The Evolution of ICT Markets: An Agent-Based Model on Complex Networks

Liangjie Zhao[1], Bangtao Wu[1], Zhong Chen[1], and Li Li[1,2]

[1] Antai College of Economics and Management, Shanghai Jiaotong University, Shanghai, 200052, China
zhaolj1981@gmail.com
[2] School of Education, Shanghai Normal University, Shanghai 200234, China

Abstract. Information and communication technology (ICT) products exhibit positive network effects.The dynamic process of ICT markets evolution has two intrinsic characteristics: (1) customers are influenced by each others' purchasing decision; (2) customers are intelligent agents with bounded rationality.Guided by complex systems theory, we construct an agent-based model and simulate on complex networks to examine how the evolution can arise from the interaction of customers, which occur when they make expectations about the future installed base of a product by the fraction of neighbors who are using the same product in his personal network.We demonstrate that network effects play an important role in the evolution of markets share, which make even an inferior product can dominate the whole market.We also find that the intensity of customers' communication can influence whether the best initial strategy for firms is to improve product quality or expand their installed base.

Keywords: information and communication technology, evolution of market, diffusion of innovations, complex networks, network effects.

1 Introduction

With the development of information and communication technology (ICT), ICT products have become more and more important in our life. The market of ICT is a widely concept. It includes not only PC market, but also the market of telecommunications equipment, customer electronics, and electronic components. According to IDC's estimation, the global ICT market investment has become 2.3 trillion dollars in 2006.

ICT products exhibit positive network effects, which mean the utility of these products will increase with the total number of users or the amount and variety of complementary goods [1]. Economic literature commonly agree that the influence of network effects for the adoption of ICT products, will lead to evolution phenomena including positive feedback, critical mass, compatibility, standardization, lock-in, path dependence and inefficiency [2,3]. Traditional economics approaches of network effects theory, which study on the evolution of ICT markets, can be classified into two kinds of models. On the one hand, the primary

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goal of theoretical models is an analysis of the competition strategies, such as installed base strategy [4], compatibility strategy [5] or pricing strategy [6]. On the other hand, many scholars use empirical approaches (e.g. hazard model, hedonic price model) to estimate the effect of direct or indirect network strength on the of evolution of markets [7,8].

However, by focusing on the effects of supply side policies, traditional theories ignore the impact of demand side on the evolution of ICT markets. The evolution of market is a dynamic process, in which all customers make their collective purchasing decisions. When customers choose between different products, they face a coordination problem [9]. For instance, customers may choose the telecom operator with larger communications network. Such network will bring more value to them, especially when their family members, friends and business partners also join the same network. In ICT markets, customers are influenced by each others' purchasing decision, so there exist interactions of potential adopters within their socio-economical system [10].

Meanwhile, Customers are intelligent agents with bounded rationality, which means they can make expectations about the market share of products. Traditional economics assume customers are perfect rationality. However, the behavior of an agent in reality is "nearly optimal with respect to its goals as its resources will allow" [11]. Because of imperfect information about the market, customers cannot make fulfilled-expectations about the future size of a network which correct with the equilibria of market. In fact, there exist some situations such as local bias-small clusters of users who adopt a product which does not have the largest installed base and not dominate in the whole market [12]. In addition, if the product cannot come up to the expected network benefits of the potential user, it may result in negative feedback. WAP is one such case [13]. The potential users are unwilling to pay for this product, so the real network benefits do not increase and this result in the users begin to abandon the product. Finally, the product will fail because it unable to get enough installed base to overcome the problem of critical mass.

Aiming at better understands of the evolution process of ICT markets, we construct an agent-based simulation model. Our main hypothesis is customer's purchasing decision is sometimes influenced more by the personal network of his or her acquaintances, which also called as "local feedback effects". It may be reasonable to make such assumption, since opinions and choices of family and friends play a significant role in a customer's selection of ICT products, which also called as "opinion leader" and "word-of-mouth". After knowing the early adopters have been satisfied, potential users are less wary of ICT products. Some empirical studies also support our assumption [14,15].

We also use complex networks to model the interactions between customers. [16] points out that complex networks give us a more direct-viewing understanding of the emergence of complex systems, i.e., the behaviors of whole systems. Recent years, theories of complex networks have also been applied into management science. [17] use small-world network and spatial dimension of sales data to predict the success of new product. [12] argue the validity of "Winner-Take-All" hypothesis, which comes from traditional theory of network effects, may depend on the topology of complex networks. We believe that the agent-based simulation models on complex network is a good tool for us to explore the complex social and economic systemsespecially the innovation and opinion dynamics.

The organization of this paper is as follows. The second section provides the agent-based model used for analysis. The third section shows the results of our simulations.Then, we discuss the main findings and their implications.

2 The Model

We model the dynamics of market evolution where two incompatible ICT products compete with each other. Following [18], we assume the total utility of a customer for one single ICT product is constituted by two parts: intrinsic utility and network utility. Intrinsic utility reflects the quality of a product. Meanwhile, network utility comes from the numbers of customers purchasing the same product. However, under the condition of imperfect information, customers do not know about the real market share of each product exactly. So we also assume, with bounded rationality, they make expectations about the market share of each product by the fractions of its neighbors who have already adopt separately.

2.1 Basic Model

Considered a social network size of $N = 1000$ nodes, i.e., there are one thousand customers. The total utility of purchasing product $j\{j = AorB\}$ for individual i at time t is given by

$$U_{it}^{j} = r_i + q^j + \beta^j N D_{i(t-1)}^{j} \tag{1}$$

where r_i is customer i 'preference for quality, q^j represents quality, β^j measures the strength of network effects,and $D_{i(t-1)}^{j}$ is the fractions of customer i'neighbors that have already adopt.

Following assumptions by many prior scholars (e.g., [1,12]), we suppose $r_i < 0$ for most of customers.Meanwhile, it is distributed normally, where mean μ and variance σ^2. Quality q^j reflects theintrinsic utility of products. Further, network utility depends not only on the expected network size $ND_{i(t-1)}^{j}$,which is equivalent to installed base[1], but also network strength, stemming from some characteristics of customers, such as personal interests, product loyalty[7].

2.2 Adoption and Repurchase Processes

we consider the discrete version of the continuous dynamics, i.e. the purchase decisions of customers are made in a sequential order, so in every period only one agent is chosen to revise his decision.

[1] Like [19], we replace installed base by market share.

By obeying dynamic preference rules as follows, Each customer makes a decision whether to buy or repurchase one unit of either product A or B.The dynamics of the adoption process is as follow.

(1) If both $U_{it}^A < 0$ and $U_{it}^B < 0$, customer will choose nothing;
(2) If $U_{it}^A > U_{it}^B > 0$,customer will choose product A ;
(3) If $U_{it}^B > U_{it}^A > 0$, customer will choose product B ;
(4) If both $U_{it}^A > 0$ and $U_{it}^B > 0$, customer will choose a product by probability based on the different total utility of different product:

$$Prob(choice = j) = \frac{U_{it}^j}{U_{it}^A + U_{it}^B} \tag{2}$$

From (2), we can see the larger total utility of a product, the larger probability it will be chosen by customers.

2.3 Simulation Design

Considering the condition when two incompatible ICT products are introduced to the market simultaneously, we use two different average connectivity scale-free networks to conduct simulations. The average connectivity of social networks $< k >$ (approximately $< k >$ neighbors per node) reflects the intensity of communication between customers [20], so we want to explore how the intensity of customers' communication influence the evolution of ICT markets. In order to comparative analysis the different emergence from the diverse average connectivity of network, we keep those two SF networks have the same numbers of nodes. Further, we suppose there have some seeds at the beginning of the simulations, i.e., adopters who have already own one product at first period. Those adopters, similar to "innovators" defined by [21], can be seen as initial market share or installed base of each product.

In particular we set $< k >= 6, 16$, $\mu = -30$ and $\sigma^2 = 5$.The degree distribution of network which $< k >= 6$ follows $P(k) = k^{-2.16}$.The other one with high average node degree $< k >= 16$ follows $P(k) = k^{-2.86}$ .All results are the average value of 100 independent simulation runs. The iteration of each run is 10000 periods.

3 The Results

First of all, we study on the issue whether a firm chooses between investment in initial installed base or in initial quality of its product in the initial periods of market. Because this issue concern about the business strategy of firms whether could dominate in market finally. Traditional views of network effects theory emphasize the importance of installed base products, since there exists a critical mass point. If the installed base of a product exceeds this turning point, the sales of this product will increase quickly by positive network effects. So investment in initial installed base strategy is also called as Get-Big-Fast strategy. However, managers could also use improving quality of its product strategy to compete. Meanwhile, we can see a lot of business cases in which the superior technology win the market finally although it doesn't have bigger installed base than the old inferior technology[2]. Those cases show quality drives the success of ICT products.

So there are two different strategies that firms may face: *quality advantage strategy* (QAS) or *installed base advantage strategy*(IBAS). In order to comparison, we construct a simulation by assuming both initial market shares of product A and B are 5%, i.e., $IMSA = IMSB = 0.05$, both qualities of product A and B are 20, i.e., $q^A = q^B = 20$. Further, we consider two different situations. One is when network strength is weak. i.e., $\beta^A = \beta^B = 0.5 < 1$; another is when network strength is strong. i.e.,$\beta^A = \beta^B = 2 > 1$.

We keep the determinants of product B constant, since we focus on the effects of quality advantage vs. installed base advantage on final market share of product A. Then, we make a paired comparison between initial quality advantage and initial installed base advantage at 20%, 40%, 60%, 80%, 100% level separately. For example, at 20% level, if the firm adopts an initial quality advantage strategy, it improves quality of product A .So the quality become

$$q^A = 20 * (1 + 20\%) = 24 \tag{3}$$

On the contrary, if the firm adopts an initial installed base advantage strategy, it promotes initial market share of product A by some marketing methods such as free sampling.So the initial installed base become

$$IMSA = 0.05 * (1 + 20\%) = 0.06 \tag{4}$$

Figure 1 and Figure 2 show different scenarios. When the intensity of customers' communication is low ($<k>= 6$), QAS is a dominant strategy whether network strength is weak or strong.however, when the intensity of customers' communication is high ($<k>= 16$), which strategy is better depend on the strength of network effects in the market. on the one hand, QAS is better strategy than IBAS when network strength is weak. On the contrary, IBAS strategy is a better choice for firms when network effects is strong.To sum up, we use table 1 to depict the choice of strategy when firm investment in installed base or quality of its product at the initial periods of market.

So our results indicate that whether intrinsic utility (e.g., quality) or network utility (e.g., installed base) drives the success of ICT products may depend on the intensity of communications between customers and the strength of network effects in the market.

Why our findings contradict with the conclusions of traditional economics theory? To answer this question, we examine local bias in four situations. Recall that our basic assumption is that agents are bounded rationality. Without perfect

[2] Yet, in fact there also may result in a bad situation in where the inferior technology will still dominate the whole market. The most famous case is QWERTY keyboard against Dvoak [22]. We will discuss this phenomenon next.

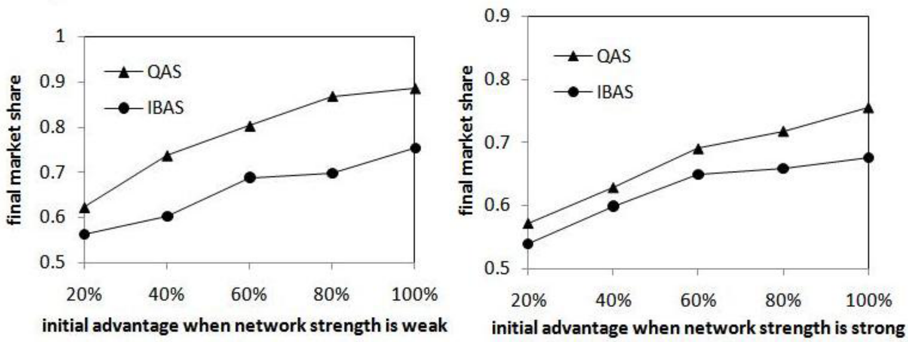

Fig. 1. The effects of initial quality advantage vs. the effects of initial installed base advantage on final market share of product A when the intensity of customers' communication is low

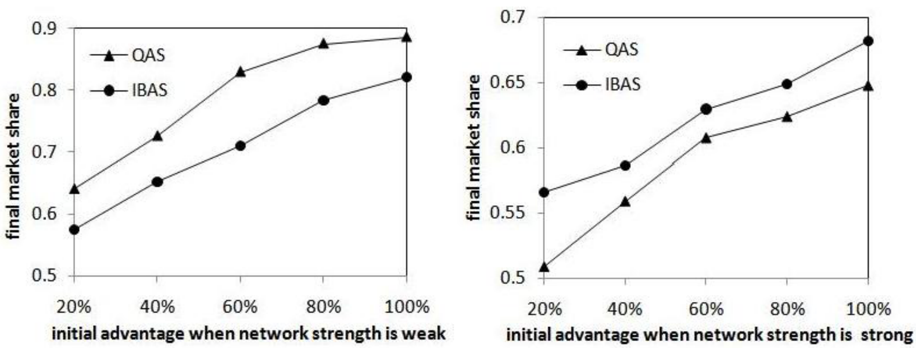

Fig. 2. The effects of initial quality advantage vs. the effects of initial installed base advantage on final market share of product A when the intensity of customers' communication is high

Table 1. Business strategy at the initial periods of market

		Intensity of customers' communication	
		Low	High
Network Strength	Weak	quality strategy	quality strategy
	Strong	quality strategy	Installed base strategy

information, they cannot know the market share of each product completely. So they make expectations about the market by observing the choices of their acquaintances. Like [12] We measure the local bias as follow:

$$Localbias = \sum_{i=i}^{N} \frac{\left|((s_{it}^{A} - s_{it}^{B}) - (s_{t}^{A} - s_{t}^{B}))\right|}{N} \quad (5)$$

Where s_{it}^A and s_{it}^B are the shares of products A and B in customer i's neighbor network at t period, respectively, and s_t^A and s_t^B are the market shares of products A and B in the whole market at t period, respectively. From the measurement above, we can know that there is no local bias if it is zero.

Figure 3 shows the different evolution of local bias under four scenarios. Table1 gives the details of parameter values for simulations. The simulation results show the clusters or communities of social networks seem to let customers make locally based choice. As a result, the level of local bias increases at first and reach the steady state finally.When the initial advantage (installed base or quality) is small, i.e. scenario 1 or 2, the level of local bias is much higher. On the contrary, i.e. scenario 3 or 4, the level of local bias will lower because the final market is a dominant market, which means most of market has been occupied by single product.

Then we turn to another question which has been discussed in economies hotly. Under which condition, the market will become an inefficient market.[9] point out that there are two kinds of inefficient markets. One is excess inertia, i.e., customers are reluctant to adopt a new product with incompatible superior technology, although its quality is much better than the old one. Another is insufficient friction, i.e., customers always favor a new product with incompatible superior technology.

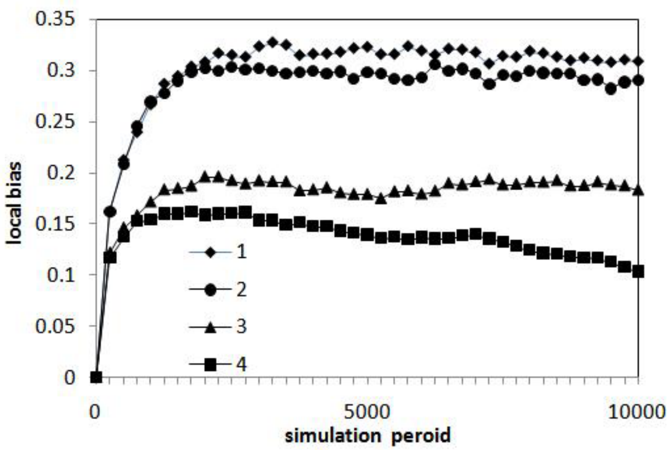

Fig. 3. Local bias over time

Table 2. Simulation parameter values for Local bias

scenario	q^A	q^B	*IMSA*	*IMSB*	β^A	β^B	$< k >$
1	20	20	0.06	0.05	2	2	6
2	24	20	0.05	0.05	0.5	0.5	6
3	20	20	0.1	0.05	2	2	16
4	40	20	0.1	0.05	0.5	0.5	16

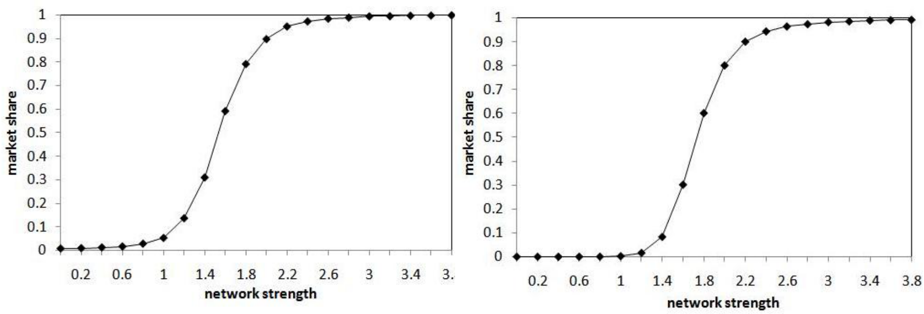

Fig. 4. Left graph:the effects of superior product A's network strength on the evolution of market. Right graph:the effects of inferior product A's network strength on the evolution of market.

In this simulation, we assume the old product B dominates the whole market,so its market share is 95% and network strength $\beta^B = 1.2$.Then a new superior product A is introduced, which has 5% initial market share. The quality of product A is twice as high as the old one. i.e., $q^A = 2 * q^B = 40$. It is to explore whether product A can lead to success by promoting its network strength β^A.The left graph of Figure 4 shows that the market will be excess inertia when $\beta^A < 0.6$. The old product B takes all the share of market.When $0.6 < \beta^A < 2.8$, final market becomes multiple equilibria.Both two kinds of products could coexist at the steady state. When $\beta^A > 2.8$, the new product A always corners the market, so the phenomenon of insufficient friction happens.

Can a product with both inferior quality and small installed base compete by improving its network strength? To answer this question, we consider the extreme situation when the quality of B is more than twice as A. i.e.,.While, other conditions are as same as in the left graph of Figure 4.

The right graph of Figure 4 shows that the winner-take-all of product B happens when $\beta^A < 1.4$.In addition,the product A takes off when $\beta^A > 1.4$.If β^A could be promoted to more than 2, product A becomes dominant.When $\beta^A >= 3.4$, product A even could take the whole market, although this event may not happen since the network strength must be more than twice as much as the competitor. However, it also indicates that firms can manipulate its network strength to win the market.This is similar to empirical study[9].Although we don't report the results when average connectivity is 6, the simulations show there are not qualitatively different.

4 Conclusions

We have developed simulation models to examine the effects of a firm's initial advantage, the intensity of customers' communication, the customer decision-making process and the network strength of products on the evolution of ICT markets. We found that when the intensity of customers' communication is low, quality advantage strategy is always better than installed base advantage strategy whether network strength is weak or strong. However, when the intensity of customers' communication is high, initial installed base advantage strategy is better than initial quality advantage strategy only when network strength is strong. This conclusion gives insight into managerial implications that whether managers choose quality advantage strategy or installed base advantage strategy at the beginning of the market may depend on the intensity of customers' communication and network strength. Traditional theory emphasizes the importance of installed base since firms can get big fast by the positive network effects. Our model suggests that this strategy may be only valid when both network connectivity and network strength are high. So managers should do some marketing research to measure network effects of the market and the intensity of customers' communication.

In addition, we found that whether market evolves into an inefficient market depends on the strength of network effects. When the network strength of superior product is too low, the market will be excess inertia. On the contrary, it may result into insufficient friction. Traditional theories use the heterogeneity of customers' preferences to explain why Apple's Macintosh still survives, although it is incompatible with the dominantly Wintel architecture. Our study suggests that there may be another two reasons. On the one hand, the network strength of PC market is not high. On the other hand, Apple's quality is very good. In fact, according to the American Customer Satisfaction Index (ACSI) published by the University of Michigan, Apple has kept customer satisfaction at the highest level in PC market since 1994, the first year of the index introducing [23].

Further, our simulation also gives implications that firms can beat competitors by increase its network strength. This is due to asymmetries of network effects between different products. In 16-bit home video game market, Nintendo beats Sega by higher network strength, although Sega has larger installed base [7].

However, our model assumes all of customers make expectations about the market by the fractions of adopters of different products in their acquaintances. In fact, there are also many customers know the market clearly through media's reports. So it needs to separate the whole customers. On the other hand, how the topology of complex networks affects the diffusion of innovations, such as degree distribution, connectivity, still needs to examine. We will explore those issues in future.

5 Sensitive Analysis

In order to test the validity of our results, we did a sensitivity analysis. First, we use WS networks[3] ($< k >= 6, 16$) to instead of SF networks for simulation. Then, we change σ^2, the variance of customers' preferences, from 0 to 25. Although the simulation results have some quantitative variance, the qualitative of our conclusions have no change.

[3] The probability of rewiring connections between nodes is 0.05.

Acknowledgments

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References

1. Katz, M.L., Shapiro, C.: Network externalities, competition, and compatibility. The American Economic Review 75(3), 424–440 (1985)
2. Farrell, J., Saloner, G.: Standardization, Compatibility, and Innovation. Rand Journal of Economics 16, 70–83 (1985)
3. Wendt, T.W.O., Westarp, F.v.: Reconsidering Network Effect Theory. In: 8th European Conference on Information Systems (2000)
4. Farrell, J., Saloner, G.: Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation. The American Economic Review 76(5), 940–955 (1986)
5. Gandal, N.: Compatibility, Standardization,Network Effects: Some Policy. Implications, Oxford Review of Economic Policy 18, 80–91 (2002)
6. Economides, N., Viard, V.B.: Pricing of Complementary Goods and Network Effects, working paper, New York University (2002)
7. Shankar, V., Bayus, B.L.: Network Effects and Competition: An Empirical Analysis of the Video Game Industry. Strategic Management Journal 24(4), 375–394 (2003)
8. Stremersch, S., Tellis, G.J., Franses, P.H., Binken, J.L.G.: Indirect network effects in new product growth. Journal of Marketing 71(3), 52–74 (2007)
9. Katz, M.L., Shapiro, C.: Systems Competition and Network Effects. Journal of Economic Perspectives 8, 93–115 (1994)
10. Schoder, D.: Forecasting the success of telecommunication services in the presence of network effects. Information Economics and Policy 12, 181–200 (2002)
11. Simon, H.A.: Models of Man. In: Social and Rational. John Wiley & Sons, Chichester (1957)
12. Lee, E., Lee, J., Lee, J.: Reconsideration of the Winner-Take-All Hypothesis: Complex Networks and Local Bias. Management Science 52(12), 1838–1848 (2006)
13. De Marez Lieven, S.B., Verleye Gino, B.M.: ICT-innovations today: making traditional diffusion patterns obsolete, and preliminary insight of increased importance. Telematics and Informatic 21, 235–260 (2004)
14. Goolsbee, A.: Evidence on Learning and Network Externalities in the Diffusion of Home Computers, Working paper, University of Chicago, GSB (2002)
15. Lim, B.L., Choi, M., Park, M.C.: The late take-off phenomenon in the diffusion of telecommunication services: network effect and the critical mass. Information Economics and Policy 15, 537–557 (2003)
16. Strogatz, S.H.: Exploring complex networks. Nature 401(8), 268–276 (2001)
17. Garber, T., Goldenberg, J., Libai, B., Muller, E.: From density to destiny: Using spatial dimension of sales data for early prediction of new product success. Marketing Science 23(3), 419–428 (2004)
18. Arthur, W.B.: Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal 99, 116–131 (1989)
19. Clark, B.H., Chatterjee, S.: The evolution of dominant market shares: the role of network effects. Journal of Marketing Theory and Practice 7(2), 83–95 (1999)

20. Wendt, O., Westarp, F.V.: Determinants of Diffusion in Network Effect Markets. Working paper. J. W. Goethe-University, Germany (1999)
21. Rogers, E.M.: Diffusion of Innovations, 3rd edn. The Free Press, New York (1985)
22. David, P.A.: Clio and the economics of QWERTY. American Economic Review, Papers and Proceedings 75, 332–337 (1985)
23. Guglielmo, C., Thaw, J.: Dell Falls, Apple Gains in Customer Satisfaction, Survey Says. Bloomberg (retrieved November 14 - August 16) (2007), http://www.bloomberg.com/apps/news?pid=10000103sid=ahi5j9WcL8VMrefer=us