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Price Regulation and Growth Pattern of Network Industries: A Simulation Analysis

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1. INTRODUCTION

Today we are surrounded by a variety of network industries which have been rapidly evolving in complicated forms. In fact, the network service plays an essential role in various industries such as telecommunications, transport, banking, electricity and gas supplies. It is well-known that these industries exhibit network externalities which enable large established networks to be more attractive than small ones. Suppose, for instance, you are joining a mailing list on the internet. If the list is sufficiently large, you will be able to exchange information and opinions with a lot of other members of the list. In contrast, you may expect less information and discussion to be available on a small mailing list. In other words, enrollment of new members to a list benefits all existent members as well as new entrants. As a result, a large network attracts more new members and becomes more attractive. Network externalities work like entry barriers to protect established firms from small potential newcomers. Whereby they likely form a monopolistic situation in the network service market.

In addition to the above externalities, network industries are characterized by their enormous setup costs which provide another source of natural monopoly.[1] Owing to such cost structures, many of the large network industries listed above have been operated by national governments in many countries for a long time. In several advanced countries, however, these public firms have been recently privatized because of their inefficient business practices. Of course, the monopolistic nature of the industries is not eliminated as far as network externalities exist. Hence, in many cases of privatization, network firms are still regulated by several means such as price controls, licensing, and regular monitoring by the government. Those regulations are basically designed to control the market power of the monopolist companies; i.e., to pull down the monopoly price, and create incentives for cost-saving efforts. In other words, the regulations are mainly aimed at realizing optimal utilization of existent networks. This view is somewhat static but makes sense in the case of advanced economies like the EU, Japan, and the US where existing network coverage already encompasses the whole economy. In those economies, policy makers can consider how-to-use problems separately from how-to-build problems.

In developing countries, on the contrary, many network services are still in a state of infancy at present. Here, regulations affecting network industries may also influence the growth processes of the networks. For example, a price regulation on electricity supply may critically affect the form of the distribution network in a country. In electricity supply service, if a region has been linked to an interregional cable network, it costs relatively small to open new supply to an additional user in the same region since it requires only marginal extension of cables. But if the region is not linked, then costs soar, as electricity from a neighboring region has to be transferred as well as various new facilities like transformers and distributors built. Due to these fixed capital costs, the growth process of the electricity supply network itself is subject to a critical mass of users upon which the growth process can start in a region. Moreover, the above suggests that an electricity supply network is likely to developed in areas close to existing facilitated regions. That is, the present form of the supply network affects the future growth of the network. In this sense, the process of network development is subject to path-dependency.

A number of studies have been undertaken on the topic of regulations regarding network industries. Their major interests, however, have focused on the static issue; i.e., how to control the monopoly power of industry giants like telecoms, utilities, airlines and railways (e.g., Berg and Tschirthart [1988], Kahn [1988], Hayashi [1994]). They do not pay much attention to the dynamic nature of networks. On the other hand, since the seminal study by Katz and Shapiro [1985], various researchers have shed light on the topic of network externalities (e.g., Hayashi [1992] and Laffont and Tirole [1993]). But these studies recognize networks only by their size, neglecting their structure. Recently, however, several studies have appeared which analyze the spatial structure of networks like Jonard and Yildizoglu [1998] and Oltra and Schenk [1998], this has been possible mainly due to advances in computer technology.

In this chapter, we examine the dynamic effects of price regulations on the growth pattern of a network. A simulation analysis is done to see the price effects on the network structure, by using a simple model of network growth. In the model, a network is defined on a two-dimensional regular lattice in which each member can be linked only with its four neighbors. Of course, all members of the network are indirectly connected to each other through the links between other members. Next we assume that the decision to join the network is entirely left to individuals. The growth pattern of the network thus depends on individual demand for the network, which in turn depends on the price of the network service as well as on the form of the network at every point of time. We will investigate how the pricing policy of the network company affects the pattern of the network growth. By doing so, we can see the effects of price regulations.

In the next section, the basic framework of our simulation model is explained. There we derive four different pricing policies; i.e., monopoly pricing, average cost pricing, uniform pricing, and compensation pricing. As mentioned above, a network service market tends to be dominated by a monopolistic company. Then the company may set the monopoly price without regulation. In Section 3, we examine the effects of the other three regulated pricing policies in comparison to monopoly price. It is shown that regulations on a company's pricing policy have significant effects on the development pattern of a network. Furthermore, they differently affect the welfare of the network users. It is of interest that monopoly pricing is not always harmful for consumers. Our results show that network users obtain the least welfare when companies apply compensation pricing which yields completely equal benefits to all users. Some concluding remarks are given in Section 4.

2. MODEL

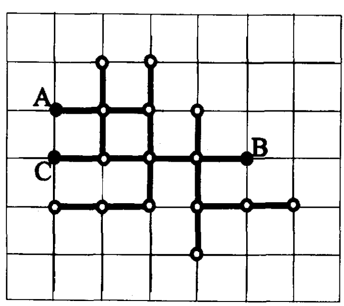
Let us examine the growth pattern of a network on a two-dimensional regular lattice. As a simple example of such a network, let us imagine an inter-library network service, in which people can borrow books from any library on the net. At the initial stage (without the network), the libraries are independently operated for their local residents. To simplify the analysis, it is assumed that all libraries are identical and uniformly distributed on the lattice. Let us suppose that every cross point of the lattice has a library and that all libraries serve the same number of users. Each library can choose either to stay as a local library or to be a member of the network by opening an inter-library shuttle service to neighboring libraries. In the network, a library can be linked only with its four neighbors. But it can also borrow books from any library indirectly connected through the other libraries (see Figure 4.1).

Individual demand for borrowing books depends on the service price and the time length to transport books. Suppose the time to obtain a book increases in proportion to the distance to the library from which the book comes. Moreover, the unit of distance is given by the length of a link, and the distance between any pair of libraries is measured along the network. For instance, Points A and B in Figure 4.1 are apart from each other by 5 units of distance, while A and C are apart by 3 units. Now the demand for *j th* library's books by *i th* library's users is assumed to be decreasing in both price of transport service and the distance between the libraries, as given by the following demand function.

$$q_{ij}=e^{-(P+\alpha r_{ij})}, \qquad i, j = 1, 2, \ldots, \mathrm{N} \qquad (1)$$

where P represents the price which can be different by transport distance,

Figure 4.1: Network Map



r_{ij} is the distance between i and j, and is a constant. Under this demand function, the consumer's surplus of the i th library's users is presented by:

$$CS_i(P^*) = \sum_{j \neq i}^{N} e^{-(P^* + ar_{ij})}, \qquad i = 1, 2, \ldots, \mathrm{N} \tag{2}$$

where P^* represents the equilibrium price.

The decision to open a shuttle service between i th and j th libraries is entirely left to the two libraries. If the users of the two libraries expect to attain sufficient benefits from the shuttle service, it will actually be established. It is natural to measure the benefits by the increment of the consumer's surplus yielded by opening the link (shuttle service). Let us thus assume that the link between i and j is realized if the resulting increase in CS_i and CS_j exceeds the cost to open the link. If P^* is constant, an increase of the member libraries yields larger CS as shown by Eq (2) and attracts more libraries to the network, which in turn makes the network more attractive. This process of self-reinforcing growth will continue till all libraries join the network unless there is an adverse force like congestion effects.[2] In this study, we do not put any growth-discouraging factor except price rise in the maeket of the network service, because our purpose is to see the development process.

Under these basic rules of network development, the book transport service is provided by a private network company. The market is dominated by the company, but the service price can be fully regulated by the government. We try to find how the difference in pricing policy affects the pattern of network growth. In particular, let us investigate the four ways of pricing as follows.

(a) monopoly pricing

Suppose the company can put different prices for different distance to transport; i.e., $P = P_{ij}$, $(i, j = 1, 2, \ldots, \mathrm{N})$. Then the profit is given by:

$$\pi = \sum_{i=1}^{N} \sum_{j \neq i}^{N} (P_{ij} - cr_{ij}) e^{-[P_{ij} + acr_{ij}]}, \tag{3}$$

where $c\, r_{ij}$ represents marginal cost (= average cost) of transport for distance r_{ij}[3]. When there is no regulation on price, the company will offer the monopoly price given by Eq (4).

$$P_{ij}^{M}=1+cr_{ij}, \qquad r_{ij}=1,2,\ldots,\text{N-1} \tag{4}$$

The price gets higher when a user borrows a book from a library far away. Then i's demand for the books transported from j is given by:

$$q_{ij}^{M}=e^{-[1+(\alpha+c)r_{ij}]}, \qquad i,j=1,2,\ldots,\text{N} \tag{5}$$

(b) average cost pricing

When the government regulates the price to be set at the level of average cost, the price and the demand are given as follows.[4] As in the case of monopoly pricing, the price is higher for a book from a farther library, and thus people tend to borrow more books from near libraries. For any distance, however, the price is lower than the monopoly price noted in (a).

$$P_{ij}^{A}=cr_{ij}, \qquad r_{ij}=1,2,\ldots,\text{N-1} \tag{6}$$

$$q_{ij}^{A}=e^{-(\alpha+c)r_{ij}}, \qquad i,j=1,2,\ldots,\text{N} \tag{7}$$

(c) uniform pricing

Suppose a network company is regulated to transport a book at a given price irrespective of the transport distance. In many countries we can observe this sort of pricing policy in the postal service. The charges for domestic parcels are different by weight but not by distance to be transported. Usually the postal services are directly operated or subsidized by the government. So, sometimes they do not care about deficits incurred under this price regulation, which yields large inefficiency in the sector. Here, we assume that nobody subsidizes the company, and hence that the price is determined at the company's break-even level. Then we have:

$$P^{U}=c\hat{r}, \tag{8}$$

$$q_{ij}^{U}=e^{-(c\hat{r}+\alpha r_{ij})}, \qquad i,j=1,2,\ldots,\text{N} \tag{9}$$

where $\hat{r}$ represents the weighted average of transport distance; i.e.,

$$\hat{r}=\sum_{i=1}^{N}\sum_{j\neq i}^{N}q_{ij}^{U}r_{ij}\Big/\sum_{i=1}^{N}\sum_{j\neq i}^{N}q_{ij}^{U} \tag{10}$$

With this pricing policy, all users can access the network at an equal price. So, if the network covers the whole country, it provides all the population with the service at the same price. This kind of service is often called universal service.

(d) compensation pricing

Finally let us consider an extreme case of egalitarian policy in which all network users obtain totally equal benefits. Suppose that the network company is regulated to set its service price at the level offsetting the time cost of book borrowing; i.e.,

$$P_{ij} + \alpha\, r_{ij} = A, \qquad i, j = 1, 2, \ldots, \mathrm{N} \tag{11}$$

where A is a constant. As with uniform pricing, we assume that the level of A is set so that the company's deficit equals zero. Then A is given as follows.

$$A = (\alpha + c)\,\bar{r}, \tag{12}$$

where $\bar{r}$ represents the simple average of distance; i.e.,

$$\bar{r} = \sum_{i=1}^{N} \sum_{j \neq i}^{N} r_{ij} \Big/ N(N-1). \tag{13}$$

As a result, the price and demand are given by:

$$P_{ij}^{C} = (\alpha + c)\,\bar{r} - \alpha\, r_{ij}\ , \tag{14}$$

$$q_{ij}^{C} = e^{-(\alpha + c)\bar{r}}, \qquad i, j = 1, 2, \ldots, \mathrm{N} \tag{15}$$

The service price, P_{ij}^{C}, is lower for long-haul so as to compensate for time spent waiting delivery. Hence the users try to borrow the equal amount of books from all libraries, as shown in Eq (15). The company shows a profit in short distance services and deficits in long-haul.

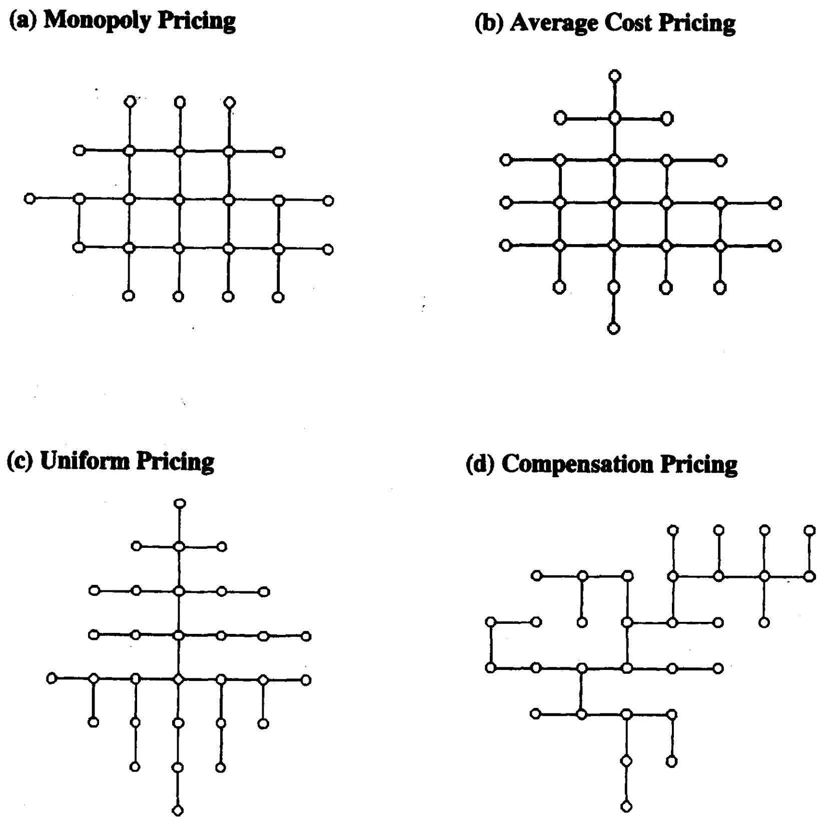
3. SIMULATION RESULTS

In the simulations below, we set the parameter values at α=c=1/2. Each simulation is started at the same initial state whereby two neighboring libraries at the center of the lattice are linked (two-member network). Then among all potential links to the network we select the one which yields the largest consumer's surplus to the libraries at both ends of the link. When there are multiple potential links yielding the same largest benefit, we select one of them by generating a random number. After establishing the new link, we iteratively conduct the above calculation for selecting the next link to connect.

The four figures in Figure 4.2 show the forms of the networks with 30 links yielded by simulation, assuming the above four pricing policies, respectively. The network with monopoly pricing in figure (a) looks similar to that with average cost pricing (figure (b)). These two pricing policies tend to form dense networks in a relatively small range of space. Under these policies, the network distance becomes a critical determinant of the transport costs since both transport price and time cost increase as the distance gets longer. As a result, libraries try to save transport distance as much as possible by building direct connections to their neighbors. Obviously, this causes the emergence of a dense network.

In contrast, under uniform pricing, we can observe a different pattern of network growth. The linkage is not dense compared with the above two cases. In fact, there are only four libraries which have direct links to

Figure 4.2: Network Formations



all their neighbors in figure (c), while those libraries are 10 and nine in figures (a) and (b), respectively. This tendency appears more clearly in the case of compensation pricing. In figure (d), we can find only one library having direct links to all its neighbors. Since distance does not matter in compensation pricing, libraries want to spread the network as wide as possible, in order to fully exploit network externalities.

Table 4.1 summarizes the aspects of the networks shown in Figure 4.2. Reflecting the density of network linkage, the numbers of member libraries is small in the cases of monopoly and average cost pricing. Since the number of links is 30 in every case, 31 libraries in networks (c) and (d) mean that they always attract new members in the growth process, while networks (a) and (b) sometimes construct new links between old members. This difference in development patterns contrasts the average distance of member libraries shown in column (2); i.e., 3.46 and 3.62 for monopoly and average cost pricing, while 4.32 and 5.48 for uniform and compensation pricing, respectively.

Column (3) shows the average price for transport of a book for each pricing policy. They are calculated as weighted averages of the price to transport a book for various distances.[5] Not surprisingly, monopoly price is higher than average cost price and uniform price since it is the price which maximizes profit for the network company. But it may seem a bit strange that compensation price exceeds monopoly price. This is basically because the libraries in (d) locate apart form each other. As long-haul transport costs are high, the network company must set compensation price at a high level to avoid deficit. This expensiveness on the other hand spoils demand and thus the consumer's surplus in the case of compensation pricing. The values in column (4) indicate the total surplus which is given as the total of consumer's surplus and profit of the network company. Since the company makes no profit in the lower three cases, total surplus is equivalent to consumer's surplus. The value is

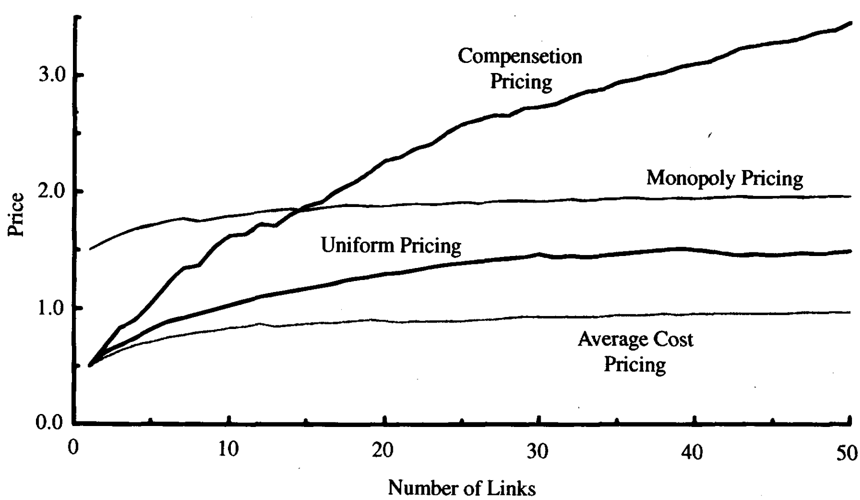
Table 4.1: Simulation Result

	no. of libraries (1)	average distance (2)	average price (3)	total surplus (4)	average surplus (5)
(a) monopoly pricing	25	3.460	1.920	34.849	1.394
(b) average cost pricing	26	3.622	0.930	47.420	1.824
(c) uniform pricing	31	4.318	1.461	35.477	1.144
(d) compensation pricing	31	5.475	2.738	0.008	0.000

extremely small in the case of compensation pricing as seen above. Probably, the network stops growing at an earlier stage of the development process, i.e., when consumers attain surplus just covering the cost to build a link.[6] Finally, column (5) shows the value of surplus per library. Again the value is quite small for compensation pricing. In addition, it should be noted that the average surplus is larger in the case of monopoly pricing than in the cases of compensation pricing and uniform pricing too. This exhibits the inefficiency of the price system which does not reflect transport distance. Uniform pricing benefits people on the periphery in exchange for increasing the burden on people in central locations.[7] Hence, it works as an interregional income transfer and yields distortions in resource allocations in the economy.

What can we learn about the dynamic nature of pricing policies? First of all, let us take a look at the behavior of average prices in the process of network growth which is presented in Figure 4.3. The horizontal axis of the Figure represents the number of links in the network. Hence, a growing network moves from left to right in the figure. All four curves in Figure 4.3 are upward sloping, which shows that prices rise as the networks become larger. But monopoly price and average cost price are relatively stable compared with the other two prices. This follows the difference in the development patterns of the networks. With monopoly pricing or average cost pricing, a network grows by fostering close connec-

Figure 4.3: Average Prices



tions of libraries by building dense linkages as observed in Figure 4.2. This structure of network maintains transport cost at a low level which in turn allows the network price to stay low. In contrast, uniform pricing and compensation pricing stimulate network growth with sparse linkage, which likely derives high cost and high price for network services. As a result, these prices tend to rise rapidly in the process of the network growth. In particular, compensation price exceeds monopoly price in large networks as shown in Figure 4.3.

Price behavior is reflected in demand for the network service and thus to the consumer's surplus. Figure 4.4 shows the marginal increase of the consumer's surplus attained by the users of the two libraries building the latest link.[8] As mentioned in the previous section, the libraries decide to build links if the marginal increase of the surplus exceeds the cost of the link. Hence the value is a major determinant of the dynamic behavior of the network. The curves in Figure 4.4 keenly fluctuate, but if they are smoothed out, we can observe upward slopes for monopoly pricing and average cost pricing. For the other two pricing policies, on the contrary, the curves rise first and then turn to decline. In particular, under compensation pricing, the benefit of a link drops sharply and becomes the lowest among the four cases. It is a little paradoxical that the consumer's surplus under compensation pricing is lower than the that under monopoly pricing. Despite the fact that compensation price is designed to benefit

Figure 4.4: Marginal Increase in Consumer's Surplus

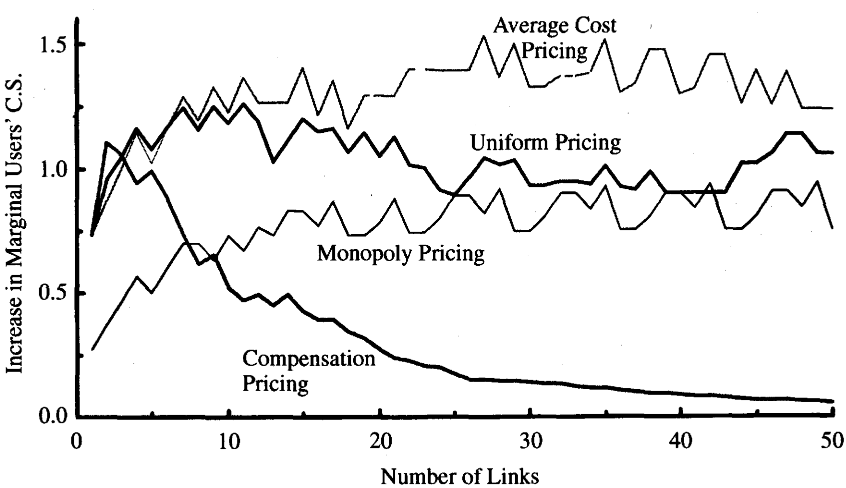
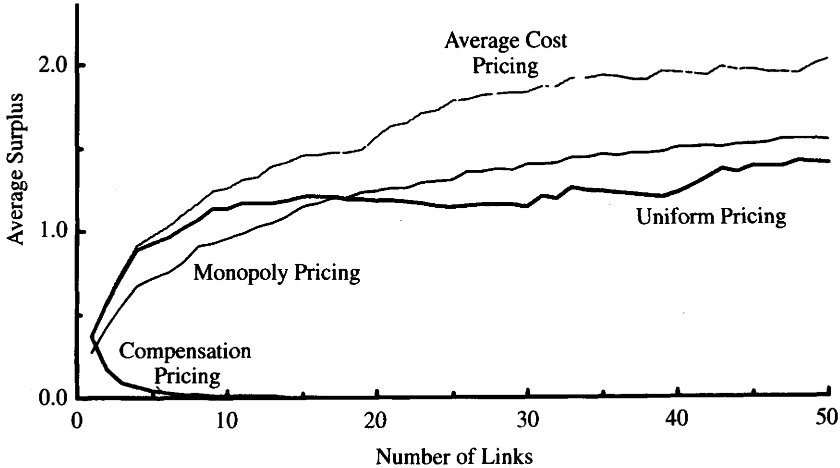


Figure 4.5: Average Surplus per Library



coousumers by compensating time cost, it results in harming consumers by raising the price of the network service. Uniform pricing also exhibits a similar tendency to some extent. In fact, for networks with more than 15 links, there is no big difference in consumer's surplus between uniform pricing and monopoly pricing. In this sense, the traditional emphasis on the harmfulness of monopoly pricing may not be quite so robust.

Figure 4.5 indicates the average surplus per library. The surplus is composed of consumer's surplus and network company's profit. For the three pricing policies other than monopoly, however, it is equal to the value of consumer's surplus since the company makes no profit. In all ranges of network size, average cost pricing exhibits the best performance among the four pricing policies. Hence, this pricing policy is highly recommendable if governments can efficiently force it on companies.[9] Another striking profile in Figure 4.5 is that the surplus under compensation pricing falls quickly to zero. It shows that compensation pricing benefits nobody. This is mainly because the price rises as the network grows, which is caused by the adverse customer selection that the network attracts i.e., more users in peripheral areas (high cost) than in central areas (low cost). It is reasonable to expect that networks with this pricing policy cannot grow large unless they are subsidized by government. And, such a subsidization program also has a high cost. Therefore, compensation pricing is not a rational way to stimulate network growth, despite its apparent initial philosophical attractiveness.

Uniform pricing yields more surplus than monopoly pricing in the first part of the network growth process. However, when the network becomes large, monopoly pricing contributes more than uniform pricing. This role reversal is also caused by the difference in the growth patterns derived by the two pricing policies. As uniform pricing tends to attract more users in peripheral areas, network growth with this pricing policy brings price rises and less consumer's surplus, compared with monopoly pricing. Again, monopoly pricing may not be very harmful when the network has sufficiently grown.[10] In addition, this pricing policy has a practical advantage since it does not require regulatory costs like monitoring and enforcement. Moreover, it seems effective to make a selective use of monopoly pricing and uniform pricing, referring to the stage of network development; i.e., in the first stage, stimulate growth by forcing uniform pricing, and then deregulate to allow monopoly pricing.

4. CONCLUDING REMARKS

Pricing policies of network companies have a significant influence on the development patterns of the networks. Hence, price regulation by the government has dynamic effects on network growth as well as static effects which are regularly discussed in economics. Monopoly pricing and average cost pricing encourage the development of networks with dense linkage among a relatively small number of users (libraries). In contrast, sparse networks are likely to emerge under uniform pricing and compensation pricing.

This contrast in the network form is caused by the difference in price structure with respect to transport distance. In the former two policies prices get higher with distance, while in the latter two, prices have no relation or adverse reaction to transport distance. Hence uniform pricing and compensation pricing tend to attract more users in the periphery where people are located relatively far from existing members of the network. Obviously, this yields a sparse network structure. But for the network company, the above mechanism works as an adverse selection which invites more of costly users. As a result, in the process of the network growth, the company must raise rapidly the price to avoid deficit, which spoils demand for the network service.

The increase in price brings less consumer's surplus in the networks with uniform pricing and compensation pricing. In fact, the benefits of a link to the two libraries connected quickly decreases in the case of compensation pricing. It implies that the network cannot grow large unless it is subsidized by the government. It is of interest that compensation pricing generates less consumer's surplus than monopoly pricing. The inefficiency of the former pricing system forces the network to operate in the opposite direction of its initial purpose to subsidize consumers. On the contrary, monopoly pricing seems to work rather well. In this sense, the traditional emphasis on the harmful effects of monopoly pricing may not be quite so robust.

If we evaluate the pricing policies by average surplus including profit of the network company, the advantage of monopoly pricing becomes more clear. It yields more surplus than uniform pricing when the network is sufficiently large. Probably we may make selective use of monopoly pricing and uniform pricing, referring to the stage of network development; i.e., in the first stage, stimulate growth by forcing uniform pricing, and then deregulate to allow monopoly pricing.

Finally it should be noted that the presented simulation results are, needless to say, relying on our specific assumptions like the lattice structure of space and the exponential form of demand. We put them to avoid complexity of analysis, but of course it is desirable to relax them as much as possible. In particular, the assumption of the lattice space places a tight restriction on the possible growth patterns of the network. In addition, we need to incorporate competition among networks. However, these have been left for future studies. There is no doubt that network industries play an essential role in the process of economic development. And that we really need to study these implications more closely in order to know what to do for healthy network growth.

Notes

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1 Of course, the market may not be monopolized if the sunk cost of the network service is sufficiently small.

2 Congestion effects appear if there are upper limits in transport capacities. For example, road congestion by heavy traffic among the libraries will

increase the time cost of the book transport service. But even in our model, as shown in Section 3, CS may decrease with an increase in member libraries since P^* can rise in the process.

[3] We assume linear transport cost both in distance and in bulk of transport.

[4] A situation between (a) and (b) will appear when the network company is allowed to receive profit with a constant markup rate on the average cost.

[5] The prices are weighted by the amount of borrowing demand for books.

[6] Here, the simulation has continued until getting 30 links, by assuming zero cost to build a link.

[7] Compensation pricing works in the same way, but more strongly.

[8] The value does not represent the *total* consumer's surplus but the *increment* of consumer's surplus, which is calculated by subtracting the consumer's surplus without the new link from that with the link.

[9] Of course, there are various problems in practicing price regulations. They are mainly caused by asymmetric structure of information between companies and the government. In details, see Berg and Tschirthart [1988], Kahn [1988], Laffont and Tirole [1993], and Tsuji [1992].

[10] The surplus under monopoly pricing contains profit. Hence, of course, there still remains the problem in income distribution between consumers and producer.

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