

e-mail: jlee@kgsm.kaist.ac.kr

phone: 82-2-958-3678

fax: 82-2-958-3124

Jaeyong Song

Yonsei University

134 Sinchon-dong, Seodaemoon-Ku,

Seoul, 120-749, Korea

e-mail: jsong@yonsei.ac.kr

phone: 82-2-2123-2498

fax: 82-2-364-6887

To be presented at the Wharton Technology Mini-Conference

April 2003

ABSTRACT

We develop a computational model to address the question of when a new, incompatible technology can survive in competition with an incumbent technology in the presence of network effects. We experimented mainly with network topology and the timing of new-technology introduction. Like much of prior work, our study does show that the survival of the new technology depends on the timing or the installed base. But our findings suggest that network topology may be more important and essential. Our study shows that delayed entries do not exclude the possibility of the new technology's sustainability when the customers' social networks are characterized by a high degree of clustering with no or few shortcuts (e.g., co-worker networks for instant messaging). In this network topology, we also find that it is worthwhile for an entrant to attempt to win the market with a new incompatible technology by offering stand-alone customer benefits such as price discount or higher quality. On the other hand, when shortcuts are substantial, the market dynamics show tipping, and the entrant's strategy would quickly become ineffective beyond some delay in entry. That is, an entrant would be better off by offering its product compatible with the existing one.

Key Words: Network topology; Network effects; Technology; Standard

INTRODUCTION

As the Internet has recently influenced the competitive landscape in many industries, researchers and practitioners have begun to recognize the importance of networks in shaping market dynamics and competitive strategy. For example, Shapiro and Varian (1999: 173) noted: “[T]he new information economy is driven by the economics of networks.” Similarly, Kelly (1998) argued that understanding how networks work would be the key to understanding how the new economy works. Indeed, a driving force behind many of the giant mergers of the late 1990s is attributed to firms’ desires to own customer networks (Cairncross, 2000). Among the key managerial questions associated with networks are often the followings: Will a new, incompatible technology survive in competition with an established one that has built up its customer networks? Could an entrant sponsoring the new technology drive out the established one if it aggressively takes some strategic action? Or should the entrant make its technology compatible with the existing standard?

Seemingly, answers depend on the types of customer networks firms would build up (Lee, Lee, and Lee 2002). However, much of prior work on network effects has sidestepped the complexity of network topologies, while highlighting market dynamics driven by installed bases. For example, Shapiro and Varian’s (1999) popular book, *Information Rules: A Strategic Guide to the Network Economy*, emphasizes economics of networks. Yet, installed bases rather than networks lie at the heart of their discussion.

In general, prior studies of network effects suggest that the benefits of obtaining a large installed base will pay off over time when incompatible technologies compete. As a consequence, the early mover with the largest installed base will corner the market (e.g., Arthur 1989, 1994). This argument has led to an acrimonious debate in the

academic community. In particular, Arthur's emphasis on lock-in and the difficulty of gaining a footing by a new, incompatible technology stimulated counter-arguments. It has been argued that cases of lock-in are not common in history and that many new incompatible technologies instead are introduced successfully (Lebowitz and Margolis 1990, 1995, Katz and Shapiro 1994). The richness of seemingly confirming and disconfirming examples has deepened confusions and disagreements. The debate has stimulated theoretical research for technology competition with sequential entry—that is, at stage one, an incumbent technology builds its installed base; at stage two, a new, incompatible technology is introduced, thereafter competing for customer base (e.g., Katz and Shapiro 1994, Lee, Lee and Lee 2003). Among the key findings of this research is that the new technology's survival depends on the timing of new-technology introduction, the size of the incumbent technology's installed base, strategic pricing, and the presence of technology enthusiasts.

Although the impressive contribution of prior work is evident, it has ignored the role of a network itself in the discussion of network effects. The prince of Denmark has been missing in discussing *Hamlet*. This ignorance is rather understandable given the complexity of specifying social networks. Recently, however, unprecedented advances in graph theory (e.g., Watts and Strogatz 1998, Barabasi, Albert, and Jeong 1999, Strogatz 2001) have allowed social scientists to tackle the complexity of social networks and their dynamic implications. It is believed that scientists could discover underlying laws behind all rich behaviors of complex systems by pushing the surface level appearances to the background and bringing the more abstract structure of interacting elements into focus (Buchanan 2002). Lee, Lee, and Lee (2002) took an early step in this direction by developing a dynamic model of technology competition

when two technologies are introduced simultaneously. We attempt to build upon this work. The primary difference is that we build a sequential model, which is more appropriate to address the acrimonious debate described above. We also consider incompatible entry by a sponsored product by assuming that the sponsor of the technology can take some strategic action.

A motivating case is the instant messaging (IM) service market, where multiple companies are now competing for users by offering incompatible services. This market was first opened in 1996 as AOL introduced Buddy List. Since then, AOL has been taking the lead in the IM market. The conventional wisdom in the literature suggests that latecomers with smaller user bases will become disadvantageous in attracting users. Indeed, Varian predicted it in an interview with New York Times (2001):

The power of the network effect can be seen in technologies like America Online's Instant Messenger. Once teens realized that they could gab after school online, it became a must-have, Mr. Varian said -- and its use exploded, rapidly bringing AOL a near-lock on a market of more than 100 million people that Microsoft is struggling to break into.

When MSN and Yahoo! entered this market in 1999, there was an enormous gap between them and AOL. However, there has been no sign of the demise of the late entrants to date. To the contrary of Varian's expectation, the gap between AOL and MSN Messenger Service has been narrowed very rapidly.

This paper endeavors to offer insights into how this could have been possible. More generally, we explore when a new, incompatible technology can survive in competition with an established technology. The key to our explanation lies in connection topologies. IM users build up a highly clustered network like a coworker network, where any pair of acquaintances will share common acquaintances and where strangers' contacts are

deliberately blocked. Unlike chat room, email or fax, where contacts with strangers are sources of customer benefits, the IM service does not grow valuable simply because more and more people use it. Indeed, the majority of adopters in the installed base are irrelevant to customer benefits. Instead, network benefits come from a swift exchange of notes between close acquaintances. In such a network, a lead technology may not be able to drive out its smaller rivals in the long run. We confirm this intuition by developing a computational model.

Through an extensive review of the literature, Farrell and Klemperer (2001: 69) recently noted: “Incompatible entry even by a sponsored product is often hard.” In a network like the coworker network mentioned above, we show that the entrant sponsoring the new technology could drive out the established one by offering customer benefits such as improved quality, price discount, bundling with other products, and so on. Thus, engaging in a standards war with an incompatible technology may not be a bad idea. On the other hand, we confirm Farrell and Klemperer’s intuition in networks like chat room, email, and fax networks, where incompatible entry is not likely to be rewarded. The upshot is that network topology should be an important variable for an entrant to choose whether to make its technology compatible or not.

This paper is organized as follows. First, we take a close examination of the evolution of the IM service industry. Second, we briefly survey the literature on network effects as well as network topology. Then, we develop a computational model to address these questions. Fourth, we show the results of our computer simulations. At last, we discuss our findings in light of the extant literature.

THE EVOLUTION OF THE INSTANT MESSAGING MARKET

Instant messaging allows users to exchange displayed message with others. Two or more buddies using compatible IM programs can connect instantly to exchange small talks just as they would do in a phone conversation. They can also exchange work files, graphics, and other items of mutual interest. In a small software window on a PC, a user can watch a list of her acquaintances to see who is currently logged onto the Internet. It also alerts the user immediately when her acquaintances are online.

Although instant messaging initially appeared on the Internet in the 1980s, it was the province of geeks until AOL capitalized on it by introducing its popular “Buddy List” in 1996. A typical list in instant messaging consists of buddies, coworkers, or family members. Such a network of close acquaintances is quite in contrast to a chat room, which is designed to facilitate contact with strangers.

The IM service has drawn a growing attention from Internet experts as a next generation killer application. Some analysts even believe that IM may become a communications platform as important as the telephone (Washington Post, August 15, 2001). An explosive increase in user hours for IM has made it central in competitive strategies of major portals like AOL, MSN, and Yahoo!, which are now seen more as communication platforms than an information platforms (Morgan Stanley Dean Witter, February 21, 2001).

Despite the explosive growth, IM services have lacked a standard for interoperable messaging to date. The Media Metrix study found that many U.S. users are juggling more than one instant-messaging service to connect to their buddies who are using different IM services (The Jerusalem Post, November 21, 2000).

DOMINANCE OF AMERICA ONLINE

AOL built its dominance by first offering instant messaging called the “Buddy List” on its proprietary online service in 1996, where it became one of the best-used applications. Buddy lists are like an interactive address book—names light up when someone is online and ready to chat. The primary reason why AOL introduced the buddy list was to enhance the loyalty of its paid subscribers by strengthening the bond among its subscribers.

The company decided in 1997 to open its messaging to anyone who downloads a free copy of America Online Instant Messenger, also called AIM. The primary purpose for opening its service was to make it more valuable to its paid subscribers since they can be connected to their friends, even those who are non-AOL subscribers (Berstein Research Call, September 19, 2000).

Although AOL pioneered the concept of the buddy list, it was ICQ that triggered a boom of IM services on the Web. ICQ (pronounced “I seek you”) was introduced in July 1996 by an Israeli startup named Mirabilis. As the first free, third-party IM program, ICQ became an instant sensation to computer-savvy young user groups such as college students and Net denizens. These people who are dubbed by some the “ICQ Generation” encouraged their friends, family members, and colleagues to join the ICQ so that they can be added to contact lists (The Toronto Star, December 21, 2000). After realizing that it cannot drive out ICQ from the IM market, especially outside the United States where AOL is relatively weak, AOL decided to acquire the company (Friedman, Billions, Ramsey, and Co, June 8, 1998). At the time, ICQ had 28 million users worldwide, many of them were savvy, sophisticated techies who have avoided AOL before.

RAPID GROWTH OF LATECOMERS

As IM emerged as a new killer application, Microsoft and Yahoo introduced their own IM services in summer 1999. Microsoft's MSN and Yahoo were among the leading portal sites in the world. Moreover, when MSN and Yahoo launched their IM services, they had 40 and 47 million account holders for their e-mail programs. To encourage their existing e-mail account holders to open IM accounts, MSN and Yahoo enabled users to integrate e-mail and IM.

To the surprise of some experts, the late entrants such as Microsoft's MSN quickly caught up with AOL. When Microsoft and Yahoo launched its IM service in summer 1999, AOL was a dominant IM service provider, and ICQ was the distant second company. According to Media Metrix, by August 1999, AOL had already built up user bases of 18 million people for AIM and 10.4 million for ICQ in the United States. In spite of such early dominance of AOL, MSN has narrowed the gap with the market leader quickly. By April 2002, MSN increased the number of unique visitors to 29.1 million, while AIM had 31.5 million unique visitors (Media Metrix, May 2002).

The rapid erosion of the AIM's market share by the emergence of MSN and Yahoo in conjunction with the survival of ICQ suggests that incompatibilities can persist in the presence of network effects. In spite of the dominance of AOL, Microsoft as a latecomer has quickly caught up with the leader. How has this been possible? In the next section, we offer a conceptual framework to address this question by sorting out different types of customer networks.

NETWORK EFFECTS AND NETWORK TOPOLOGY

Networks have been subject to economic analysis since the value of connecting to a network depends on whether other people are connected to it (Shapiro and Varian, 1999).

This section sketches the literature on network effects and highlights how the central issue of the present work fits into this literature. Then, we discuss the importance of specifying a network topology in the studies of network effects.

NETWORK EFFECTS

When the market exhibits positive network effects, the value of a product or service one uses depends on how many other users there are. Over the last two decades, numerous theoretical studies have examined how such interdependence of customer choices influence market dynamics and equilibrium outcomes (e.g., Katz and Shapiro 1985, Farrell and Salnor 1986, and Arthur 1989, Farrell and Klemperer 2001). One of the outcomes that have drawn a lot of attention not only in academia but also in industries is marketing tipping or the winner-take-all hypothesis (Arthur 1994, 1996, Farrell and Klemperer, 2001, Lee et al. 2002, Shapiro and Varian 1999). This hypothesis states that when incumbents compete with incompatible technologies and when customer benefits are positively affected by other customers' choices, a dominant winner will emerge and will corner the market. The theoretical literature could be divided up into two categories: (1) technology competition with simultaneous entry and (2) that with sequential entry.

Among the key issues that have drawn much attention is the difficulty of late entrants with incompatible technologies when an incumbent technology builds up its installed base. From his formal analysis of technology competition with simultaneous entry, Arthur (1994: 24) conjectured: “[A]n early-start technology may already be

locked in, so that a new arrival, although potentially superior, cannot gain a footing.” This conjecture has ignited an acrimonious debate in the community. Leboiwitz and Margolis (1990; 1995), for example, argued that the history of technology competition has rarely shown the possibility of lock-in to an inferior technology. Katz and Shapiro (1994) called for research to resolve this debate.

A stream of theoretical research has tried to shed light on this debate by building sequential entry models (e.g., Farrell and Saloner 1986, Katz and Shapiro 1992, Lee, Lee, and Lee 2003). A typical setup of these models is that an early-start technology builds up its market share alone at stage one. Then, a new, incompatible technology is introduced, competing for customer bases. Among the key findings of prior work is that the survival of the new, incompatible technology depends on the date of new-technology introduction, the size of the installed base of incumbent technology, the costs of the two technologies, strategic pricing, the presence of technology enthusiasts and so on. The present work builds upon and extends this stream of research. We wish to add new insights to the literature by exploring how the topology of customers’ social networks affects the long-run dynamics of technology competition. In particular, we show that not all network effects lead market dynamics to tippy behavior.

NETWORK TOPOLOGY

In determining the value of a network, researchers as well as practitioners have predominantly regarded its overall size (or the size of installed base) as the most important strategic variable (e.g., Farrell and Saloner, 1986; Arthur, 1989; Shapiro and Varian, 1999). The implicit presumption has been that everyone in a network is connected to everyone else. This presumption is rather too simple to characterize

various kinds of networks and their long-term effects. Apparently, there could be a gain from classifying network topologies and sorting out their dynamic consequences. Strogatz (2000: p. 268) noted such a gain as follows:

Why is network anatomy so important to characterize? Because structure always affects function. For instance, the topology of social networks affects the spread of information and disease, and the topology of the power grid affects the robustness and stability of power transmission. From this perspective, the current interest in networks is part of a broader movement towards research on complex systems.

Usually, configurations of networks are modeled by graphs, which consist of two main elements, nodes and links (or edges). Germane to our discussion here are complete graph and sparse graph. A network is classified as a complete graph when every node of the network is connected to every other node. E-mail, telephone, and fax networks can be approximated as a complete graph if user benefits reflect whether a user can contact not only her acquaintances but also any strangers in the world. Indeed, Metcalfe, who invented Ethernet, formulated the value of a network with this sort of approximation. His formulation is well-known as “Metcalfe’s law,” which states: as the number of users increases by n times, the value of a network increases by $n(n-1)$ times, or approximately n^2 times.

There are two things that are worthy of note regarding Metcalfe’s law. First, the values of small networks will be much smaller than those of large networks. That is, it is difficult for small networks to compete with large networks. Second, once a network grows beyond some critical mass, it has the potential to grow very fast. Much of prior work modeled network effects with this sort of approximation. The aforementioned Varian’s prediction of the AOL’s dominance in the IM market also hinges on this

assumption, too.

There are instances when users' benefits come mostly from connections to their acquaintances in a network rather than the majority of strangers in a communication network. Furthermore, it is reasonable to assume that each individual maintains relationships with a small number of acquaintances relative to the size of population.¹ Then, the network could be better approximated by a sparse graph, which is characterized by partial connections among nodes in a graph. Consider a buddy list for instant messaging. AOL estimated that its clients built up lists of about 20 to 50 people (The Ottawa Citizen, 1999). Apparently, a user will not build up a list of all the members in the AOL network. Neither such a long list can be feasibly covered over her computer screen, nor it is useful to her, since her delight comes from exchanging talks with her close acquaintances.

In characterizing a sparse network, a key issue lies in how to construct a network architecture for an individual's relationships with her neighbors. The sociological literature has suggested two basic types of network architecture (Granovetter, 1973; Rogers, 1995). First, a network can consist of small subnetworks of individuals, and within each subnetwork, individuals closely interact with one another. Each subnetwork is a densely knit clique or a cluster of highly overlapping acquaintances. An extreme version of such a cliquish subnetwork is cavemen (Watts, 1999). Consider cavemen in the prehistoric era. Cavemen in a cave would interact with one another quite well, but the whole group would be isolated from cavemen in other remote caves. Because of the ingrown nature of each subnetwork, the connectivity between subnetworks is low. An example for such networks is a buddy network or a

¹ Studies have shown that connectivity distributions for social networks follow either a gaussian or a power-law (Barabasi 2002, Lilijeros et al. 2001, and Strogatz 2001).

coworker network for instant messaging users. Individuals in this type of network tend to exchange talks with highly overlapping acquaintances. Suppose that individual *A* has built up a coworker list, which includes individuals *B* and *C*. It is highly likely that *B* and *C* also exchange talks with each other.

This type of ingrown network can be modeled by regular (lattice) graphs (Watts and Strogatz, 1998; Watts, 1999). An example is shown on the right in Figure 1. An interesting mathematical property of a regular graph is that the average degree of separation between nodes is long because there are few bridges or shortcuts between remotely dispersed subnetworks (Granovetter, 1973; Watts and Strogatz, 1998; Watts, 1999). When such shortcuts are absent, information can travel slowly throughout a chain of adjacent cliques.

Second, an entire network may consist of subnetworks that are less dense and more open, allowing the focal individual to exchange information with a wider scope of individuals (Rogers, 1995). Internet chat rooms and Internet auctions belong to this extreme class. Here, each individual contacts other individuals, who are not likely to share common acquaintances. Put another way, the network is characterized by a low degree of clustering. Such networks have been modeled by random graphs of Erdős and Rényi, in which each node is randomly linked to other nodes. An interesting mathematical property of these graphs is that the average degrees of separation between nodes become small. This is so even when the total number of nodes is very large.

Thus far, we have discussed either completely regular or completely random networks. Many social networks appear to lie between these two extremes. Recently Watts and Strogatz (1998) developed graph models that can be turned through the middle ground between the two extreme cases, calling them as “small-world graphs”.

These graphs are built on a ring substrate with n nodes and k links per node. Each of n persons is assumed to maintain k relationships with others, where k is strictly smaller than n . Examples are shown in Figure 1. Here $n = 20$, and $k = 4$.

Figure 1 about here

To construct small-world graphs, one should start from a connected, regular graph on the left in Figure 1, which has the highest degree of clustering. One can rewire each edge from a node with a randomly chosen, other node with probability β . When $\beta = 0$, no edge will be rewired, and the regularity and the clustering will be preserved. When β is sufficiently small, the high degree of clustering will be preserved with a few random connections among cliques—some of these connections, what are called “shortcuts,” reduce the degrees of separation between distant nodes. On the right, a network becomes completely random, when $\beta = 1$. Here, shortcuts are abundant, and the average degrees of separation or the network diameter is the smallest. In this graph, however, the clustering is almost destroyed.

The most interesting topological property of the Watts and Strogatz (1998) (WS) model is that only a small number of random shortcuts are sufficient to dramatically reduce the diameter of a network. That is, there exists an interval of small β , where the average degrees of separation is as small as that in a completely random graph, but the clustering of a regular graph is preserved more or less. In particular, Watts and Strogatz (1998) discovered that for small β , the introduction of a few shortcuts has a nonlinear effect on the size of a network diameter. Furthermore, a few edges removed from a regular graph at small β will not affect the local density or clustering much.

The upshot is that shortcuts lie at the heart of the WS small-world networks.

Research in sociology has provided some insights on the role of shortcuts. A study of homosexual networks in the early spread of AIDS illustrates how a shortcut can spread the disease beyond a local boundary. When investigators at the Centers for Disease Control and Prevention (CDC) interviewed the first forty patients with AIDS symptoms, they found that nineteen of these patients lived in Los Angeles, and twenty-one other patients resided in San Francisco, New York, and elsewhere in the U.S. (Rogers, 1995). It was discovered that one patient, who was a flight attendant for Air Canada, played a role of shortcut in the spread of the disease across wide geographical areas. Granovetter (1973) also identified random contact, or meeting with strangers, as a source of shortcuts. An anecdotal example of such random contact was cited in Rogers (1995: 309):

An example of successful job searching through weak network links was an accountant who flew to Boston to attend a convention. The accountant shared a taxi at Logan Airport with a Bostonian businessman. They began a conversation, and the businessman disclosed that his company was seeking to hire an accountant. You can imagine what happened next. The accountant, who later resided in Newton, was one of Granovetter's respondents.

In both contexts, the important characteristic of shortcuts is that they reduce the role of physical distance, which otherwise constrains social interactions within some physical proximity.

We believe the network topologies reviewed here can equip social scientists to tackle complex, social networks. Barabasi et al. (1999: p. 174) noted: "Uncovering the universal properties characterizing the formation and the topology of complex networks could bring about the much coveted revolution beyond reductionism." In particular, social scientists can incorporate some of these graph models into their dynamic models,

investigating phenomena that have been considered intractable before. Below, we develop computer simulation models to examine the important issues in the literature on network effects. The issues are: Could a new, incompatible technology survive in the market where an early-start technology established its customer networks? Would the answer depend on the topology of customers' social networks (e.g., the presence of shortcuts)?

MODEL

We now develop a computer simulation model to address the central question of this paper: Would a new technology have difficulty establishing a foothold in the market when the old technology builds up its installed base? Like Lee, Lee, and Lee (2002), this paper incorporates users' acquaintance networks with diverse coupling topologies shown in Figure 1. When some users adopt a firm's IM service, they influence their friends to adopt it. If some of these friends adopt the service, they in turn will affect their friends. Thus, a firm can build their user base through this sort of chain of friendship network.

ADOPTION DECISION

Let us first consider the basic diffusion process of incompatible instant messaging services when they are not bundled with other services such as e-mail. Since the essence of competition in this market lies in building user base, our model restricts attention mostly to the demand side dynamics. Strategic action in the supply side will be considered in a limited fashion in the additional analysis section. In our model, each individual's willingness to adopt the service is represented by two factors: consumer's reluctance to adopt the service and the effects of friendship network. The reluctance

can be regarded as a threshold value, whereas the network effects are customer benefits.

When these benefits are greater than a user's reluctance, she will begin to use it.

In the basic model, there are only two incompatible services, A and B for simplicity. In simulation, we extend this into four, eight, and sixteen technologies cases to show that model behavior does not change much. We assume that there is no difference in quality among the two services. Then, individual i 's willingness to use service j ($j = A, B$) at time t is

$$U_{ijt} = R_i + aN_{ij(t-1)} \quad (1)$$

where R_i is user i 's inherent reluctance to adopt any service,² a represents the importance of network effects, and $N_{ij(t-1)}$ represents a proportion of user i 's friends who are using service j at time $t - 1$. More specifically, $N_{ij(t-1)} = (\text{the number of } i\text{'s friends who adopted service } j \text{ at time } t - 1) / (\text{the total number of } i\text{'s friends})$. Thus,

$$0 \leq N_{ij(t-1)} \leq 1.$$

Note that R_i is time-invariant. It is because the reluctance is assumed to represent a user's inherent disposition to the service itself. R_i is assumed to follow a normal distribution with mean μ and variance σ^2 .

ADOPTION RULE FOR TECHNOLOGY ENTHUSIASTS

Users with $R_i > 0$ are enthusiasts or geeks who will adopt a service first. At $t = 0$, their network benefit from choosing between the services is absent. That is, $N_{iA0} = 0$. An enthusiast's adoption stem from her inherent positive valuation of the service, i.e.,

² One can consider that customer i 's reluctance R_i is the sum of his or her reservation price r_i and price p . That is, $R_i = r_i - p$. Given that $r_i < 0$ for the majority of customers, both r_i and p negatively affects i 's willingness to adopt a service.

$R_i > 0$. Initially, some enthusiasts adopt A with probability p while other enthusiasts (with probability of $1 - p$) do not adopt it. This inaction may happen because these unactivated enthusiasts are not aware of the service or because it is not available to them—these users may be geographically isolated from zones where the service is available. The unactivated enthusiasts may adopt the service simply by the influence of their acquaintances during the diffusion of A like normal users. If this does not happen, these enthusiasts will adopt the new service, B , when it is introduced to the market. Obviously, whether any enthusiasts will remain to wait for the new service or not depends on chance events as well as the timing of the new service introduction.

ADOPTION RULE FOR NORMAL USERS

In the case of a majority of normal users, $R_i < 0$. That is, normal users will wait until the benefits due to network effects exceeds their negative valuation of the service. So, the adoption rule is $U_{ijt} > 0$. This condition can be satisfied when their more enthusiastic friends use a service, thereby influencing normal users. A normal user's choice of service A depends on the size of $N_{iA(t-1)}$ in comparison with that of service B . Between A and B , she chooses a service of which $U_{ij(t-1)}$ is the largest. Enthusiasts and normal users can switch to an alternative service at every period. Switching decision criterion is the same as the normal users' decision criterion described just above.

RESULTS

The simulation results here numerically demonstrate competition between incompatible technologies when network effects are present. We first show typical simulation runs to illustrate dynamics of the technology competition by network topology. Then, we conduct simulation experiments by varying two key parameters, network topology and

the timing of new-technology introduction.

TYPICAL SIMULATION RUNS

As a starting point, we show the behavior of our sequential entry model when the customer network is ill-clustered with abundant shortcuts or when $\beta = 1$. As shown in Figure 2A, the early-start technology quickly builds up its customer base. When the new technology is introduced at time step ten, there is little room left for it to gain its foothold. The early-start technology corners the market at the steady state, which was quickly reached at time step 11. When beta is set to 0.1—at this level, there should be some shortcuts (less than 10% of links) that dramatically reduce the degree of separation between any two customers—, the speed of adoption dynamics is a little bit slowed down. The steady state as well as 100% market penetration was obtained at time step 14. As was the case for $\beta = 1$, the new technology fails to survive, and the early-start technology monopolizes the market. This is reminiscent of Arthur’s (1994: 24) argument: “[A]n early-start technology may already be locked in, so that a new arrival, although potentially superior, cannot gain a footing.”

In contrast, when $\beta = 0$ or when the customer network is highly clustered with no shortcut, the diffusion process is the slowest. As shown in Figure 2C, it took 55 time steps for the diffusion process to reach 100% market penetration. When the new technology enters at time step ten, there is enough room for it to establish its foothold and to survive. At the steady state, the two technologies share the market. Note that the market sharing is obtained even though the new arrival is not set up to be superior to the early-start technology. All typical realizations together seem to suggest that the survival of the new, incompatible technology depends on network topology as well as its entry

timing.

Figure 2 about here

SIMULATION EXPERIMENTS

We conducted simulation experiments by varying the values of the two parameters, beta and the timing of new technology introduction. To reduce statistical errors, we ran each simulation two hundred times. All of the results reported here are the averages over two hundred runs.

Figure 3 shows that whether a new incompatible technology survives at the steady state depends on the timing of the entry as well as network topology. When the value of beta is set to zero (diamond)—the close customers maintain a cliquish network where there are highly overlapping acquaintances among its members with no shortcuts—, two technologies tend to coexist at the steady state by sharing the market. Obviously, the degree of market share difference gets larger as the new technology arrives later. This happens because the late arrival gives time for the old technology to increase its market share more. On the other hand, when the value of beta is at least as big as 0.1, the degree of market share difference invariably jumps into the theoretical limit of 1. This value basically says that the old technology almost always corners the market, or the new incompatible technology has almost no chance to create its own niche to survive. This winner-take-all phenomenon is observed even when the new technology arrives at time step ten. The entry timing, when it is above 10, does not play an important role.

Figure 3 about here

Figure 3 could be misleading in understanding the long run behavior of the systems for various network topologies. For example, the values of average market share difference are close to zero for all values of beta when two technologies are introduced simultaneously at time step zero. Either this could mean that the two technologies evenly share the market, or it may simply reflect the fact that each technology completely drives out the other one half of the times. To eliminate this ambiguity, we construct another measure, what we call “tippiness,” by taking the average of the absolute values of realized market share differences.³ When the value of this measure is 1, this means that either of the technologies dominates the market with 100 percent market shares. On the other hand, when two technologies evenly share the market, the value should be 0.

Figure 4 plots entry time against tippiness. Unlike Figure 3, Figure 4 shows diverse average values across different network topologies when the two technologies are introduced simultaneously at time step zero. When the value of beta is as big as 0.5 (or bigger), the degree of tippiness is 1 regardless of the timing of the new technology introduction. In other words, the market is completely tippy when there are sufficiently a large number of short cuts in customers’ social networks. On the other hand, when the

³ A static formulation of tippiness was introduced and discussed by Katz and Shapiro (1985, 1994). The notion basically reflects the condition that an interior pure-strategy equilibrium does not exist. For operational purpose, we measure tippiness θ as

$$\theta = \frac{\sum_i |\pi_i^{old} - \pi_i^{new}|}{M}$$

where π_i^j is i th realization of technology j 's ($j = \text{old, new}$) market share at the steady state and M is the total number of simulation runs. Note that $0 \leq \theta \leq 1$. The greater the value of θ is, the more tippy the market is.

value of beta is below 0.5, the degree of tippiness is lower than 1. This reflects that some realizations result in market sharing or coexistence of two incompatible technologies at the steady state. Interestingly, the tippiness of the system with $\beta = 0$ is not much sensitive to the timing of new-technology introduction. The degree of tippiness is consistently below 1 over all observations.

Figure 4 about here

The possibility of market sharing is more clearly shown in Figure 5, which presents cumulative distributions of market share difference when beta is set to 0. In this figure, we also add a common cumulative frequency distribution when the market is completely tippy or when the old technology completely drives out the new technology at the steady state. This winner-take-all outcome in favor of the old technology is observed for all values of beta above 0.1 when the new technology is introduced at time step ten or larger.

On the other hand, when beta is 0, cumulative distributions show s-shaped patterns when the entry timing of the new arrival is early. An increase in the timing shifts the curves of the cumulative distributions to the right, but the shape is more or less robust in sharp contrast to the tippy market case. Even when the new technology's entry is delayed as late as time step 50, the distribution curve does not overlap completely with the tippy case. That is, the probability that two technologies share the market at the steady state is nonzero.

In sum, these results together suggest that the degree of tippiness is a function of beta. The greater the value of beta is, the more likely the market becomes tippy up to

some critical point. Beyond this point, the market's tippiness takes the extreme value of 1 independent of the timing of the new-technology introduction. Our results suggest that the timing of new-technology introduction may not be as essential as network topology in understanding the long-run behavior of adoption dynamics.

Figure 5 about here

ADDITIONAL ANALYSIS WITH ENTRANT'S STRATEGIC ACTION

In the previous model, each user's decision to adopt a technology or service is assumed to be affected only by its network benefits, which result from interactions among acquaintances. There was no difference in effort between the incumbent and the entrant effort to induce new customers to adopt their services. In reality, a newcomer usually recognizes its weakness due to the smaller size of its networks, and may attempt to do what it takes to win (Farrell and Klemperer 2001). Such newcomer's strategic actions may include offering price discounts,⁴ freebies, improved quality, bundling with other services or any other benefits that are associated with customer acquisition activities. The questions, then, are whether such an attempt is worthwhile, and if so, under what circumstances it would work.

To address these additional questions, we now modify our model with this new assumption. Let service A denote the incumbent's service. As was the case in the basic model, user i 's willingness to adopt service A is

$$U_{iA_t} = R_i + aN_{iA(t-1)}$$

⁴ The theoretical literature suggests that firms often charge prices below their costs to win customers (see Farrell and Klemperer 2001).

(2)

On the other hand, user i 's willingness to adopt service B introduced by the entrant is now

$$U_{iBt} = R_i + aN_{iB(t-1)} + c$$

(3)

where c represents an extra customer benefit the entrant could offer (e.g., price discount, improved quality, freebies, etc.). In essence, c serves to reduce the level of customer reluctance in adopting the new service, given that R_i takes a negative value for the majority of customers. This is the only added feature in the extended model, and the other aspects of the diffusion process are the same as the one in the basic model.

We report the results of the simulations of the entry with additional customer benefits under diverse network topologies. The results could be divided up into two parts: (1) the tippy market case and (2) the non-tippy market case.

We are interested in how the timing of the entry affects the effectiveness of the entrant's effort to overcome its weakness. Figure 6 shows the results of simulations when $\beta = 1$. The horizontal axis represents the level of additional customer benefit offered by the entrant, and the vertical axis represents an average market share difference (MSD) between the incumbent and the entrant. The simulation with entry time = 5 considers the case where the entrant quickly follows the early mover before the demand for the latter's service takes off. One can easily expect that the success of the entry is a function of customer benefit offered by the entrant. Indeed, the result indicates that the bigger this benefit, the smaller the value of MSD. When customer benefit is above 40, the value of MSD approaches -1 . This means that the entrant drives out the incumbent. This result suggests that a greedy entrant can try to win the whole customers

by aggressively offering a price discount, a freebie, or other customer benefits.

In contrast, when the entry is somewhat delayed (e.g., entry time ≥ 15) as shown in Figure 6, the entrant's effort to overcome its weakness becomes almost ineffective. For example, when there is a 15-period time lag between the incumbent and the entrant, the entrant cannot survive regardless of whether it increases the value of extra customer benefits or not. That is, the value of MSD is close to 1 over the whole range of the parameter values chosen.⁵ This extreme result happens primarily because the demand for the established technology quickly takes off in the tippy case or a network with a substantial number of shortcuts. Although sensitivity analysis is not reported here, we varied the value of β . We found that these results are rather robust when the market dynamics show tipping (e.g., $\beta \geq 0.4$).

Figure 6 about here

Now, let us consider the non-tippy market case, where network topology reflects a collection of semi-isolated cliques with no or few shortcuts. We again examined whether the entry would be successful when the entrant offers an extra customer benefit. Figure 7 shows that an increase in customer benefit allows the entrant to take away all the customers from the incumbent. Timing of entry changes the slope of the curve, but this relationship holds true even when the entry is delayed as late as period 35. This finding is somewhat surprising since the greedy strategy of winning all the customers is easier and more likely to work in the non-tippy case than the tippy case

⁵ When customer benefit c is extremely large, the entrant can take all the customers from the incumbent even when the entry is far delayed. For example, given that the possibility of under-adoption is absent, if $c > a$, the entrant will always win all the customers immediately after the entry. This possibility, however, is remote from reality where increasing customer benefit c is not that easy.

when the entrant increases its effort to offer standalone benefits.

Figure 7 about here

DISCUSSION

We developed a computational model to address the question of when a new, incompatible technology can survive in competition with an incumbent technology in the presence of network effects. We found that the survival of the new technology primarily depends on network topology, which affects the tippiness of the system. When a customer network is highly clustered with no or few shortcuts that connect remotely-located individuals (e.g., coworker networks), the behavior of the system is found to be non-tippy—i.e., we can observe the persistence of incompatible technologies. In this case, the probability that the new technology survives at the steady state is positive. Unless the incumbent technology locks out the opportunity completely with 100% monopoly, the new, incompatible technology can carve out its own niche and survive even with a quite delayed entry. This was observed when the new technology is not superior to the old one and there is no sponsor's strategic action.

On the other hand, when there are a substantial number of shortcuts that dramatically reduce the degrees of separation between any two individuals, market dynamics become tippy. That is, one technology tends to corner the market, and two incompatible technologies rarely share the market. In this case, the early introduction is crucial for the survival of the new, incompatible technology. Even a small time gap with the incumbent technology could allow it to quickly dominate the market, and as a consequence, the new technology has almost no chance for survival.

Our findings speak to the acrimonious debate in the literature on network effects. Arthur (1994: 24) informally argued: “[A]n early-start technology may already be locked in, so that a new arrival, although potentially superior, cannot gain a footing.” Critics responded to this conjecture by arguing that the history of technology competition has rarely shown the possibility of lock-in to an inferior technology (Leiboitz and Margolis 1990; 1995, Katz and Shapiro, 1994). A few studies have addressed this issue by building sequential entry models in the presence of network effects (e.g., Farrell and Saloner 1986, Katz and Shapiro 1992, Lee, Lee, and Lee 2003). Among the key findings of prior work is that the survival of the new, incompatible technology depends on timing of new technology introduction. Prior work was exclusively focused on the structure that generates tippy behavior, where the timing is closely related to the size of the early-start technology’s installed base. Our result is not inconsistent with this literature, indicating no reason to downplay the role of installed base. But our findings suggest that a deeper truth lurking behind all these appearances may be the structure of social networks. Our study showed that delayed entries do not exclude the possibility of the new technology’s sustainability when a network is structured in a way to constrain the tippiness of dynamics. Confusions and disagreements, which stem from the rich behavior of the system with network effects, can be better addressed in light of the network perspective.

Farrell and Klemperer (2001) argued that incompatible entry even by a sponsored product is hard. To address this issue, we conducted additional analysis by assuming that the entrant sponsoring the new technology can aggressively offer price discount, bundle the product with other products, or improve the quality of the product. Obviously, this greedy assumption is more likely a scenario for a large firm like

Microsoft. The questions were: Is it worthwhile for the entrant to take such an aggressive strategic action?; if so, when would this more likely to work? Our findings indicate that the entrant's greedy attempt is much easier and more likely to work in the non-tippy case than the tippy case. In the latter case, the customer benefit offered by the entrant would quickly become ineffective beyond some delay in entry timing, primarily because the network structure allows the incumbent's technology to build up its benefits very quickly, where even Microsoft might have difficulty catching up with the market leader. The entrant would be better off by choosing to make its product compatible with the established technology.

An important implication of these findings is that network structure can be a firm's strategic variable. Our study suggests that the entrant's survival depends on the network topology of its target customers. Some customer groups are structured with fewer shortcuts than others. For example, instant messaging services deliberately target groups of individuals who wish to communicate with highly overlapping acquaintances such as coworkers, where any pair of acquaintances will share common acquaintances and where shortcuts are often deliberately blocked. Our study suggests that in this case, installed base *per se* would not be as strategically important as much of prior work has emphasized. For example, AOL's large installed base should have a limited effect on the diffusion of new, incompatible instant messaging services because customer benefits do not come from the majority of irrelevant links in the AOL's total installed base but from interaction with close acquaintances. A small entrant has some hope by targeting non-adopters the majority of whose acquaintances have not adopted any service either. A large entrant may take a greedy strategy of winning the whole market by aggressively offering customer benefits.

Appendix: Parameter Values for Simulation

Figure	<i>n</i>	<i>k</i>	<i>P</i>	μ	σ	<i>a</i>	β	<i>Entry Time</i>
2A	1000	10	0.5	-90	45	400	1	10
2B	1000	10	0.5	-90	45	400	0.1	10
2C	1000	10	0.5	-90	45	400	0	10
3	1000	10	0.5	-90	45	400	Variation	Variation
4	1000	10	0.5	-90	45	400	Variation	Variation
5	1000	10	0.5	-90	45	400	0	Variation
6	1000	10	0.5	-90	45	400	1	Variation
7	1000	10	0.5	-90	45	400	0	Variation

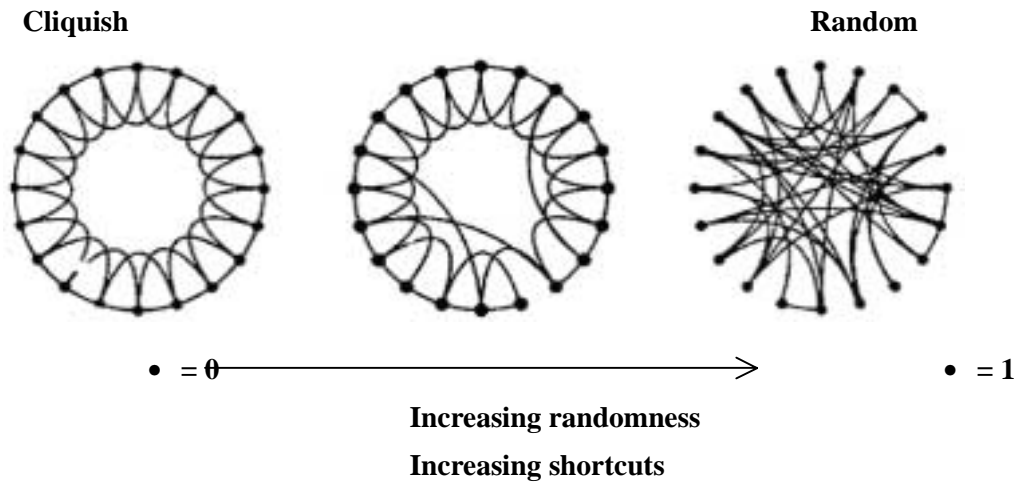
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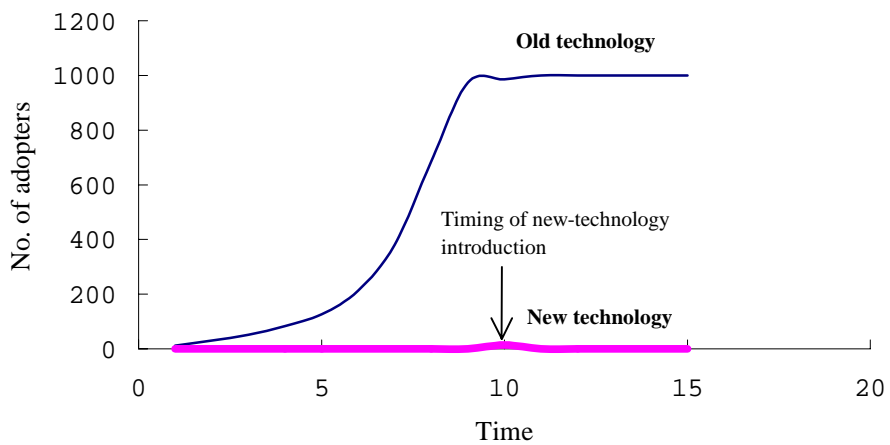
FIGURE 1. COUPLING TOPOLOGY FOR SOCIAL NETWORKS



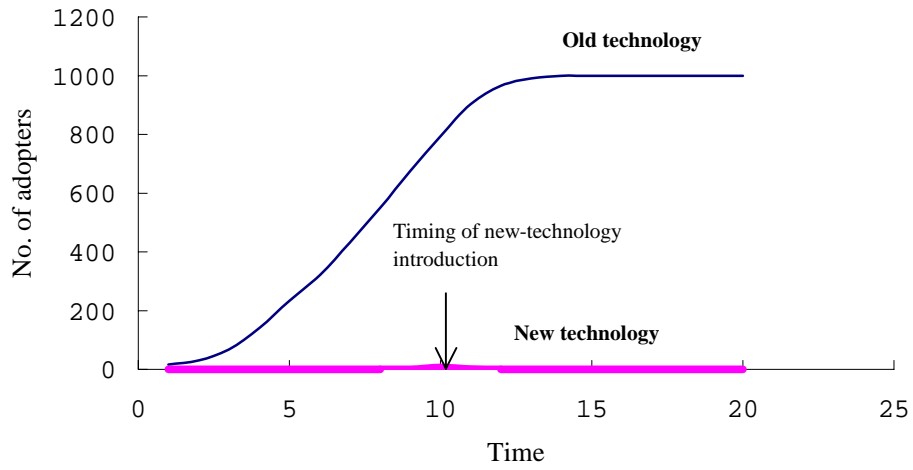
Source: Watts J. Duncan (1999: p.68)

FIGURE 2. ADOPTION DYNAMICS:

A. Typical simulation run with $\beta = 1$



B. Typical simulation run with $\beta = 0.1$



C. Typical simulation run with $\beta = 0$

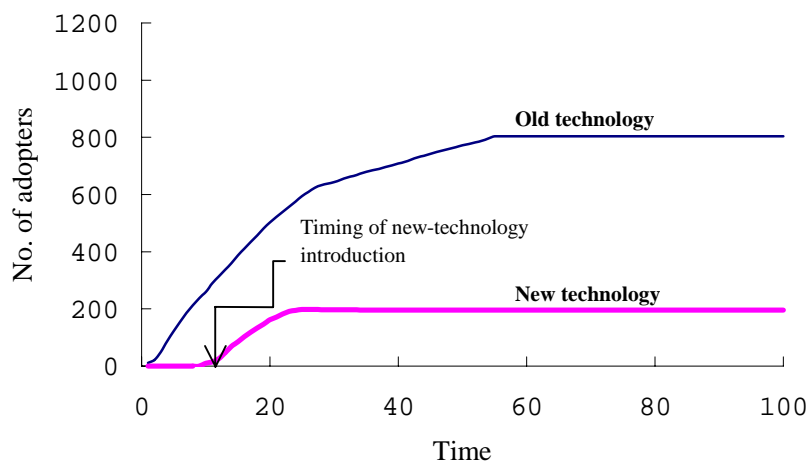


FIGURE 3. AVERAGE MARKET SHARE DIFFERENCES AGAINST ENTRY TIME:

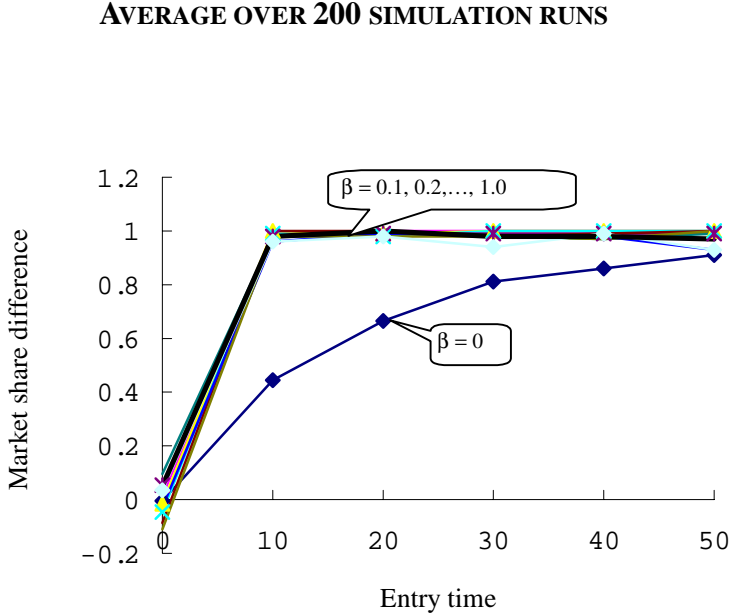


FIGURE 4. DEPENDENCE OF TIPPINESS ON ENTRY TIME:

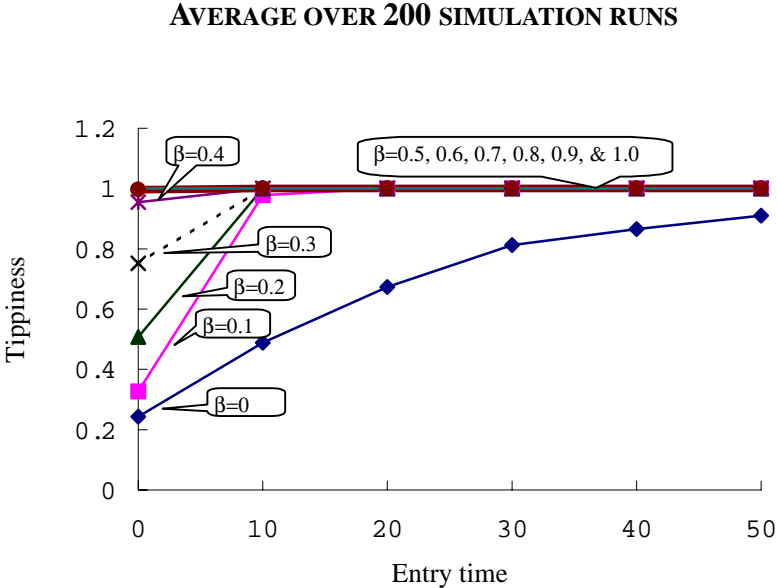


FIGURE 5. CUMULATIVE DISTRIBUTIONS OF MARKET SHARE DIFFERENCE BY ENTRY TIME: WHEN BETA IS 0

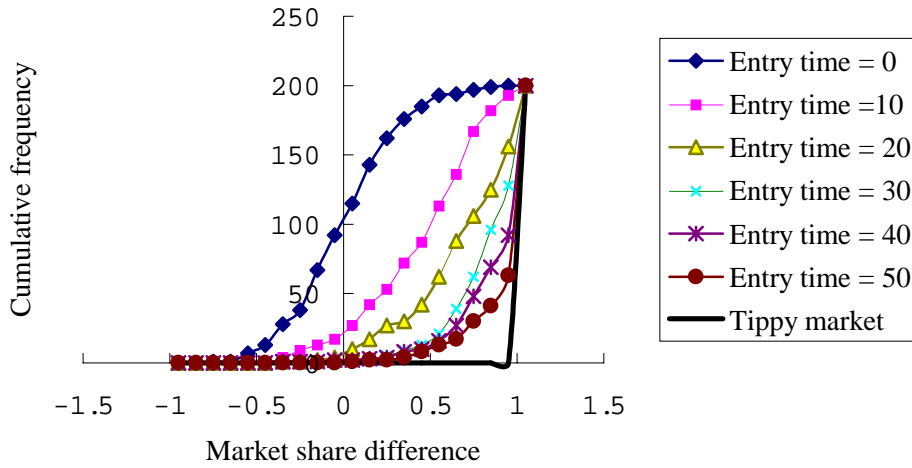
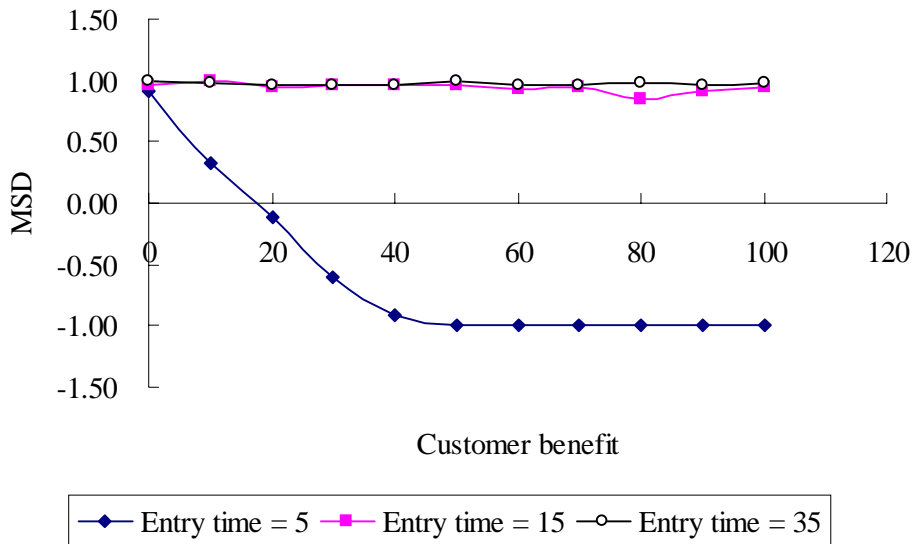


FIGURE 6. AVERAGE MARKET SHARE DIFFERENCE BY CUSTOMER BENEFIT: WHEN BETA IS 1



**FIGURE 7. AVERAGE MARKET SHARE
DIFFERENCE BY CUSTOMER BENEFIT: WHEN BETA IS 0**

