Mobile Internet Pricing: Circuit Pricing versus Packet Pricing

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Abstract

In this paper, we compare the market performances under circuit pricing whereby users are charged based on their length of usage time and under packet pricing whereby users are charged based on the amount of information received. We show that, if packet pricing is introduced, the market price rises contrary to the government's expectation but that the overall social welfare is unambiguously increased because packet pricing reflects the social cost properly while circuit pricing does not. Also, we show that, if delivery of multi-media files requires a much higher speed, a move to packet pricing lowers the price of multi-media transmission, thereby increasing the usage of multi-media data in the absence of congestion, which may not be the case in the presence of congestion.

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1 Introduction

With a fast increase in internet users combined with the popularity of cellular phones, the demand in the wireless internet service is also on the increase. Moreover, a recent development in the technology of the wireless communication enabling transmission of moving pictures has put the market of the wireless internet into one of the most promising and lucrative areas. According to the OVUM (2001)'s forecast, the number of mobile connections worldwide will grow from almost 727 million at the beginning of 2001 to 1,266 million at the beginning of 2003, and will reach more than 1,764 million by the beginning of 2005. Also, the number of mobile e-commerce subscribers will grow from a small base in 2001 to over 415 million by 2005. These subscribers are expected to generate mobile e-commerce revenues of more than $230 billion in 2005.

It is of course that there is much debate over pricing in such an evolving industry. Yet, most countries in which the user base is on a rudimentary level adopt circuit pricing whereby users are charged based on their length of usage time.

In the meantime, the pricing system in a contrast with circuit pricing is so-called packet pricing whereby users are charged based on the amount of information received. It was first introduced in the i-mode service by NTT DoCoMo in Japan in February, 1999. i-mode, which was the first wireless internet in the world, has enjoyed phenomenal success and it had more than 11 million subscribers as of Sepember 2000. NTT's strong market position, successful partnership, secure content strategy, and strong links with handset manufacturers, among many others, are considered to have helped to shape i-mode's success. But it has been widely believed that, among many characterstics of NTT DoCoMo's success, packet pricing was the key to its success. i-mode clients are charged per packet of information downloaded, not based on time used, as for circuit-switched networks. It has been argued that packet charging is cheaper than time-based charging for data transmission and that this cheap price has helped to boost its customers.

The Korean government also recommended wireless internet service providers (ISPs) to turn into packet pricing, starting on April, 2001. The aim of such a move was, as in the case of i-mode, to foster the wireless internet industry by inducing a fall in the wireless internet usage fee thereby enlarging the user base. In particular, the Korean government intended to encourage the use of multi-media data by recommending a much lower price for a unit packet of multi-media than for a unit of text-based data.[1] In this paper, we will investigate the validity of this reasoning by analyzing a formal model of circuit pricing and packet pricing.

Unfortunately, it turns out that much of the above reasoning supporting packet pricing is misleading. First, it should be recognized that the whole connection time a consumer uses the internet consists of the time of data transmission and the time of data processing, for example, of simply reading the screen, or just thinking over the internet etc. Circuit pricing used in most countries is to charge for the total connection time which is the sum of the transmission time and the data processing time, as in telephone charges, while packet pricing is typically to charge only for the amount of data transmitted. So, even if the market price were to fall after packet pricing is introduced, this would be not because firms moved from circuit pricing to packet pricing, but because they charged only for the part of data transmission rather than for the total service during the whole connection time. Thus, if we consider another pricing system whereby a user is charged for the whole connection time net the data processing time, which is the pure transmission time, one can hardly say that the price will be higher under this pricing than when users are charged for the data amount to be received as under packet pricing. Second, when the government decided to move to packet pricing, it seemed not to care much about the effect on the possibility of congestion that ought to be seriously considered in determining the pricing system. A too low price inducing unnecessary internet use may aggravate congestion, thereby making consumers worse off.

In this paper, we derive some interesting results. First, it is shown that it is an illusion that turning into packet pricing will lower the price. Rather, the price goes up unambiguously after packet pricing is adopted. Moreover, congestion is aggravated despite the higher price. Nevertheless, surprisingly, the social welfare is necessarily increased under packet pricing. Also, we show that a move to packet pricing lowers the price of multi-media transmission, thereby increasing the usage of multi-media data in the absence of congestion, which may not be the case in the presence of congestion.

Discussion hitherto can be also applied to wired internet pricing. Currently, flat-rate

[1] As of April 2001, per packet prices for text-based data and for multi-media data are 6.5 Won and 2.5 Won respectively.

pricing dominates in the market of the wired internet service.[2] Apart from discussion on the advantages and disadvantages of flat-rate pricing versus usage-based pricing, domination of flat-rate pricing in the market seems to be attributed to situational or strategic consideration. Mason (2000) ascribes this dominance to metering costs. If the cost of metering the usage is not negligible, flat-rate pricing may emerge as a consequence of cost minimization.[3] He also shows that firms prefer flat-rate pricing more for a strategic reason as the market becomes competitive. Kim (2001) asserts that firms may prefer to choose flat-rate pricing in an earlier stage of the market evolution if habit formation matters in consumers' behavior in using the internet. This explanation may help to account for why, contrary to the case of the wired internet service, we rarely observe flat rate pricing in the wireless internet service in which, due to many restrictions in time and space, the usage volume is not large enough to form a habit.[4]

The paper is organized as follows. In section 2, we set up the basic model. In Section 3, we compare the outcomes under circuit pricing and packet pricing. In Section 4, we extend the model into the case that there are two types of files requiring different velocities of transmission. Concluding remarks follow in Section 5.

2 Model

We consider homogeneous ISPs and homogeneous consumers each with size one in a competitive wireless internet market.

We assume that the utility a consumer gets by using the internet depends on the amount of the information he receives, q, and the length of time he receives the information, $T(q)$.

[2] Usage-based pricing corresponding to circuit pricing is rarely used in the wired internet service with few exceptions. Chile has tried the usage-based pricing policy for several years, but has not been so successful. On the other hand, in New Zealand, this policy has been effective. In the case of New Zealand, since 1990, Internet gateway has been managed by Waikato University which adopts usage-based pricing to recoup the initial investment costs and, contrary to the case of Chile, the network has been steadily growing with providing the velocity of 9,600bps - 512kbps. See Brownlee (1994) for more details.

[3] This explanation is basically borrowed from literature on buffet pricing. See e.g. Nahato *et al.* (1999) or Fishburn *et al.* (1997).

[4] A survey reports that one-time connection time of the wireless internet service does not exceed 2 minutes on the average.

Delay in receiving information incurs disutility to a cousumer. It is assumed that the time of data processing is negligible throughout before the appendix.[5]

A consumer's utility function is denoted by $U(q, T(q))$.[6] We will make some assumptions on $U(\cdot, \cdot)$.

Assumption 1 $U_1 > 0$, $U_{11} < 0$.

Assumption 2 $U_2 < 0$, $U_{22} < 0$.

Assumption 3 $U_{12} = 0$.

[A1] is a standard assumption of decreasing marginal utility. [A2] simply says that the utility is decreasing with an increase in the time of receiving given data and that the marginal disutility is also increasing with it. [A3] says that U is additively separable in q and T, implying that the time of receiving data does not affect the marginal utility of q.

Also, we assume that the velocity of transmitting data is constant when the network is not congested, in other words, that the transmission time is uniquely determined entirely by the size of data a user receives. Normalizing the time of receiving data q by q, we assume that $T(q) = q$ if $q \leq K$ and that $T(q) > q, T' > 0, T'' > 0$, if $q > K$. Here, K is the network capacity. We call the network to be congested if $T(q) \neq q$.

We assume that the cost of transmitting a unit size of data is $c(> 0)$ which is constant,[7] that the additional transmission cost due to delay does not occur and that there is no fixed cost.

[5]This assumption may be justified by imagining that one could make the time of processing information on the internet close to zero by disconnecting the internet just after downloading the data and then processing it on the palmtop computer.

[6]In Mackie-Mason *et al.* (1994), they explicitly incorporate the negative externalities a user causes to others into the model by considering finite consumers. However, in a situation where the effect of a user's consumption behavior on others is negligible in a world of a large population, our model becomes more relevant than their model in which an individual user's behavior can influence others in a tangible way.

[7]It is believed that the cost of transmitting data is not independent of the data size, especially in the wireless internet service, because it is required to expand transmission facilities in proportion to the volumn of the traffic.

3 Analysis

In this section, we will compare the outcomes under circuit pricing whereby firms charge a price p for $T(q)$ and under packet pricing whereby they charge for q.

Analysis will be made in two steps under each pricing. In the first step, we consider a consumer's choice problem given p. In the second step, we characterize the equilibrium market price.

3.1 Circuit Pricing

Given the market price p, a consumer chooses q so as to

$$\max_q U(q, T(q)) - pT(q).$$

The first-order condition implies that

$$U_1 + U_2 T' = pT'. \tag{1}$$

Equation (1) says that a consumer chooses the amount of data equating a net increase in utility from choosing an additional unit of data (a direct increase in utility minus an indirect increase in nonmonetary disutility through delay in transmission) to an increase in monetary disutility due to delay in transmission. Notice that the second order condition is satisfied under [A1] - [A3].

If there is no congestion ($K = \infty$), equation (1) is reduced to $U_1 + U_2 = p$. Notice that $U_1 + U_2 > 0$ is not implied from our assumptions [A1] - [A3]. In reality, consumers do not choose to receive data as large as possible when it is free of charge. Too much information would prolong the delivery time and the disutility from this delay would increase exponentially, so this would ultimately dominate the utility from receiving information. On this ground, we believe that it is more realistic not to exclude the case that $U_1 + U_2 < 0$.

If we denote by $D_0(p)$ the demand function in the case of no congestion i.e., $T(q) = q$ for all q, $D_0(p)$ is characterized by $D_0(p) = q$ satisfying $U_1(q, q) + U_2(q, q) = p$. Assume that there is $\overline{p}(> 0)$ such that $D_0(\overline{p}) = K$, implying that congestion occurs if it is free to use the internet. Here, $\overline{p}$ can be interpreted as the highest price generating congestion.

Now, let us denote by $D(p)$ the demand function taking into account the possibility of congestion. It is easy to see that $D'(p) < 0$ by differentiating (1). Also, observation of (1) yields the following proposition.

Proposition 1 *(i)* $D(p) = D_0(p)$ *if* $p \geq \overline{p}$*. (ii)* $D(p) < D_0(p)$ *if* $p < \overline{p}$*.*

Proof. From the definition of $\overline{p}$ and $D'(p) < 0$, (i) is trivial. To prove (ii), we have, for any $q > K$,

$$\begin{aligned} \frac{U_1(q, T(q))}{T'} + U_2(q, T(q)) &< U_1(q, T(q)) + U_2(q, T(q)) \text{ by } T' > 1 \\ &< U_1(q, q) + U_2(q, q), \text{ since } U_{12} = 0 \text{ and } U_{22} < 0. \end{aligned}$$

Since $D'(p) < 0$ and $D_0'(p) < 0$, it follows that $D(p) < D_0(p)$ for all $p < \overline{p}$.

Intuitively, an internet user demands data less in the face of the possibility of congestion, because receiving an additional unit of information delays the transmission time, which increases both non-monetary and monetary disutility. Notice that this result depends on the assumptions of U_{12} and U_{22}. Suppose that, as the transmission time gets longer, the marginal disutility is decreasing ($U_{22} > 0$) or the marginal utility of q is increasing ($U_{12} > 0$). Then, an internet user may demand q more given p in the face of the possibility of congestion than when he does not have to worry about congestion. (See Figure 1.) However, since neither cases are plausible in reality, it seems reasonable to exclude these cases by [A2] and [A3].

Now, a representative firm's profit is given by

$$\pi = pT(q) - cq,$$

where $q = D(p)$. If firms compete in a Bertrand fashion, all firms get zero profit in equilibrium, which implies that

$$p^* = \frac{q}{T(q)}c, \tag{2}$$

where p^* is the market price. From (2), it follows that $p^* < c$ when the network is congested, while $p^* = c$ when the network is not congested. However, this does not imply that the firm loses money when congestion occurs in the network because the price p is charged not for a unit of information q, but for a unit of transmission time $T(q)$. In the case that transmission is delayed due to congestion than at normal times, the firm breaks even only when the market price is determined at a level below the marginal cost, because an additional cost is not incurred in delivering data on a congested network.

3.2 Packet Pricing

Now, suppose that p is charged for a unit packet. Consumers will choose q so as to

$$\max_q U(q, T(q)) - pq.$$

The first-order condition requires that

$$U_1 + U_2 T' = p. \tag{3}$$

Let the demand function under packet pricing be $\tilde{D}(p)$. Then, differentiating (3) yields $\tilde{D}'(p) < 0$. Also, by comparing (1) and (3), we have the following proposition.

Proposition 2 $D(p) \leq \tilde{D}(p) \leq D_0(p)$.

Proof. This is trivial since $T'(q) \geq 1$.

Also, it is easy to notice that $\tilde{D}(\overline{p}) = K$. This leads the following proposition.

Proposition 3 *The network is congested under packet pricing if and only if it is congested under circuit pricing.*

Due to Proposition 3, Proposition 2 can be decomposed into

$$D(p) = \tilde{D}(p) = D_0(p) \text{ if } p \geq \overline{p} \text{ and} \tag{4}$$

$$D(p) < \tilde{D}(p) < D_0(p) \text{ if } p < \overline{p}. \tag{5}$$

We will call the case where $p \geq \overline{p}$ the non-congestion regime and the other one the congestion regime.

Equation (4) and (5) say that, given a price, the demand is, in general, larger under packet pricing, while the demand is the same under two pricing systems only in the non-congestion regime. Intuitively, this is because, under packet pricing, there is no demand-reducing effect that appears under circuit pricing as a consequence of an effort to avoid paying extra charges in the congestion regime.

Let the market price under packet pricing be $\tilde{p}^*$. Since a firm's profit is $(p - c)\tilde{D}(p)$ under packet pricing, we can see that $\tilde{p}^* = c$ from the zero-profit condition. In other words, under packet pricing, internet users pay for using the internet the amount exactly equal to the social cost they incur.

3.3 Comparison

First, let us compare market prices under circuit pricing and packet pricing. We can easily see that $p^* = \tilde{p}^* = c$ in the non-congestion regime, while $p^* < c = \tilde{p}^*$ in the congestion regime. That is, the price under packet pricing is, in general, higher. As put earlier, this is because, under circuit pricing, the competitive firm breaks even in a price lower than the marginal cost when a delay in data transmission occurs due to congestion.

Second, we compare social welfare. Let us denote by W the social welfare defined by the sum of consumers' surplus and firms' profits. Then, the socially optimal usage level, q^s, is to

$$\max_q W = U(q, T(q)) - cq.$$

Thus, q^s must satisfy the first-order condition

$$U_1 + U_2T' = c. \tag{6}$$

This says that a user should use the internet until the marginal private benefit from his usage (marginal utility net of marginal disutility from delay) equals the marginal social cost.

From discussion given in Subsection 3.1, we can see that, under circuit pricing, users choose the consumption level satisfying

$$U_1 + U_2T' = p^*T' = \frac{q}{T}T'c > c, (\text{since } T'' > 0)$$

which implies that the internet is underused under circuit pricing. The intuitive reason is that, although the actual unit social cost for the delayed transmission is c, consumers have to pay extra costs for delay.

On the other hand, under packet pricing, users choose the usage satisfying

$$U_1 + U_2T' = \tilde{p}^* = c,$$

implying that the social optimum is achieved under packet pricing. This is because the marginal private cost, which is equal to the market price, always corresponds to the marginal social cost, c, under packet pricing. This leads to one of our main results summarized by the following proposition.

Proposition 4 *Under packet pricing, the social optimum is always attained, while, under circuit pricing, the internet is underused.*

Proof. omit

Interestingly, Proposition 4 has the following corollary.

Corollary 1 *Packet pricing makes congestion more severe.*

Considering Proposition 4 and Corollary 1 together, we can say that, despite its negative effect on congestion, packet pricing should be encouraged in the sense that it increases the social welfare.

4 Two Types of Data

In Section 2, we assumed that all data are transmitted at the same speed. However, a multi-media files usually require much higher speed of transmission than text-based files.

In this section, we extend the model set up in Section 2 by considering two types of data whose average transmission velocities differ like text-based files and multi-media files.

Let the usage of text-based data and the usage of multi-media data be q_1 and q_2 respectively and the delivery time of q_1 and q_2 be $T_1(q_1)$ and $T_2(q_2)$ respectively. Then, a consumer's utility, in general, depends on all of q_1, q_2, $T_1(q_1)$ and $T_2(q_2)$. For simplicity of analysis, we will consider a special form of utility function,

$$U(q_1, q_2, T_1(q_1), T_2(q_2)) = (1-\theta)u(q_1, T_1(q_1)) + \theta u(q_2, T_2(q_2))$$

by assuming that the utility function is additively separable with respect to $(q_1, T_1(q_1))$ and $(q_2, T_2(q_2))$. θ represents a consumer's relative preference of multi-media data over text-based data. All the assumptions [A1] – [A3] made in Section 2 will be preserved for $u(\cdot,\cdot)$.

For delivery times, we assume that $T_1(q_1) = q_1$, $T_2(q_2) = t(q_2) < q_2$ if $q_1 + q_2 \leq K$ and $T_1(q_1) > q_1$, $T_2(q_2) > t(q_2)$ if $q_1 + q_2 > K$. In addition, we make the following assumptions on $T_1(q_1)$ and $T_2(q_2)$.

Assumption 4 $T_1(q) > T_2(q) > 0$, $T_1'(q) > T_2'(q) > 0$ *and* $T_1''(q) > T_2''(q) > 0$, *for all* q.

Transmission costs of the unit usage q_1 and q_2 are assumed to be c_1 and c_2 respectively where $c_1 < c_2$.

We will consider tariff whereby firms charge different prices for q_1 and q_2 both under circuit pricing and under packet pricing.[8]

4.1 Circuit Pricing

Under circuit pricing, a consumer's choice problem is to

$$\max_{q_1,q_2}(1-\theta)u(q_1,T_1(q_1)) + \theta u(q_2,T_2(q_2)) - p_1T_1(q_1) - p_2T_2(q_2).$$

The optimal usages, q_1^* and q_2^*, must satisfy first-order condition given by

$$(1-\theta)[u_1(q_1,T_1(q_1)) + u_2(q_1,T_1(q_1))T_1'(q_1)] = p_1T_1'(q_1), \tag{7}$$

$$\theta[u_1(q_2,T_2(q_2)) + u_2(q_2,T_2(q_2))T_2'(q_2)] = p_2T_2'(q_2). \tag{8}$$

Notice that, if $\theta = 1/2$ and $p_1 = p_2$, we get $q_1^* < q_2^*$, that is, if a consumer has no particular preference between text-based data and multi-media data and their prices are the same, he uses multi-media data more than text-based data under circuit pricing. This is simply because $T_1' > T_2'$ i.e., multi-media files are delivered faster. Moreover, assuming the second-order condition is satisfied, we can see that a larger θ decreases q_1^* and increases q_2^*.

[8]In reality, firms do not charge individual prices for $T_1(q_1)$ and $T_2(q_2)$ but charge a single price for $T_1(q_1) + T_2(q_2)$. However, it is viewed simply as a consequence of minimizing administrative costs. It seems hard to find a logical ground to rationalize such pricing. Even if a consumer's utility does not depend on each of $T_1(q_1)$ and $T_2(q_2)$, but on $T_1(q_1) + T_2(q_2)$, such pricing faces a serious logical inconsistency, because the total delivery time is not uniquely determined for q, but varies for a different combination of q_1 and q_2 such that $q_1 + q_2 = q$. For this reason, we do not consider such pricing in this paper for a fair comparison between circuit pricing and packet pricing.

Denote by $D_1(p_1)$ and $D_2(p_2)$ the demand functions for q_1 and q_2 obtained from (7) and (8). Due to additive separability, q_1 and q_2 are independent goods, which means that D_1 depends only on p_1, while D_2 depends only on p_2. Also, obviously, [A1] – [A2] imply that $D_1' < 0$ and $D_2' < 0$. Now, we will denote by A the congestion regime. Then, $A = \{(p_1, p_2) \mid D_1(p_1) + D_2(p_2) > K\}$. So, the boundary of the congestion regime, denoted by A^b, is a (two-dimensional) locus of (p_1, p_2) satisfying $D_1(p_1) + D_2(p_2) = K$, unlike in the previoius section.

A firm's profit under circuit pricing is given by

$$\pi = p_1 T_1(q_1) - c_1 q_1 + p_2 T_2(q_2) - c_2 q_2,$$

where $q_1 = D_1(p_1)$ and $q_2 = D_2(p_2)$. If we let $\pi_1 = p_1 T_1(q_1) - c_1 q_1$ and $\pi_2 = p_2 T_2(q_2) - c_2 q_2$, Bertrand competition implies that $\pi_1 = 0$ and $\pi_2 = 0$ in equilibrium. Otherwise, a firm could earn positive profits by slightly cutting the price of the service such that $\pi_i > 0$. After all, from the zero-profit conditions, we obtain the market prices

$$p_i^* = \frac{q_i}{T_i(q_i)} c_i, i = 1, 2.$$

Notice that the market price for transmitting multi-media data is higher than that for text-based data in the non-congestion regime. The reason is two-fold. One is that the cost of transmitting a unit of data is higher for multi-media files requiring speedy transmission, and the other is that, due to a shorter delivery time of a given usage, a higher price for a unit delivery time is required to break even.

4.2 Packet Pricing

Under packet pricing, a consumer chooses q_1 and q_2 so as to

$$\max_{q_1, q_2} (1-\theta) u(q_1, T_1(q_1)) + \theta u(q_2, T_2(q_2)) - p_1 q_1 - p_2 q_2.$$

First-order conditions imply that

$$(1-\theta)[u_1(q_1, T_1(q_1)) + u_2(q_1, T_1(q_1)) T_1'(q_1)] = p_1, \tag{9}$$

$$\theta[u_1(q_2, T_2(q_2)) + u_2(q_2, T_2(q_2)) T_2'(q_2)] = p_2. \tag{10}$$

Denoting by $\tilde{D}_1(p_1)$ and $\tilde{D}_2(p_2)$ demand functions obtained from (9) and (10), we can easily see that $D_1(p_1) \leq \tilde{D}_1(p_1)$ and $D_2(p_2) \leq \tilde{D}_2(p_1)$ with the equality holding when $(p_1, p_2) \in A^c$.

Now, from zero-profit conditions, we have $\pi_1 = (p_1 - c_1)\tilde{D}_1(p_1) = 0$ and $\pi_2 = (p_2 - c_2)\tilde{D}_2(p_2) = 0$, accordingly, $\tilde{p}_i^* = c_i$.

4.3 Comparison

We characterized market prices under two pricing systems. Now, we will compare them to draw some policy implications.

First, notice that $p_2^* = \frac{q_2}{t_2}c_2 > c_2$ in the non-congestion regime under circuit pricing, while $\tilde{p}_2^* = c_2$ under packet pricing. This means that, if K is large enough to induce no congestion, a movement from circuit pricing to packet pricing lowers the price for multi-media data, thereby increasing the usage of multi-media data. In other words, packet pricing encourages the use of multi-media data. The intuitive reason is that, under packet pricing, a price is charged for a unit size of data regardless of the delivery time, contrary to circuit pricing. Under circuit pricing, firms break even only if the price for multi-media data whose transmission time is short is kept above the unit cost. So, the price for multi-media data is lower under packet pricing under which the price is always equal to the unit cost. Of course, the effect of packet pricing on the price for multi-media data in the congestion regime is ambiguous. It depends on how much congestion delays data transmission.

Now, we will compare the effect of an increase in θ on prices under two pricing systems.

Under circuit pricing, p_1^* must satisfy

$$p_1^* T_1(q_1) - c_1 q_1 = 0.$$

Differentiating it with respect to θ yields

$$\frac{\partial p_1^*}{\partial \theta} T_1 - (p_1 T_1' - c_1)\frac{\partial q_1}{\partial \theta} = 0.$$

Since $p_1 T_1' - c_1 > p_1 \frac{T_1}{q_1} - c_1 = 0$ and $\frac{\partial q_1}{\partial \theta} < 0$, it follows that $\frac{\partial p_1^*}{\partial \theta} > 0$. Intuitively, as θ gets higher, q_1 is decreased, consequently the market price for q_1, p_1^*, must be increased for break-even. Similarly, we obtain $\frac{\partial p_2^*}{\partial \theta} < 0$. This implies that prices for multi-media data will gradually decline under circuit pricing if consumers' tastes are changed in favor of multi-media data over time. Notice that an increase in θ has no effecet on prices under packet pricing.

Finally, it it should be stressed that we still have the first best result under packet pricing, since the market outcome under packet pricing is always MC pricing.

5 Conclusion

In this paper, we compared the market performances under circuit pricing and under packet pricing in a simple model of competition on the internet market.

Main results can be put in order. If packet pricing is introduced, firstly, the market price rises contrary to the government's expectation. Secondly, congestion is aggravated. Thirdly, the overall social welfare is unambiguously increased, though, because packet pricing reflects the social cost properly while circuit pricing does not. Finally, the market price for high-speed data transmission falls in the absence of congestion, and, consequently, the use of multi-media data is increased, according to the government's expectation.

Throughout this paper, we have assumed that the market is competitive. However, if the market is not competitive, the results may be affected. For example, if the market is monopoly, the monopoly power drives the price up above the marginal cost under both circuit pricing and packet pricing, so that the internet will be underused under both pricing systems. Also, the effect of packet pricing on the price is, in general, ambiguous.

Another limitation of this paper is on the assumption that all consumers are homogeneous in their taste. However, in reality, consumers are heterogeneous in some sense, in particular, in the size of θ. For example, some consumers use the internet mainly for email, while others devote most of their connection time to multi-media data transmission. Then, firms may offer consumers more than one menu of prices to distinguish among them. However, such price discrimination will not work in a competitive environment we are considering. For this reason, the issue of price discrimination was not addressed in this paper, but deserves to be pursued as a future research.

We believe that our results are derived under fairly natural assumptions. Although our assumptions do not comprehend all possible situations that are relevant in reality, they provide a basic framework for analysis. However, if some new technologies are developed in the future, the model might have to be extended to accommodate such a change in the environment, which will belong to our future project.

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