The Evolution of Korean Information Infrastructure and Its Future Direction: A System Dynamics Model

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CONTENTS

ABSTRACT

The recent technological and industrial revolution dictates a new approach in constructing Korean Information Infrastructure. Lacking past data on the newly emerging markets, econometrics methodologies cannot accurately forecast future paths of advanced networks, let alone dynamic impacts of public policies. In this paper, we have built a system dynamics model of the Korean Information Infrastructure and simulated diverse policy measures including market integration and government initiative in investment for experimenting their effectiveness. The most counterintuitive result of our research is that the market integration policy will facilitate CATV networks at an early stage until the year 2010, but will result in a diminished market size in the long run. With the system dynamics approach, we can enhance our understanding of the complex policy systems and get valuable insights through learning by modeling and simulation.

I. INTRODUCTION

The telecommunications and broadcasting industries are showing rapid convergence. While telcos plan to provide video-on-demand service through their networks, CATV operators are providing Internet-access service that has been regarded as a type of telecommunication services for years. In addition to the convergence, mobile communications services have grown explosively in Korea.

The recent technological and industrial revolution dictates a new approach in constructing the Korean Information Infrastructure (KII). There has been a lot of debates going on about market integration between CATV networks and B-ISDN [1]. Market integration between them is expected to accelerate the construction of KII through competition among different industrial sectors. However, CATV operators argue that the market integration would reduce their subscribers because of their lower competitiveness [2].

In deciding whether or not to introduce the market integration policy and in figuring out how to incorporate it into the current KII policy scheme, it is necessary to analyze its effects on the evolution of advanced networks. Lacking past data on the newly emerging markets, econometrics methodologies cannot accurately forecast the future paths and impacts of diverse policies. In this paper, we use system dynamics methodologies to capture the dynamic effects of diverse policies on the future evolution of KII. For analyzing dynamic impacts of KII policies, we make a system dynamics model for KII, which allows various simulations.

In the second section, we introduce the basic concepts of system dynamics methodology, and explain important structures of our system dynamics model of KII. The third section reports our simulation design for testing KII policies and simulation results. In the final section, we discuss the policy implications of the simulation results and propose future research agenda.

II. SYSTEM DYNAMICS MODELING OF KOREAN INFORMATION INFRASTRUCTURE

1. Overview of the System Dynamics Methodology

System dynamics methodology, originated from the work of Jay Forrester, has been used to investigate various systems including industrial dynamics [3], urban dynamics [4], [5], environmental systems [6], growth and selection process of new technologies [7], [8], and competitive markets for different telecommunication services [9]. System dynamics modeling focuses on the feedback structure of a system rather than its parameters. Emphasizing structure rather than precise analysis of parameters, system dynamicists model those systems that have explicit causal structures that elude precise measurement. Emphasizing feedback mechanisms rather than external interruptions or noise, system dynamics model can trace driving forces of system evolution. Because of these methodological features, we have decided to use system dynamics to investigate the dynamic impact of KII policies.

In general, system dynamics modeling proceeds from sketching a causal loop diagram, constructing a stock-flow diagram, and finally to defining equations for model variables [10]. A causal loop diagram identifies important feedback structures embedded in a system. It consists of many causal relations between two consecutive variables. A causal relationship between two variables is positive if they vary in the same direction, it is negative if they vary in the opposite direction. A causal loop itself can be either positive or negative. A feedback loop with zero or even number of negative causal relations is positive and is characterized by self-reinforcing behavior, a feedback loop with odd number of negative causal relations is negative and shows self-balancing behavior.

A stock-flow diagram is composed of variables and their causal relationships. Variables in the stock-flow diagram include stock variables, rate variables that change the value of stock variables, and auxiliary variables that represent intermediate variables between stock variables and rate variables. After constructing a stock-flow diagram, one can define equations for each variable.

Although a system dynamics model is mathematical and can be reduced to a set of differential equations, one must note that it is not used to forecast system behavior precisely. Instead, it is used to find out dynamic patterns of system behavior.

2. Causal Loop Diagram of the Basic Model

We introduced system dynamics methodology to understand the dynamic evolution of different kinds of networks and the effectiveness of diverse policy measures. Since the policy measures we considered in this research are concerned mainly on the markets of advanced networks, our system dynamics model will focus on the competition among different network providers for acquiring their consumers.

Our system dynamics model of KII is composed of three sectors. They represent growth and decay of B-ISDN, CATV and Mobile networks respectively. These networks are incorporated into the model because they are commonly regarded as the most promising networks for emerging information infrastructure of Korea. Through group modeling workshops facilitated by David Andersen, we have found that each sector consists of three kinds of key actors: network providers, information service

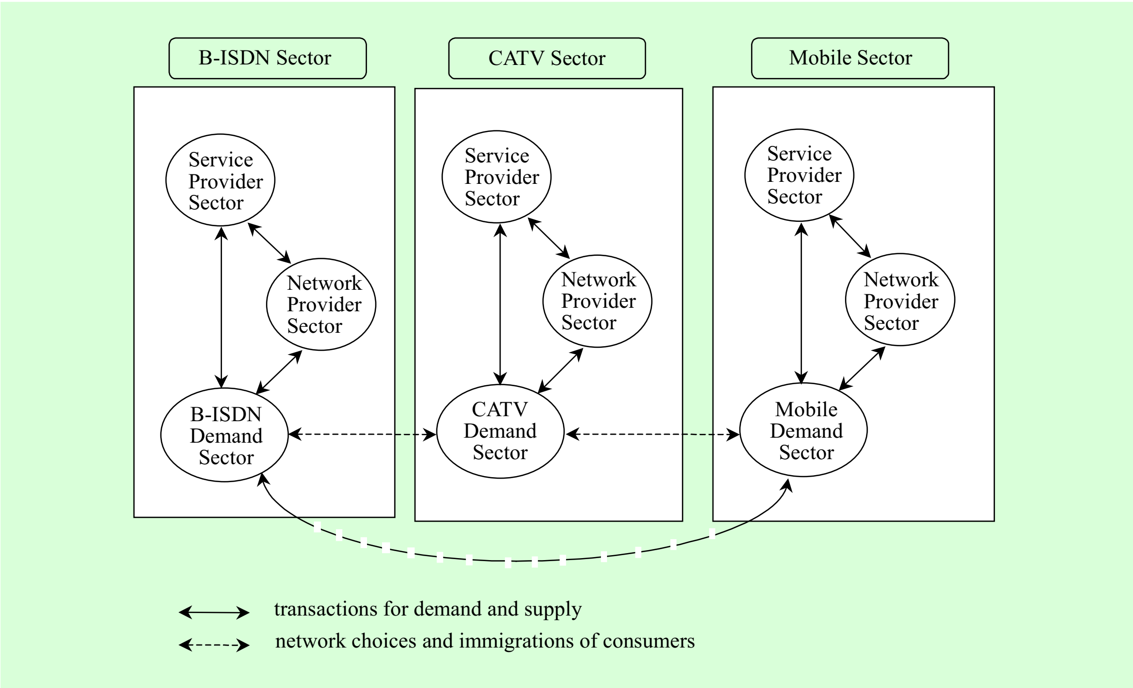

Fig. 1. Sector structure of system dynamics model of KII.

providers, and consumers (for review of the group modeling methodology, see [11]).

Figure 1 shows a three-sector structure of our model and their key actors. In Fig. 1, solid lines denote demand and supply relationships between key actors. For example, information service providers demand networking service from network providers, while they, in turn, supply information service to end-users or consumers. From the standpoint of consumers, the three networks can be interpreted as alternative products which differ in their band-width, cost, and mobility. Dotted lines represent immigration of consumers among B-ISDN, CATV, and mobile networks. Immigration of consumers represents market competition among them.

Since the growth of the number of subscribers to a particular network means subsequent increase in overall market demand for information service and other networks, the relationship among different networks is not only competitive but also complementary. These relationships form essential feedback loops of the KII development. Figure 2 is a set of causal loops between CATV and B-ISDN networks. Similar causal loops also exist in the sector of the mobile network and its interaction with the other two networks.

Feedback loops in each sector, L1, L2, and L3 of Fig. 2, are symmetrical across sec-

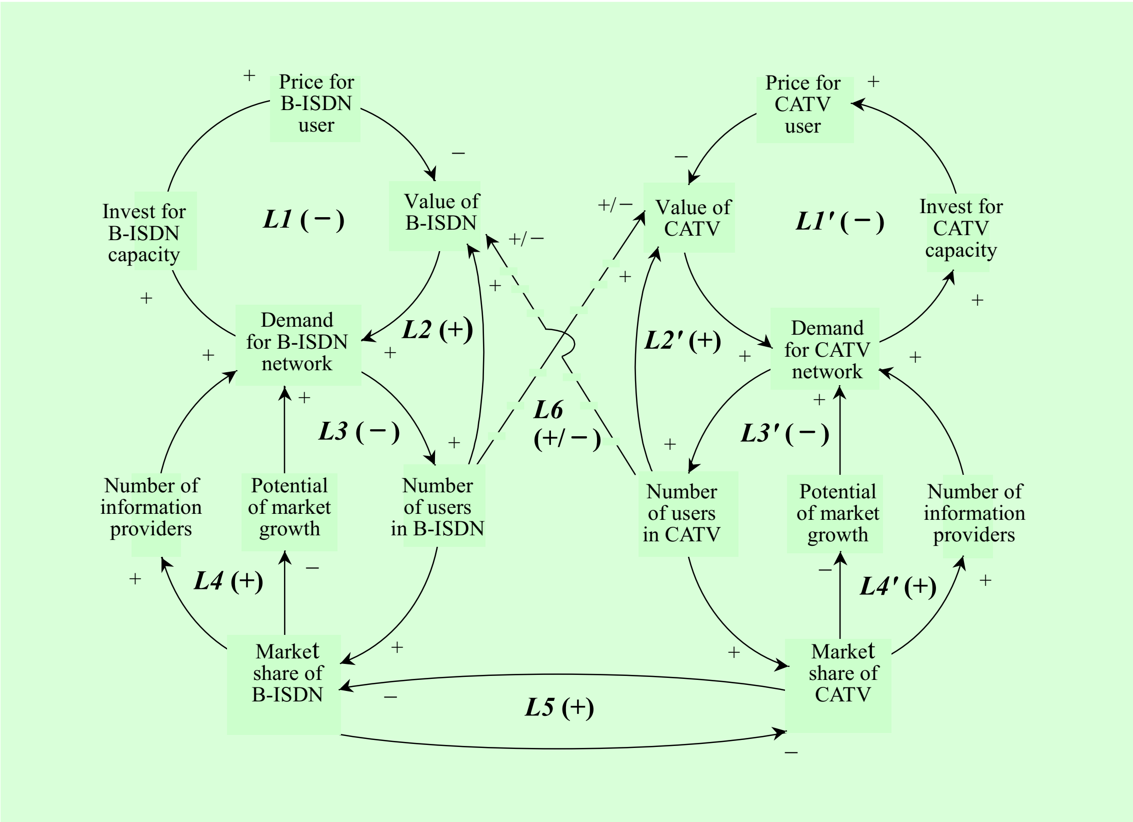

Fig. 2. Causal loops between CATV and B-ISDN networks.

tors. The first feedback loop (L1 and L1′) is a negative loop representing the price mechanism. The second feedback loop (L2 and L2′) is a positive loop incorporating network externality that plays a crucial role in determining winners in telecommunications markets [12], [13]. However, as subscribers to networks increase in number, the size of the population that remains detached from the networks decreases. The third feedback loop (L3 and L3′) has a negative gain and incorporates a limit to the growth of networks [14]. The fourth feedback loop (L4 and L4′) is a positive loop reinforcing the number of network users and that of information service providers.

In Fig. 2, all feedback loops across the two sectors are positive. The fifth feedback loop (L5) is a positive loop describing competition between B-ISDN and CATV networks. If the market share of B-ISDN increases, that of CATV will decrease. As the market share of CATV decreases, that of B-ISDN will increase all the more. The sixth feedback loop between CATV and B-ISDN sector (L6) represents a complementary relationship between them. It can be negative or positive depending on the existence of network externality. If market integration between B-ISDN and CATV is introduced, a subscriber of one network can use other networks as well. An increase in the number of subscribers to one network will not only increase the externality of that network but also enhance those of others. The market integration policy will allow network providers to share externality of their respective networks. Thus the sixth feedback loop is activated only when market integration and interoperability between different networks are institutionalized. However, as the network externality can be either negative or positive, the sixth feedback loop has bi-polarity.

3. Stocks and Flows of the Basic Model

One of the most complicated aspects in modeling KII system is the network choice behavior of consumers. First of all, consumers can use more than two networks simultaneously. Secondly, consumers can move from one network to another at any time. We modeled the consumers' network choice behavior by introducing the concept of market shares. By introducing a mechanism for market share, network choice and immigration of consumers can be represented by competitive factors of each network. Following factors are assumed to affect the market share of each network.

- *Quality of network*: Quality of network is represented by the number of information service providers that are connected to that network.
- *Cost of network*: Cost of network is represented by the tariffs for using the network, which are determined by the network construction cost and operating cost.
- *Current market share*: Current market share is assumed to affect future market share. This assumption is made for reflecting the effect of network externality and the imitation effect of consumers. With the network externality, the value of a network increases as its number of users increases. Imitation effect is a psychological attribute that says, "I want to use this network because others already use it" [15].
- *Current market share of other networks*: Effects of other networks are both negative and positive. On the one hand, networks can be assumed to be substitutive to each other. This assumption reflects the fact that only a few consumers will use all networks simultaneously. Substitutive effects are assumed to be great between B-ISDN and CATV but small between B-ISDN and Mobile. In other words, B-ISDN and CATV are assumed to be the most competitive, whereas B-ISDN and Mobile are assumed to be complementary. On the other hand, competition among networks should not be interpreted as zero-sum game alone.

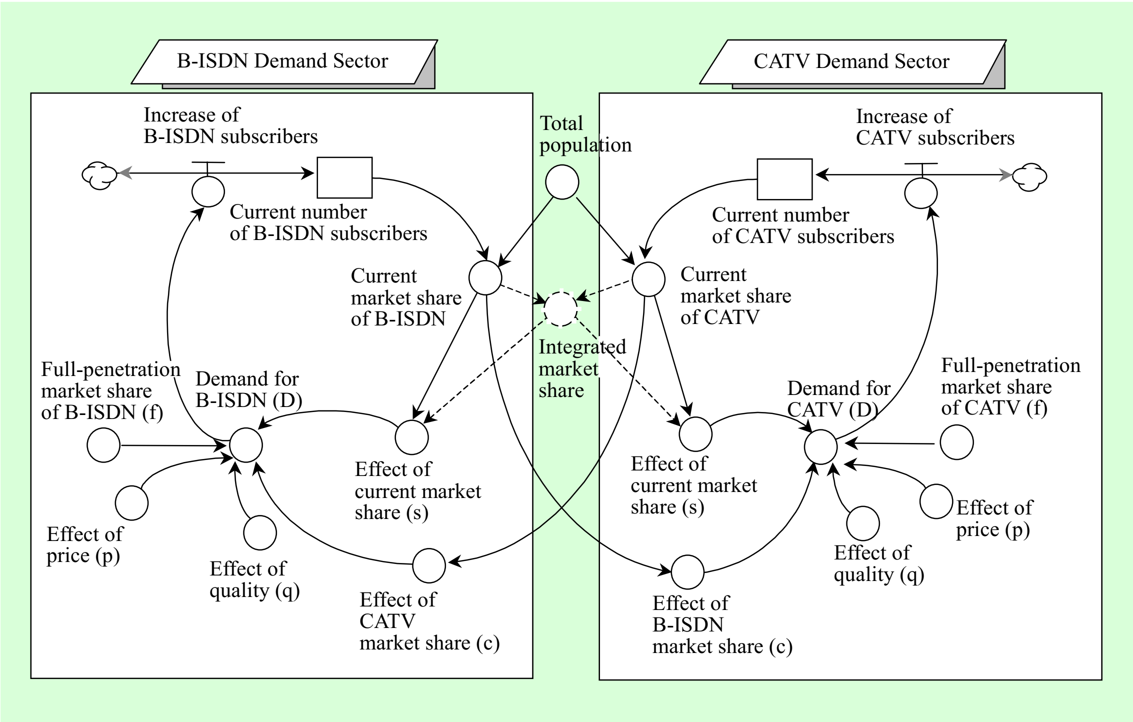

Fig. 3. Part of system dynamics model for determining current market shares. Dotted lines represent causal relations that will be introduced by market integration policy.

As explained in Fig. 2, market integration will connect different networks and they will share externality effects.

In addition to these factors, we assumed full-penetration market shares for each network, which are derived from interviews with business managers and from documents on telecommunications plans of the USA, Japan and Korea. The full-penetration market share is estimated on the assumption that there will be no competing networks. Four limiting factors discussed above will facilitate or retard potentials of each network which are denoted by the full-penetration market shares.

The stock-flow diagram in Fig. 3 is a part of our model that defines the process of determining demand for each network. Rectangles in Fig. 3 represent stock variables that accumulate their values over time and the valves represent flow variables that change the level of stock variables. Circles in Fig. 3 are auxiliary variables. Auxiliary variables in the system dynamics model simplify equations of flow variables and make a model conceptually and visually clear. The arrows in Fig. 3 represent casual relationships among variables [16].

Demand for B-ISDN and CATV network are calculated by multiplying the four ele-

Table 1. Policy scenarios for KII.

		Initiatives	
		Initiative of private sectors	Initiative of government network
Market Integration	market separation	1. separation - private initiative	2. separation - government initiative
	market integration	3. integration - private initiative	4. integration - goverment initiative

ments described above to the full penetration market share of each network.

$$D^i = f^i \times p^i \times q^i \times s^i \times \Pi C^j \ \ (j \neq i).$$

In the above equation, i and j indicate B-ISDN, CATV, and Mobile networks. D denotes the demand for the specific network. On the right hand side of the equation, f represents full penetration market share, p represents the effect of network price on demand, and q denotes the effect of the quality of networks. Although both s and C mean market share of networks, s is for representing network externality while C is for competitive effect among different networks. When the three networks are separated, the competitive effect is small. Market integration will increase the competitive effects among them. We assume that the competitive effect will be the highest between B-ISDN and CATV, and it will be the lowest between B-ISDN and mobile networks. For incorporating diffusion of network externality across different networks, we can rewrite the demand function as follows:

$$D^i = f^i \times p^i \times q^i \times \sum s^i \times \Pi C^j \ \ (j \neq i).$$

Note that the fifth feedback loop in Fig. 2 is represented by C^j, while the sixth feedback loop in Fig. 2 is denoted by $\sum s^i$ under the market integration policy.

III. SIMULATION RESULTS

1. Design of Simulation: Policy Scenarios

Current national policy for facilitating KII focuses on the government initiative in investing in advanced networks. However, some scholars cast doubts on the effectiveness of such government initiative and argue that private sectors must initiate the construction of KII. In order to test the effectiveness of government initiative and the market integration policy, we have designed policy scenarios summarized in Table 1.

The first cell of Table 1 can be used as a basic scenario with which government policies can be compared and evaluated. We simulate the market separation-private sector initiative scenario as our base-run

Table 2. Budget plan for constructing government B-ISDN network (unit: 100 million won).

	Ground stage (1995 - 1997)	Diffusion stage (1998 - 2002)	Completion stage (2003 - 2010)
Total government budget for facilitating KII	2,901 (967 per year)	3,882 (776 per year)	5,011 (625 per year)
Input parameters for constructing B-ISDN in our model	1,000 per year	500 per year	300 per year

model. And then we simulate the remaining three scenarios to investigate the impact of government policies.

Our system dynamics model of KII focuses on the market mechanism among network providers. For this reason, government policies for KII should be represented in the model by external variables, while market integration policy can be incorporated by introducing network externality and competitive effects into the demand function as described above. The government investment in constructing B-ISDN network can be introduced into the model by external variables that increase the capacity of the B-ISDN network without any burden of construction cost. These external variables can be formulated by step functions incorporating government budget plan, which are all summarized in Table 2. Since our model is a highly abstract and truncated representation of the system, one must note that our scheme for incorporating the government budget plan is also higly approximated.

We can evaluate the effectiveness of government policies in terms of time and size of its markets. The time dimension of effectiveness is related to how fast the advanced networks grow, while the size of networks is measured by the number of network users.

2. Simulation Results

Figure 4 shows our simulation results of market separation – private sector initiative scenario. The number of users in the mobile communication network rises abruptly, while that of B-ISDN follows in its early stage. However, after the year 2007, the number of users of B-ISDN surpasses that of the mobile network. The number of subscribers in the CATV network rises slowly.

Since the mobile network is most popular and has a relative advantage of price, it leads the network market in the early stage. When the market expansion of mobile network slows down around 2007 (the first and third feedback loops in Fig. 2), the market share of B-ISDN grows beyond that of the mobile network (the second and fourth feedback loops in Fig. 2). Only after the year

2005 does the number of users in B-ISDN and mobile network exceed 10 million respectively.

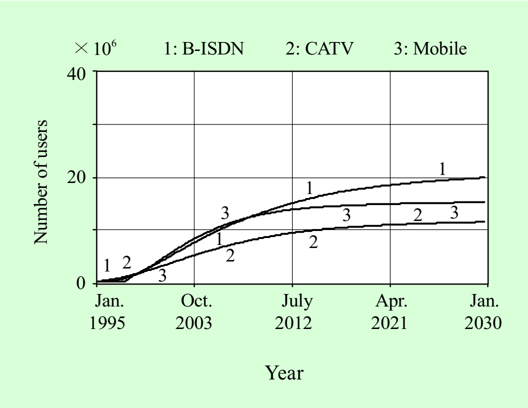

Fig. 4. Trend of diffusion: market separation – private initiative.

Figure 5 shows the effectiveness of government initiative in investment for B-ISDN. When comparing Fig. 5 with Fig. 4, one can see that the time for reaching 10 million users of B-ISDN is reduced by 3 or 4 years. Considering the small amount of the government budget invested, it can be evaluated as highly effective in facilitating KII.

Furthermore, although the government investment is finished by the year 2010, its impact continues until 2030. In 2030, the government initiative produces more than 2 million users of B-ISDN. This result implies that initial investments has a crucial role in constructing KII.

Figure 6 shows our third simulation result for market integration – private initiative scenario. Comparing Fig. 6 with Figs. 4

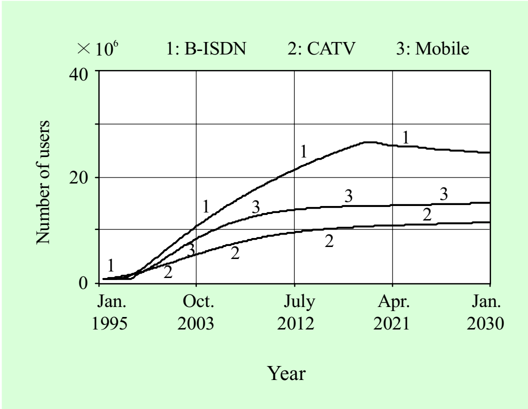

Fig. 5. Trend of diffusion: market separation – government initiative.

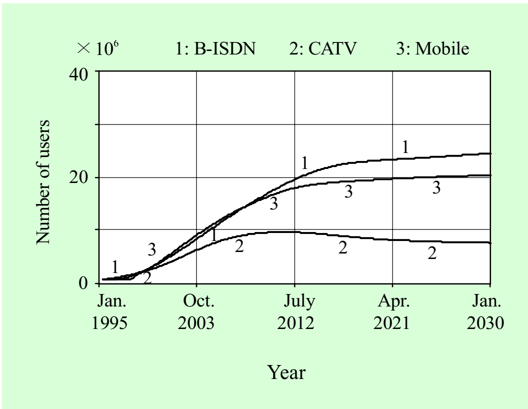

Fig. 6. Trend of diffusion: market integration – private initiative.

and 5, one can find that market integration between B-ISDN and CATV will stimulate the growth of CATV market in its early stage, while the number of its users diminishes in the long run.

Even without the interruption of government initiative, market integration shortens the time necessary for social diffusion of B-ISDN by 2 or 3 years. This effect results from the synergy effect between the B-ISDN and the CATV network. Even though there is low demand for B-ISDN, subscribers to CATV and mobile networks will provide a critical mass that induces people to use B-ISDN (the sixth feedback loop in Fig. 2). As a result, both networks grow quite fast.

Figure 7 shows the overall effectiveness of mixed policies of market integration and government initiative. While there seems to be little progress in the diffusion time of B-ISDN, the number of its users grows to more than 1 million with the government initiative. The introduction of government investment seems to bring little change in either the CATV or the mobile network.

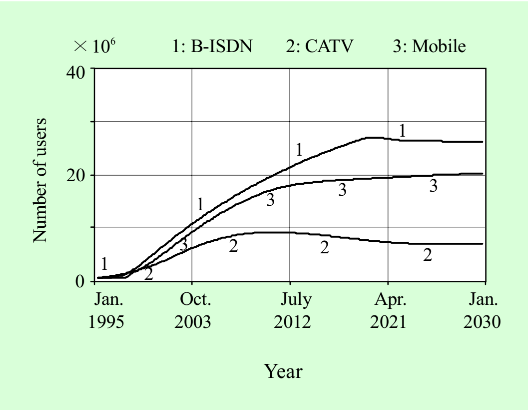

Fig. 7. Trend of diffusion: market integration – government initiative.

We can detect different performances of diverse policies easier when we compare them directly. In Figs. 8 and 9, MS is used for market separation, MI for market integration, PI for private sector initiative, and GI for government initiative.

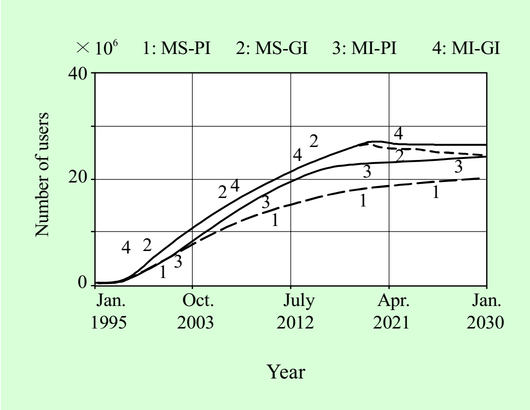

Fig. 8. Trend of diffusion: B-ISDN network.

Figure 8 is a set of time behavior of B-ISDN users according to four policy scenarios. Figure 8 shows that the 'market integration – government initiative' scenario (line 4) will bring the largest market with the shortest time delay. Also, one can find that 'market separation – government initiative' scenario (line 2) is more beneficial to B-ISDN than the 'market integration – private initiative' scenario (line 3). Under the market separation – private initiative scenario (line 1), the B-ISDN grows rather slowly. These results imply that the government initiative policy is more effective than the market integration policy in facilitating the diffusion of B-ISDN.

Figure 9 shows different impacts of government policies on CATV networks. In contrast to the policy effects on B-ISDN, the market integration policy is the most influential on the CATV market. Government initiative policy makes little difference. This can be identified by comparing lines 1 and 2 with lines 3 and 4 in Fig. 9. The market integration policy (lines 3 and 4) turns out to facilitate the growth of CATV networks at the early stage until the year 2010. However, with the market integration policy, CATV networks will lose around 3 million users during 2010 and 2030.

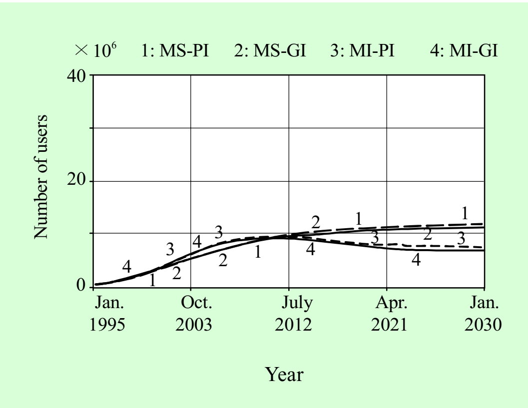

Fig. 9. Trend of diffusion: CATV network.

This result is counterintutive to the common sense expectation of policy makers and interest groups in Korea. During our interviews with them, they express belief that a market integration policy would oppress the development of CATV at the early stage. Even in the group modeling workshops, most participants could not predict the effect of market integration. It is often the case that computer modeling and simulation of complex systems produces a policy insight that cannot be reached by human inference alone. Our counterintutive simulation result can be explained by the fact that a market integration policy will produce network externality effects among different networks. Due to the network externality effect brought by the B-ISDN network, the value of CATV network to the customers will increase.

However, the market integration policy will make CATV networks as substitutive goods for B-ISDN (the fifth feedback loop of Fig. 2). When the B-ISDN grows enough around the year 2010, fierce competition between B-ISDN and CATV networks begins and the users of CATV networks start to immigrate to B-ISDN until the price of CATV goes down to an appropriate level (the first feedback loop of Fig. 2).

IV. POLICY IMPLICATIONS AND CONCLUDING REMARKS

Even though our system dynamics model does not exactly represent the real system and does not incorporate the details of diverse policies, we can observe the following policy implications from our simulation results.

First, the most favorable policy scenario for B-ISDN and mobile networks is the 'market integration – government initiative' policy. Second, the government initiative policy is more influential than the market integration policy in developing B-ISDN. Third, contrary to common sense expectation, the market integration policy will facilitate CATV networks at the early stage until the year 2010, but will result in a diminished market size in the long run. Interest groups who favor market separation should not argue that the market integration will bring CATV network to an end in the early stage. Rather, they must insist on the market loss in the long run.

Policy makers can use these implications not only in making policy but also in reaching agreements among interest groups around KII. More often than not, it is believed that interest groups of KII are so myopic and conservative that they oppose policies which are likely to bring much benefits in the long run but require huge investment in the short run. Our simulation results show that market integration may give many benefits in the short run rather than in the long run. With the help of system dynamics tools and our model of KII, policy makers can help interest groups recognize the benefits of revolutionary policies such as market integration.

In this paper, we have built a system dynamics model of KII and have simulated it to analyze the effectiveness of diverse policies. Whether or not our model described precisely, the future market system cannot be assessed at this point. As long as our model can provide policy insights for improving the current information systems from which our model is derived, we believe that our model is useful.

One of the most important conclusions from our research is that system dynamics methodology provides a promising research method for testing and analyzing new and novel policies. With a system dynamics approach, we could enhance our understanding for the complex policy systems and get valuable insights through learning by modeling and simulation.

However, we must admit that our model itself should co-evolve dynamically with the real system of information markets and as various policies are institutionalized. The most promising agenda for future research includes optimal allocation of government investment between B-ISDN construction and the information service industry, the status of the congestion effects of advanced networks, the effect of Internet on the evolution of KII, and of the global competition of advanced networks.

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