

**Optimal Pricing  
of Local Residential Telephone Service in Beijing**

**by**

**Zhonghui Wu**

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Supervisor: Professor Nguyen Van Quyen

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## INTRODUCTION

As a key component in the infrastructure, the telecommunications industry plays an increasingly important role in the economic development of a country. After assessing the social benefits of telecommunications activities in China <sup>1</sup>, Di and Liu (1994:215) found that an additional investment of 100 million yuan <sup>2</sup> in the telecommunications industry will increase national income by 1.38 billion yuan after 10 years. The cost-benefit ratio is thus approximately 1:14 with an implicit internal rate of return of 45%.

With over 1.2 billion people living across 9.6 million square kilometers of broad land, coupled with various ethnic groups, languages, and strong regional disparities, China has made great economic progress, completing nearly 20 years of economic reform. In 1994, the GDP reached 45,006 billion yuan, recording a growth rate of 11.8% in comparison to that of 1993 (China Statistical Yearbook, 1995:21).

China started to open its telephone market in the 1980s. In terms of the national telephone penetration, only 0.38% of households owned telephones in 1978 (Beijing Review, 1995a:18); in contrast, newly increased private telephone subscribers in both urban and rural areas reached 10 million by 1994, representing 3.2% of the households throughout China (Beijing Review, 1995b:IV). Moreover, the telephone penetration in the urban areas has reached 13% by 1994 (Beijing Review, 1995a:18). Table 1-1 depicts the progress of China's telephone penetration from 1978 to 1994.

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<sup>1</sup> Hereafter refers to mainland China without including Taiwan or Hong Kong.

<sup>2</sup> Yuan: Chinese currency unit, approximately US\$1 = 8.261 yuan, according to the People's (Central) Bank of China as of February 17, 1996.

Table 1-1. Development of China's Telephone System

Year	1978	1980	1983	1985	1986	1988	1989	1990	1991	1992	1993	1994
Telephone Penetration (%)	0.38	0.43	0.49	0.60	0.67	0.86	0.98	1.11	1.29	1.63	2.20	3.20

Source: the Ministry of Posts and Telecommunications(1995:212)

The main objective of this paper is to examine the telecommunications sector of China, with particular emphasis on some aspects of the local residential telephone pricing of Beijing, the capital of China. This will be accomplished by using an optimal telephone service pricing model to compare the social welfare that accrues from the current tariff and the optimal two-part tariff, respectively. The paper evaluates the optimal two-part tariff as an option for achieving the welfare optimum by analyzing its social costs and benefits. The rest of the paper is organized as follows. Chapter 1 describes the structure of China's telecommunications industry. Chapter 2 explains several economic concepts such as economies of scale and network externality, and introduces four local residential telephone pricing methods adopted in different contexts. Chapter 3 gives a profile of Beijing's telephone system, revealing some problems in its operational mechanism. Chapter 4 discusses the analytical framework of this paper and derives market demand for connections and calls from an individual household's demand curve. In chapter 5, the model is calibrated and the computations for Beijing's optimal two-part tariff are presented. The findings and recommendations for future development of the telecommunications system are presented in Chapter 6. Appendix A provides the derivation of the market demand for connections (N) and for calls (Q), together with the price elasticities of demand for connections ( $\eta^N_p$ ) and for calls ( $\eta^Q_p$ ). Appendices B and C contain the calculations produced by *Mathematica*.

## **Chapter 1**

### **Development of The Telecommunications Sector in China**

#### **1. The Telecommunications Regime in China Before 1980**

The Ministry of Posts and Telecommunications (MPT) is a monopoly which combines three functions: policy and regulation, service provision and equipment manufacturing. In other words, the MPT provides all public domestic and international telecommunications services, primarily through about 30 provincial posts and telecommunications administrations which coordinate approximate 350 city posts and telecommunications (P&T) enterprises. Immediately below these P&T enterprises, about 2,150 county P&T enterprises provide local services for the rural areas. These county-level enterprises are (usually six to eight of them in one group) responsible for reporting to each city P&T enterprise. Prior to 1980, the telecommunications system in China was large but comprised of obsolete technologies, operating with wide disparities between large cities, some of which had some advanced technologies and small centers where most of county-level installations were old manual exchanges ( Bruce et al., 1994 : 224).

#### **2. Decentralization and Telecommunications Progress**

User ministries, including the Ministry of Electronics Industry (MEI), national banks, and airlines, etc., which had their own networks, were interested in developing their own telephone services during the early stage of China's economic reform, when the State Council allowed the MPT to have *de facto* responsibility for the planning, development, and management of the national public telecommunications network. Presently, separation of telecommunications regulation from service operation has

become a global trend. This is the case in China. The MPT's three major functions were all challenged by other participants in the telecommunications market. In 1988, the MPT began to reorganize its functions by decentralizing and separating regulation from operational functions, which was implemented through the creation of the Directorate General of Telecommunications. So far, these objectives have been met only partially (Bruce et al., 1994:225).

However, with the ongoing adoption of advanced telecommunications technologies, the capacity of the national public telecommunications networks was rapidly expanded in the 1980s, reaching an annual growth rate of 16% in the later part of the decade. The number of main lines grew by 23% from 1990 to 1991. In 1994, the capacity of newly installed office telephone exchanges amounted to 19 million lines, so that the combined capacity totalled 49 million lines. The number of new telephone subscribers increased up to 10.83 million, recording a jump of 60.3% compared to 1993 (Beijing Review, 1995c:9).

### **3. The Development Scheme (1996-2010)**

In spite of China's rapid economic progress in the last decade, its telecommunications system still lags far behind those of the developed countries. From the beginning of the 1980s, the Chinese authorities started to show more concern about telecommunications infrastructure as one of the essential means to enhance economic growth. Based on this understanding, China is about to launch its most ambitious large-scale telecommunications network construction throughout the proposed Ninth Five-Year Plan period (1996-2000) and well into the early 21st century. Accordingly, the goals for 1996-2000 and 2000-2010 are set as follows:

- continuing to expand the nationwide automated telephone exchanges to 114 million lines, together with the number of main line subscribers to 93 million by the end of this century;<sup>3</sup>

- raising the total capacity of the national telephone network, which is expected to reach 400 million lines by the year 2010 so that the national telephone penetration rate will record 25% (Beijing Review, 1995c:10).

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<sup>3</sup> The effort will help to increase the telephone penetration rate to 8-9 percent, with the figure for cities reaching 30-40 percent, or an average of one telephone per household in the urban areas in 2000.

## Chapter 2

### THE ECONOMICS OF TELECOMMUNICATIONS

Until the 1960s, the analog technologies used in telecommunications evolved quite slowly. During the 1970s and 1980s, however, with the development of digital electronics, the increasing application of computer technologies to telecommunications, and the development of wide band transmission systems which can carry much larger quantity of information, the pace of change accelerated sharply. Furthermore, new industrial processes suited to large-scale mass production were introduced in the manufacturing of telecommunications equipment, making it possible to have highly reliable products at lower costs. As a result, a wide range of new facilities and services was developed (Saunders et al., 1994:37).

The invention of stored program control analog techniques in switching equipment, followed by digitization, has made equipment more flexible and improved operational facilities so that the overall system has become more efficient. In addition, call metering facilities, which required additional equipment in an electromechanical exchange, now have become a part of a digital exchange at no extra cost and have enabled the adoption of tariff system that more accurately reflects the time and duration of calls at a fairly low cost (Saunders et al., 1994:44).

#### 1. Economies of Scale

It is believed that the telecommunications industry exhibits economies of scale. This phenomenon is particularly significant for LDCs which have relatively smaller and obsolete telecommunications network as well as large unmet demand. The two

characteristics bring forth an opportunity to cut costs sharply by accelerating the expansion of the telecommunications system. Hence, the potential of economies of scale is substantial for a developing country like China.

## **2. Network Externality**

One of the distinguishing characteristics of telecommunications is that, to a great extent, the value of telephone service depends on the number of subscribers who can be reached. This is often referred to as "network externality". Because the value of access to a network increases with the number of people who can be reached through that network, interconnection of two separate networks adds to the value of both. Moreover, there are two aspects to the network externality. First, individual pieces of telephone equipment or separate systems are either of no value or limited value without interconnection to the public network. Second, the increase in the value of telephone service to a particular subscriber comes from extending the number of subscribers. Therefore, the social value of subscribing a telephone is greater than the private value because the subscription tends to increase the value of telephone service to others as well.

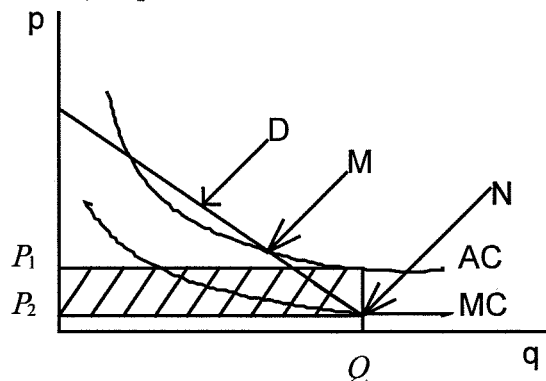
## **3. Telephone Pricing Policies**

In general, there are four ways of pricing local telephone services, namely, marginal-cost pricing, flat-rate tariff, two-part tariff and usage-insensitive pricing, which can be applied in different contexts.

### 3.1. Marginal-Cost Pricing

The starting point for all public utility tariffs is marginal-cost pricing. In general, marginal-cost pricing (MC pricing) is welfare maximizing, but it seldom covers the total cost of services (Mitchell, 1991a:38). Since the telecommunications industry entails a substantial amount of fixed costs and long-run excessive capacity, short-run marginal cost below full capacity utilization is close to zero. Furthermore, in practice, firms do not directly observe the cost changes attributable to marginal changes in output. Rather, firms observe cost change over time. Thus, marginal-cost pricing is not a feasible way of pricing telecommunications services.

As shown in Figure 2-1, AC represents the average-cost curve, MC represents the marginal-cost curve, D is the demand curve,  $P_1$  is the price of the telephone service under average-cost pricing, and  $P_2$  is the price of the telephone service under marginal-cost pricing. Point N, the intersection of the demand curve D and the MC curve, is considered to be “the first best” solution since it can maximize consumer welfare. However, given a certain number of calls  $Q$ , an economic loss indicated by the shaded area  $(P_1 - P_2)Q$  will result from MC pricing. Therefore, we can only choose “the second best” (point M in Figure 2-1) to price telecommunications services.



**Figure 2-1. Average-Cost and Marginal-Cost Pricing**

### **3.2. Flat-Rate Tariff**

Under flat-rate tariff, a customer pays a flat rate per month for using a telephone. As mentioned above, a two-part tariff requires a customer to pay a fixed monthly charge regardless of the number of calls he makes, and an additional charge per call. Actually, the flat-rate tariff is the special case of a two-part tariff with a zero price per call. At present, the flat-rate tariff is used in most areas of North America for pricing local calls.

### **3.3 Two-Part Tariff (Usage-Sensitive Pricing)**

Under a two-part tariff, the customer must pay a monthly charge and pay an additional charge every time a call is made. It is also called "usage-sensitive pricing (USP)". In general, a two-part tariff implies a lower fixed monthly charge in comparison to a flat-rate tariff, but an extra charge will be attached to each call made<sup>4</sup>, because it is not economically efficient to charge a zero price for a service that has a positive cost of provision. Since each call is charged, customers tend to reduce unnecessary calls. As a result, they pay a lower monthly bill. Hence, a two-part tariff makes telephone services accessible to low-income families so as to enhance aggregate social welfare.

### **3.4. Usage-Insensitive Pricing**

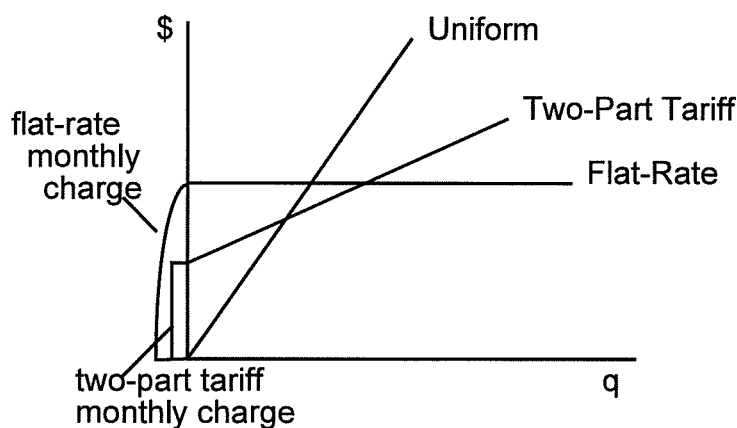
It is argued that the so-called "usage-insensitive pricing", which allows customers to choose to stay with a flat-rate tariff or to go for a two-part tariff, can lead to welfare maximum (Panzar, 1978:425). Despite the fact that a USP plan would, on average, result in a lower monthly bill, there still exists stiff customer resistance to such a plan.

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<sup>4</sup> The charge is originally based on the number of calls but increasingly on the length of the call and time of day as well.

There are two possible explanations. First, being risk averse, customers prefer the flexibility to respond costlessly to random events. Second, while aggregate welfare will be improved as a result of implementing USP, some consumers may find themselves damaged by such a change. In particular, those families with low income and high propensity to make calls may suffer from the increased monthly payment resulting from usage-sensitive pricing. However, this subject calls for more in-depth research in the years to come.

Currently, either the flat-rate tariff or two-part tariff is being adopted in many countries. Figure 2-2 depicts the outlay functions (consumer expenditures as a function of quantities of calls) for uniform<sup>5</sup>, flat-rate and two-part tariffs (Panzar, 1978:426). In general, if the metering cost is low, a two-part tariff can lead to a substantial improvement in economic efficiency.



**Figure 2-2 Uniform, Two-part and Flat-rate Pricing**

<sup>5</sup> It is also called "metered tariff", meaning that the customer must pay  $p$  per call, but no fixed monthly fee is charged.

## Chapter 3

### THE TELEPHONE SYSTEM OF BEIJING

#### 1. Overview of the System

Beijing has been placing great emphasis on telecommunications infrastructure in recent years. For example, in 1994, 0.27 million lines were installed; in 1995, 0.4 million lines were installed; in 1996, 0.65 million lines will be added to the whole network. At present, the total capacity of its telephone network amounts to 2.4 million lines, with a residential penetration rate <sup>6</sup> of 35.5% (the People's Daily Overseas Edition, 1995:2), the highest in Northern China. On May 8, 1996, Beijing is scheduled to upgrade its phone numbers to eight digits, joining the other four giant cities in the world, which are already using eight digits (The Canada-China News, 1996:1). By the end of this century, Beijing is expected to expand its residential telephone lines to 5 million so that one telephone will be available to each household, which approximates a telephone penetration rate of 67% (Beijing Review, 1994:175).

#### 2. The Current Pricing Structure

As for local telephone service pricing, Beijing has been adopting the so-called "complex message rate system", under which charges are based on the duration <sup>7</sup> of calls. Each calling unit in the immediate urban area is three minutes. Since 1989, a household in Beijing has to pay the following three parts in order to own a telephone: (1) the

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<sup>6</sup> Penetration rate is a measure of the degree to which a particular service is accepted by the target user population. It can be expressed as the average number of telephones per household (Graham, 1991:118).

<sup>7</sup> A call may include one to several calling units, depending on the length of the call.

connection fee <sup>8</sup>: 5000 yuan; (2) the fixed monthly charge <sup>9</sup>: 11.50 yuan; (3) the local calling charge: 0.125 yuan per calling unit, which remains unchanged from the late 1970s (The Monthly Statistical Report of Beijing's Telephone System, 1995:5).

### 3. Problems with Beijing's Telephone System

The telephone system in Beijing faces numerous problems. First, after being excluded from the local telephone market for more than 30 years, most of the households wished to have a private telephone once the residential telephone service became available. Owing to the wide demand-supply gap, the waiting time <sup>10</sup> is at least six months. Interestingly, although connection fee is a heavy burden for many local average-income families, the price hike does not seem to suppress the public demand (Sun, 1993:183). How to cater to the ever-increasing needs has become a major consideration for the local telephone authorities.

Second, the connection fee is 5000 yuan <sup>11</sup>, but the local usage fees are relatively low - a fixed monthly charge 11.50 yuan plus per calling unit charge 0.125 yuan. On the one hand, the exorbitant connection fee discourages new entrants and denies universal access of all the residents; on the other hand, low usage fees encourage subscribers to

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<sup>8</sup> It is also called "installation fee" or "hookup fee", which is a non-reimbursement fee for initial connection to the network. In 1989, the local telephone company was authorized to charge an installation fee within 3000-5000 yuan, which has become a main financial source for the intra-city telecommunications development.

<sup>9</sup> Also, referred to as "subscription fee", which is the monthly rental charge regardless of subscribers' use or distance from the switching center.

<sup>10</sup> The period from paying installing fee to being able to use the telephone.

<sup>11</sup> The connection fee in Beijing approximates CDN\$795, while the connection fee in Canada is typically about CDN\$50.

make excessive use of the system. In fact, the local telephone service is heavily subsidized by the revenue accruing from long distance traffic. In a word, costly access obscures the long-term strategic goals to boost telephone penetration and benefit from lower prices brought about by economies of scale.

Third, a unique dimension of China's telecommunications is the independent operation of the networks owned by those user ministries. In order to accommodate internal communications, the Ministry of Railway and the People's Liberation Army (PLA) already had their own systems in place before 1976. After that, the central government granted permission to four more ministries - the Ministry of Coal, Petroleum, Railway and Water & Power - to build their own nationwide systems (Zita, 1994:91). Besides that, a number of smaller networks emerged during the 1980s. The Ministry of Railway controlled 5-8 percent of all operating circuits of the national network. Since all the headquarters of these ministries are located in Beijing, the total telephone lines of these ministry-owned networks roughly amount to one million in the capital area. Unfortunately, the utilization of these networks is insufficient<sup>12</sup> and, interconnection among them is quite limited. The more serious problem is lack of coordination between these networks and the public network. There are numerous cases of repetitive construction of systems, signal interference, and technological incompatibility (Zhang et al., 1992:7).

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<sup>12</sup> The utilization of these private networks in Beijing is generally below 40%.

## Chapter 4

### THE OPTIMAL TELEPHONE SERVICE PRICING MODEL

#### 1. The Individual Demand Curve

The foregoing discussion makes it clear that, a new way of pricing Beijing's local telephone service, which can reflect costs and allow the firm to break even, has to be introduced in the near future. As mentioned in Section 2.3, marginal-cost pricing can maximize the consumer's utility, but it will cause substantial losses to the telephone enterprise. Hence, we can only seek "the second best" solution by maximizing customers' utility given the zero-profit constraint for the telephone company.

The model we formulate in this chapter follows that of Mitchell (1978b)<sup>13</sup>. The last two decades have witnessed unprecedented progress in designing the telephone service pricing. Prior to 1970, even though Frank Ramsey had already proposed the departures from the marginal-cost pricing in his 1927 and 1928 papers (Ramey, 1927:47-61; 1928:543-59), it was marginal-cost pricing that dominated public utilities pricing. Until the 1970s, Ramsey pricing was explored by Baumol and Bradford (1970). After that, a large number of papers on this subject appeared. By the end of the 1970s, Ramsey pricing has become the "fashion" for telephone service pricing. As an illustration, Ramsey pricing was adopted by the Interstate Commerce Commission for the public utility pricing in 1983 (Eatwell et al., 1987:49). In detail, Ramsey proposed the pricing of public utility services where demand is the most price-inelastic. Since marginal cost pricing cannot generate enough revenues to cover total costs, either the operating

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<sup>13</sup> Since an electronic exchange is designed to hold a metering function, metering cost constitutes only a small portion of the total cost. For convenience, this trivial cost will be omitted in the following calculation.

enterprise will go out of business, or a subsidy from the government will be necessary. But, both will cause a distortion in the market, and thus fail to provide the enterprise with incentives to run efficiently. Ramsey pricing asserts that, when an enterprise supplies  $n$  commodities, Pareto optimality subject to a profit constraint requires the prices,  $p_j$  of these goods to satisfy (Eatwell et al., 1987:50)

$$\frac{p_j - mc_j}{p_n - mc_n} = \frac{mr_j - mc_j}{mr_n - mc_n} \quad (j = 1, \dots, n - 1)$$

$$\sum p_j x_j = c(x_1, \dots, x_n) + k \quad (1)$$

where  $mc_j$  and  $mr_j$  are, respectively, the marginal cost and marginal revenue of output  $j$ ,  $C(\cdot)$  is the supplier's total cost function and  $k$  is any constant.

In a specific case in which none of the seller's goods is either a complement or a substitute in demand, the preceding relationship is easily shown to take the special form which is known as "the inverse elasticity formula"

$$\frac{(p_j - mc_j) / p_j}{(p_n - mc_n) / p_n} = \frac{E_n}{E_j} \quad (j = 1, \dots, n - 1)$$

$$\sum p_j x_j = c(\cdot) + k \quad (2)$$

where  $E_j$  is the price elasticity of demand for product  $j$ .

For  $k = 0$ , where marginal-cost pricing yields zero economic profit exactly, conditions (1) and (2) are transformed into the marginal-cost pricing conditions

$$p_j = mc_j \quad (j = 1, \dots, n)$$

which implies that the operating enterprise will lose money. Therefore,  $p_j$  has to deviate from the  $mc_j$  in a manner that satisfies the profit constraint and yet minimizes demand (and therefore output) reductions. For this purpose, consider two of the pertinent commodities,  $i$  and  $j$ , with  $i$ 's demand highly elastic and  $j$ 's very inelastic. Let us start with  $p_i = mc_i$ ,  $p_j = mc_j$ , and assume that profits are negative at these prices. Because the high demand elasticity of  $i$ , a small rise in  $p_i$  above  $mc_i$  will cause a relatively large "distortion" in consumer demand from its Pareto optimal quantity. Moreover, also because of the high elasticity, the rise in  $p_i$  will yield a relatively small increase in revenue to help eliminate losses. In contrast, a similar percentage increase in  $p_j$  will lead to a smaller percentage change in quantity of  $j$  demanded and a larger gain in revenue. Clearly, less damage will be done to welfare in this situation. That is, in essence, the logic of the inverse elasticity formula (Eatwell et al., 1987:51).

However, Ramsey pricing is problematic because the price elasticity of demand for telecommunications services is not entirely determined exogenously by the market. In fact, it is often affected by government policies. In addition, groups of customers with inelastic demand for telecommunications services usually include persons with no alternative to the services offered by the operating enterprise, especially in the monopoly. As a result, the enterprise is likely to charge much higher tariffs to load the burden of any internal inefficiency to those customers who have most need of telecommunications services, such as business subscribers (Saunders et al., 1994:273).

At the same time, the theory of optimal two-part tariff has been completed, and a few economists contributed to the application of the optimal pricing theory by developing models and discussing their empirical significance. Prominent among those are Mitchell (1978b), and Baumol, Panzar and Willig (1982). Mitchell developed an optimal local telephone service model, which is considered to be a pioneer of the optimal two-part

tariff pricing. Besides that, Baumol, Panzar, and Willig raised the issue of tariffs and competition. In the 1980s, nonlinear tariffs<sup>14</sup> were discussed in the paper of Spence (1980), who provided additional pricing tools for pursuing the goals of equity and efficiency simultaneously.

From the above literature survey, we know that no updated optimal two-part tariff model is available after Mitchell's. Although the model first appeared in 1978, it has not been superseded by any other model for pricing local telephone service. Mitchell's model utilizes the "representative consumer" approach to proceed from the individual level to the whole market. First, it solves the utility-maximizing problem of a customer, then obtains the market demand for connections and for calls by aggregating all the individual demands. Furthermore, since the "complex message rate system" adopted by Beijing requires the customer to pay a fixed monthly charge and per calling unit charge, it is basically a two-part tariff. Thus, as a two-part tariff model, Mitchell's fits Beijing's current local telephone system, which is at its fast-growing stage and has less competitive elements involved. In other words, the model is ideal for pricing Beijing's local telephone service.

Now we derive the individual demand curve for telephone service. Consider a household with the following utility function

$$U(x, q, y) = x + V(q, y)$$

where  $q$  is the number of telephone calls made per month,  $x$  is the utility derived from the consumption of the numeraire good and,  $V(q, y)$  is the utility derived from telephone service. Note that  $V(q, y)$  depends on both the number of calls made,  $q$ , and the household income,  $y$ . We use the following specification for  $V(q, y)$  and, in order to simplify the

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<sup>14</sup> Nonlinear tariff means that price changes with quantities purchased.

model, we assume that utility is a quadratic function of the number of calls and a positive function of income;

$$V(q,y)=\lambda(y)\left[\gamma+\alpha q-\frac{1}{2\beta}q^2\right] \quad \gamma \geq 0, \alpha > 0, \beta > 0, \lambda'(y) > 0$$

where  $\alpha$ ,  $\beta$ ,  $\gamma$  are constants specific to this household, and  $\lambda(y)$  is a positive and increasing function of  $y$ . To elaborate,  $\alpha$  is the consumer utility received from the first call;  $\beta$  is defined as the taste parameter<sup>15</sup> of various groups of customers;  $\gamma$  represents the value of having telephone service when no outgoing calls are made. Thus it reflects the consumer's willingness to pay merely to receive calls or to have emergency communications available.

Therefore, the utility of a telephone subscriber is given by the following quasi-linear utility function<sup>16</sup> so that there is no income effect involved. That is to say, the household income change will not affect its demand for telephone service.

$$U(x, q, y) = x + \lambda\left[\gamma + \alpha q - \frac{1}{2\beta}q^2\right]$$

Under a two-part tariff (L,p), the household has to pay a fixed monthly charge  $L$  as well as a per call charge  $p$ . Thus,  $x$ , the remaining household income after paying for telephone service, is equal to  $(y-L-pq)$ .

Once connected to the telephone system, a household will choose the right number of calls to maximize its utility, i.e., it solves the following utility-maximizing problem

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<sup>15</sup> Taste parameter depends on an household's income and consumption preferences as well.

<sup>16</sup> Due to the simplicity of the quasi-linear utility function, it is often used in applied welfare economics (Varian, 1992:165).

$$(1) \quad \max_q \left\{ x + \lambda \left[ \gamma + \alpha q - \frac{1}{2\beta} q^2 \right] \right\}$$

such that  $x + L + pq = y$

The first-order condition is:

$$(2) \quad -p + \lambda \left[ \alpha - \frac{1}{\beta} q \right] = 0 \Rightarrow$$

$$q^* = \beta(\alpha - p/\lambda)$$

which is a household's demand curve for calls as a function, given that the above quasi-linear utility function is strictly-concave

Substituting (2) in (1), we obtain the maximum utility level:

$$y - L - p\beta(\alpha - p/\lambda) + \lambda \left[ \gamma + \alpha\beta(\alpha - p/\lambda) - \frac{1}{2\beta} \beta^2 (\alpha - p/\lambda)^2 \right]$$

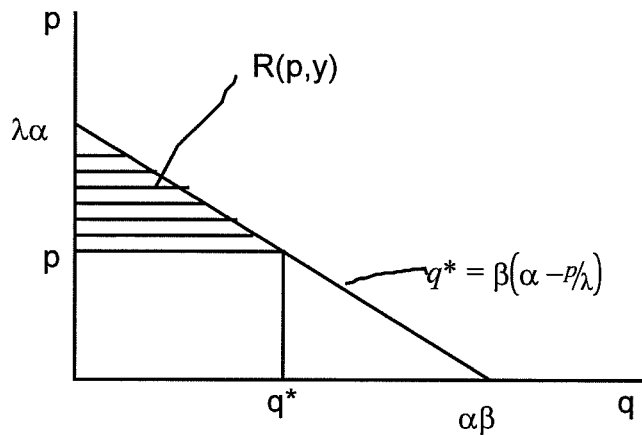
$$= y - L + \lambda \left[ \gamma + \frac{1}{2} \beta (\alpha - p/\lambda)^2 \right]$$

$$(3) \quad = y - L + R(p)$$

where  $R(p)$ , consumer surplus, is equal to the utility of  $q^*$  calls minus the total cost  $pq^*$

$$(4) \quad R(p) = \max_q [V(q) - pq] = \lambda \left[ \gamma + \frac{1}{2} \beta (\alpha - p/\lambda)^2 \right]$$

The consumer surplus is given by the shaded area in Figure 4-1 below.



**Figure 4-1. Consumer Surplus with  $q^*$  Calls Made**

From (3), we can deduce that if  $y - L + R(p) > y$ , the household would have a telephone connected. Otherwise, it is better-off without a phone. Now

$$y - L + R(p) \geq y \Leftrightarrow R(p, y) \geq L$$

In conclusion, if the consumer surplus  $R(p, y)$  is strictly greater than the fixed monthly charge  $L$  of the two-part tariff  $(L, p)$ , then the household would get a telephone installed. Therefore,

$$\begin{aligned}
 R(p, y) = \lambda \left[ \gamma + \frac{1}{2} \beta (\alpha - p/\lambda)^2 \right] &\geq L \Rightarrow \\
 \gamma + \frac{1}{2} \beta (\alpha - p/\lambda)^2 &\geq \frac{L}{\lambda} \Rightarrow \\
 \beta &\geq \frac{2(L - \lambda\gamma)}{\lambda (\alpha - p/\lambda)^2}
 \end{aligned}
 \tag{5}$$

In other words, a household will have a phone installed if and only if (5) is satisfied. Let  $\beta_m$  be the value of  $\beta$  for the marginal consumer, whose surplus is just exhausted by the monthly charge  $L$ , that is,  $L = R(p, \beta_m)$ , and who is actually indifferent between telephone service and consumption of other goods

$$\beta_m = \frac{2[L - \lambda\gamma]}{\lambda [\alpha - p/\lambda]^2}
 \tag{6}$$

Therefore, a household will have a telephone connected if and only if  $\beta > \beta_m$ .

For  $\beta = \beta_m$ , the number of calls made by the household is:

$$(7) \quad q_m = \beta_m(\alpha - p/\lambda)$$

In fact, the condition  $\beta = \beta_m$  characterizes the border that separates households who strictly need a phone ( $\beta > \beta_m$ ) from those who are strictly better-off without one ( $\beta < \beta_m$ ).

## 2. Market Demand for Connections

For a group of subscribers at a given level of income  $y_i$ , by assuming that they have the same value of  $\alpha$  and  $\gamma$  but different values of  $\beta$  and income  $y$ , we can obtain the price elasticity of calls as follows:

$$(8) \quad \eta_p^{q_i} = \frac{\partial q_i}{\partial p} \frac{p}{q_i} = \left( -\beta/\lambda \right) \left[ \frac{p}{\beta(\alpha - p/\lambda(y_i))} \right] = -\frac{p}{\lambda(y_i)\alpha - p}$$

Now, we examine the distribution of households according to type  $(\beta_i, y_i)$ . Let  $h(\beta, y)$  be the density function which describes household types. It is assumed that the random variables  $\beta$  and  $y$  are independent so that  $h(\beta, y) = f_\theta(\beta)g(y)$ , where  $f_\theta(\beta)$  is a density function of  $\beta$  and  $g(y)$  is the probability density function of households at each income level. Moreover, here we assumed that the density function of  $\beta$  is log-normal to ensure the taste parameter  $\beta > 0$ . That is to say,  $f_\theta(\beta)$  is log-normal with unknown parameter  $\theta = (\mu, \sigma^2)$ , which means,  $\ln \beta \sim N(\mu, \sigma^2)$ .

At each income level, a certain percentage of households will subscribe to the telephone system. The market demand for connections over all income levels is:

$$(9) \quad N(L, p) = M \int_y \int_{\beta_m} [f_\theta(\beta) d\beta] g(y) dy = M \int_y [1 - F_\theta(\beta_m)] g(y) dy$$

where  $\beta_m = \frac{2[L - \lambda\gamma]}{\lambda[\alpha - p/\lambda]^2}$ ,  $M$  is the total population, and  $F_\theta(\beta)$  is the cumulative distribution function of  $\beta$ .

To obtain  $\eta_L^N$ , the elasticity of market demand for connection with regard to a fixed monthly charge  $L$ , we differentiate equation (9) with respect to  $L$ :

$$(9.1) \quad \frac{\partial N(L,p)}{\partial L} = M \int_y \left[ \frac{\partial}{\partial L} \int_{\beta_m}^{\infty} f_\theta(\beta) d\beta \right] g(y) dy = M \int_y \left[ -f_\theta(\beta_m) \frac{\partial \beta_m}{\partial L} \right] g(y) dy$$

Furthermore, from equation (6), we obtain

$$(10) \quad \frac{\partial \beta_m}{\partial L} = \frac{2}{\lambda(y)[\alpha - p/\lambda]^2} = \frac{\beta_m}{L - \lambda\gamma}$$

$$(11) \quad \frac{\partial \beta_m}{\partial p} = \frac{2q_m}{\lambda[\alpha - p/\lambda]^2}$$

Substituting (10) into (9.1), we get

$$\frac{\partial N(L,p)}{\partial L} = M \int_y \frac{-f_\theta(\beta_m)}{L - \lambda\gamma} g(y) dy$$

For a given level of income  $y$ , the market demand for connections becomes;

$$(12) \quad N(L,p,y) = M \int_{\beta_m}^{\infty} f_\theta(\beta) d\beta \Rightarrow$$

$$\frac{\partial N(L,p,y)}{\partial L} = \frac{-M f_\theta(\beta_m)}{L - \lambda\gamma}$$

$$\eta_L^N(y) = \frac{\partial N(L,p,y)}{\partial L} \frac{L}{N(L,p,y)} = \left[ \frac{-M f_\theta(\beta_m)}{L - \lambda\gamma} \right] \frac{L}{N(L,p,y)}$$

In the same way, we have

$$(13) \quad \frac{\partial N(L,p)}{\partial p} = M \int_y \left[ -f_{\theta}(\beta_m) \frac{\partial \beta_m}{\partial p} \right] g(y) dy = M \int_y \left[ \frac{-f_{\theta}(\beta_m) \beta_m}{L - \lambda y} q_m \right]$$

$$(14) \quad \frac{\partial N(L,p,y)}{\partial p} = q_m \frac{\partial N(L,p,y)}{\partial L} = q_m \left[ \frac{-f_{\theta}(\beta_m) \beta_m}{L - \lambda y} \right]$$

Thus, we can obtain the price elasticity of demand for connection at a given income level;

$$(15) \quad \eta_p^N(y) = \frac{\partial N(L,p,y)}{\partial p} \frac{p}{N(L,p,y)} = \frac{pq_m}{L} \eta_L^N(y) = \frac{E_m}{L} \eta_L^N(y) \quad \text{where } E_m = pq_m$$

### 3. Market Demand for Calls

In a similar fashion, we can derive the market demand for calls,  $Q$ , by aggregating the individual demand  $q^* = \beta(\alpha - p/\lambda)$  at each income level. The market demand function for calls is:

$$Q(L,p) = \int_y \int_{\beta_m}^{\infty} (\alpha - p/\lambda) \beta f_{\theta}(\beta) d\beta$$

For a given level of income  $y$ , we have

$$Q(L,p,y) = \int_{\beta_m}^{\infty} (\alpha - p/\lambda) \beta f_{\theta}(\beta) d\beta$$

$$\frac{\partial Q(L,p,y)}{\partial p} = \int_{\beta_m}^{\infty} \{[-1/\lambda] \beta d\beta\} - (\alpha - p/\lambda) \beta_m f_{\theta}(\beta_m) \frac{\partial \beta_m}{\partial p}$$

The price elasticity of demand for calls is, therefore;

$$(16) \quad \eta_p^Q(y) = \frac{\partial Q(L, p, y)}{\partial p} \frac{p}{Q(L, p, y)} = -\eta_p^{q_i} + \frac{q_m}{\bar{Q}(L, p, y)} \eta_p^N(y)$$

where  $\eta_p^{q_i}$  is the price elasticity for calls for any type of subscribers and,  $\eta_p^{q_i} = \frac{p/\lambda(y)}{\alpha - p/\lambda(y)}$

$\bar{Q}$  is the mean number of calls per household in the group of households with income  $y$  and,  $\bar{Q} = \frac{Q(L, p, y)}{N(L, p, y)}$

Finally, the derivative of the number of calls with respect to a change in the fixed monthly rate  $L$  is

$$(17) \quad \frac{\partial Q(L, p, y)}{\partial L} = -(\alpha - p/\lambda) \beta_m f_\theta(\beta_m) \frac{\partial \beta_m}{\partial L} = -\frac{2\beta_m f_\theta(\beta_m)}{\lambda(\alpha - p/\lambda)}$$

From the equation (17), we can obtain the elasticity of market demand for calls with respect to a fixed monthly charge  $L$  as follows:

$$(18) \quad \eta_L^Q(y) = \frac{\partial Q(L, p, y)}{\partial L} \frac{L}{Q(L, p, y)} = \eta_L^N(y) \frac{q_m}{\bar{Q}(L, p, y)}$$

## Chapter 5

### AN APPLICATION OF THE OPTIMAL PRICING MODEL

#### 1. The Optimal Two-Part Tariff of Beijing

Table 5-1 summarizes the information on Beijing's current telephone penetration rate, total residential telephone lines, pricing structure, and quantities and costs of calls for 1994, obtained from statistical sources. In detail, the telephone penetration is obtained from *The People's Daily Overseas Edition* (December 6, 1995:2); the residential telephone lines, the current prices, the quantities of calls made and the costs are obtained from *The Monthly Statistical Report of Beijing's Telephone System* (1995:4-10).

Table 5-1. The Data of Beijing's Residential Telephone Service in 1994

The number of households	2.25 million
Urban telephone penetration	35.5%
Total residential telephone lines	0.8 million
Connection fee	5000 yuan
Monthly fee per household	11.50 yuan
Charge per local calling unit	0.125 yuan
Annual residential calls made	3427.2 million
Monthly residential calls made	285.6 million
Calls made per subscriber per month	120
Total fixed costs of the residential telephone system	36.38 billion
Fixed cost per capita	5381.66 yuan
Marginal cost per subscriber	1176.85 yuan
Marginal cost per calling unit	0.06 yuan

Source: *the Monthly Statistical Report of Beijing's Telephone System* (1995:4-10)

One point should be made clear is that, since an average household in Beijing has three individuals, the total population of 6.76 million implies 2.25 million households (The Monthly Statistical Report of Beijing's Telephone System, 1995:4).

Next, we transform three raw data series into a new data series on a monthly basis. Under two-part tariff system, the monthly bill of a subscriber consists of two parts: the monthly fixed charge  $L$ , and per unit calling charge  $p$ . Since the hookup fee is as high as 5000 yuan, here we take it into account while defining the monthly charge  $L$ . In other words,  $L$  should be equal to the fixed monthly charge ( $L_0$ ) plus the monthly hookup fee ( $A$ ). Since  $A$  is equal to 15 yuan<sup>17</sup>, the actual monthly charge is equal to  $L = L_0 + A = 15 + 11.50 = 26.50$  yuan.

Similarly, we can obtain the fixed cost per household  $f$  (16.1 yuan)<sup>18</sup> and the marginal cost per subscriber  $s$  (3.52 yuan)<sup>19</sup>.

Since 35.5% of the households subscribe to telephone service and make an average of 120 calls per month, on an overall per household basis, this corresponds to a mean of 42 calls per household per month. From *The Monthly Statistical Report of Beijing's Telephone System (1995:6)*, Beijing's residential calls exceeding 6 minutes (equivalent to 3 calling units), exceeding 3 minutes (equivalent to 3 calling units) and

<sup>17</sup> With current monthly interest rate  $r=0.3\%$  in Beijing, we have  

$$5000 = A + \frac{A}{(1+r)} + \frac{A}{(1+r)^2} + \dots = \frac{A}{1 - \frac{1}{1+r}} = \frac{A(1+r)}{r} = \frac{A(1+0.3\%)}{0.3\%} \Rightarrow$$
 $A=15$  yuan.

<sup>18</sup> With current monthly interest rate  $r = 0.3\%$ , the fixed cost per household  $f$  can be derived as follows:  
 $5381.66 = f(1+0.3\%)/0.3\% \Rightarrow f = 16.1$  yuan.

<sup>19</sup> Likewise, the marginal cost per subscriber,  $s$ , which represents costs of cable installing, transportation, electricity and employee salary, etc. for a new subscriber, is equal to:  
 $1176.85 = s(1+0.3\%)/0.3\% \Rightarrow s = 3.52$  yuan.

within 3 minutes (equivalent to 1 calling unit) are about one half, one-third and one-sixth of the total calls, respectively. Thus, the average calling units per household per month amount to  $42*(3*1/2 + 2*1/3 + 1*1/6) = 98$ .

The parameters of the model are  $\lambda, \alpha, \gamma, \mu, \sigma$ . Due to lack of the data on the income distribution in Beijing, this paper only deals with the optimal telephone service pricing for the average income households. In other words, we specify that  $\lambda = 1$ . Then, the parameters to be calibrated are  $\alpha, \gamma, \mu, \sigma$  and, we need four equations of  $\alpha, \gamma, \mu, \sigma$  to compute these values. If the elasticities  $\eta_p^N, \eta_p^O$  are available, we can use the four equations below;

$$N(L, p) = M[(1 - F_\theta(\beta_m))] = M \int_{L\beta_m}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\alpha^2}(x-\mu)^2} dx$$

$$Q(L, p) = \int_{\beta_m}^{\infty} (\alpha - p/\lambda) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\alpha^2}(Lnx - \mu)^2} dx$$

$$\eta_p^N = \frac{-PM}{N(L, p)} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\alpha^2}(L\beta_m - \mu)^2} \frac{q_m}{L - \lambda\gamma}$$

$$\eta_p^O = -\frac{p}{\lambda\alpha - p} + \frac{\beta_m(\alpha - p/\lambda)}{[Q(L, p)/N(L, p)]} \eta_p^N$$

to compute  $\alpha, \gamma, \mu, \sigma$ . However, since Beijing started its residential telephone service in the mid-1980s, there are not enough time series data available to conduct an econometric study on these elasticities. Thus, we can only use the first two equations to compute  $\mu$  and  $\sigma$ . In this case, we can choose  $\alpha, \gamma$  in accordance with their regular values in the telecommunications industry (Mitchell, 1978b: 534). Here we choose  $\alpha = 0.4727; \gamma = 8.365$ . A computer program has been written to find a set of parameters ( $\mu, \sigma$ ) which is

consistent with the data presented above, that is,  $\mu = 5.2697$ ;  $\sigma = 1.1674$  (see Appendix B).

Using the set of parameters presented above, we vary the monthly fixed charge from 12 yuan to 28 yuan, the per calling unit charge from 0.1 yuan to 0.25 yuan to calculate the penetration rate (N), the monthly number of calling units per capita per month (Q), the net profit per capita per month ( $\pi$ ) and the net consumer welfare per capita per month (W). The results are given in Appendix C.

$$(1) N = [1 - F_{\theta}(\beta_m)] = \int_{Ln\beta_m}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} dx$$

$$(2) Q = \int_{\beta_m}^{\infty} (\alpha - p) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(Ln x - \mu)^2} dx$$

$$(3) \begin{aligned} \pi &= (mc - s)N + (p - 0.06)Q - f \\ &= (mc - 3.52)N + (p - 0.06)Q - 16.1 \end{aligned}$$

$$(4) \begin{aligned} W &= \int_{\beta_m}^{\infty} [\gamma + \frac{1}{2}(\alpha - p)^2 x - mc] f_{\theta}(x) dx \\ &= \int_{\beta_m}^{\infty} [\gamma + \frac{1}{2}(\alpha - p)^2 x - mc] \frac{1}{x} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(Ln x - \mu)^2} dx \end{aligned}$$

## 2. Interpretation of Results

From Appendix C, we pick up four sets of results, which are the most relevant for this analysis, to make up Table 5-2 below.

Table 5-2. Optimal Tariffs Under Different Penetration and Pricing Strategies

	Optimal Tariff		Market Demand		Net Profit	Welfare Measure	
	Monthly Charge (L)	Per Calling Unit Charge (p)	Penetration Rate (N)	Number of Calling Units Per Capita Per Month (Q)	Per Capita ( $\pi$ )	Per Capita (W)	Percent Change from Current Tariff (%)
Current Tariff	26.5	0.125	35.5%	98	-1.5723	10.6481	--
	21.5	0.175	35.9%	84	0.0406	7.8623	-26.0
	14.5	0.150	66.6%	110	1.1597	13.7651	29.3
	12.0	0.150	80.9%	115	1.1026	15.5960	46.5

From the above, we discover that, under the current tariff, the net profit per capita per month is -1.5723 yuan. It means that Beijing's local telephone residential service is losing 127.55 million yuan each year, which needs to be partially cross-subsidized by the long distance service as well as to be partially offset by charging high connection fee. If this continues into the future, the enterprise will run into a vicious circle in that the high connection fee will constrain potential subscribers and, as a result, the accumulated losses will make it impossible for the enterprise to invest in R&D, adopt new technology or update its obsolete facilities. As shown in the above table, not only is the telephone enterprise suffering from losses but the corresponding social welfare has not been maximized.

The current penetration rate and social welfare indicate that the economies of scale have not been achieved yet. At a penetration of about 35%, if the two-part tariff is

set at 21.5 yuan and 0.175 yuan, which implies a moderate reduction in the connection fee and an increase per calling unit charge, the calling units per capita per month will go down to 84, and the telephone company will not lose money any more. Therefore, it will be able to self-finance and sustain on-going system expansion.

In the years to come, Beijing should start to charge less connection fee and raise per calling unit charge within a certain range, so as to accelerate telephone penetration and thereby raise consumer welfare on a positive-profit basis. As planned, by the end of this century, its penetration rate will reach 67% (Beijing Review, 1994:175). If the monthly charge and per calling unit charge can be priced at 14.5 yuan and 0.15 yuan respectively, the corresponding social welfare will be raised up to 13.7651 yuan per capita per month. As for the year 2010, the targeted penetration is about 80% with social welfare as high as 15.5960 yuan per capita per month, which implies an increase in welfare by 46.5% from the current tariff.

## Chapter 6

### CONCLUSIONS

Although Beijing's telecommunications sector has maintained a high growth rate since 1980s, there remains quite a few problems associated with the local residential telephone pricing, ministry-owned networks and network efficiency, etc.. Based on our analysis, the following policy recommendations are made:

#### (1) Rationalizing Local Residential Telephone Pricing

Optimal pricing can reflect the true social costs and benefits, provide incentives for the telecommunications industry to extend quality service, and expedite economic development. Instead of keeping new customers from entering the telephone market, the Beijing telephone authorities should acquire higher telephone penetration by properly setting the local telephone tariff and funding infrastructure construction through a variety of services. As argued before, the extent to which economies of scale reduce the unit cost of providing telecommunications service depends on the speed with which the network expands. Upon this understanding, the local telephone authorities of some southern cities already started to lower their connection fee to attract more subscribers (Zita, 1994:98). One way of doing that is subsidizing installation fee and raising the local calling charge accordingly. An alternative is to allow a certain percentage of the installation fee as reimbursement for those early subscribers some years after the telephone system achieves economies of scale.

## (2) Efficiently Utilizing The Ministry-Owned Networks

As discussed in Section 3.3, the inefficient utilization of the ministry-owned networks is considered to be an enormous waste of economic resource. On the one hand, there exists a great amount of excessive capacity in these networks; on the other hand, the public network can not be significantly expanded in a short run. Obviously, the ministry-owned network management is essential for the efficient operation of the whole national network. One solution is that, these networks should start to merge into the public network. By doing so, the telephone authority can expect a higher level of network externality, and more revenue will be generated for ongoing upgrading of the networks. As a matter of fact, the PLA has been attempting to attract some customers in its neighborhood in recent years.

## (3) Improving Network Efficiency

From the beginning, Beijing's telephone authorities have been dealing with the grievances from customers who are kept waiting long. If the local telephone authorities try peak-load and off-peak rates to encourage people to call outside prime time, not only can the spare capacity of the whole network be utilized, but traffic congestion can be eliminated and thus network efficiency will be somehow improved. Nevertheless, the authorities must ensure that; (i) the discounted prices should be no less than the short-run marginal cost of providing off-peak service; (ii) where networks are to be expanded to meet increasing demand, prices should be set no less than long-run marginal cost.

## Appendix A. The Derivation of $N$ , $Q$ , $\eta_p^N$ , $\eta_p^Q$

By assuming  $Ln\beta \sim N(\mu, \sigma^2)$ , we specify the cumulative distribution function of  $\beta$  as follows:

$$F_{\theta}(\beta) = \int_0^{Ln\beta} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} dx$$

Accordingly,  $f_{\theta}(\beta)$ , the log-normal density function with unknown parameter  $\theta = (\mu, \sigma^2)$ , is:

$$f_{\theta}(\beta) = \frac{1}{\beta} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(Ln\beta - \mu)^2}$$

Hence, based on the optimal telephone pricing model presented in Chapter 5, we can obtain:

$$N = [1 - F_{\theta}(\beta_m)]$$

$$= \int_{Ln\beta_m}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} dx$$

$$\begin{aligned} Q(L, p) &= \int_{\beta_m}^{\infty} (\alpha - p/\lambda) \beta f_{\theta}(\beta) d\beta \\ &= \int_{\beta_m}^{\infty} (\alpha - p/\lambda) \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(Ln\beta - \mu)^2} d\beta \end{aligned}$$

$$\begin{aligned} \eta_p^N &= \frac{pq_m}{L} \eta_p^N = \frac{pq_m}{L} \frac{\partial N}{\partial L} \frac{L}{N} = \left( \frac{pq_m}{L} \right) \left[ -\frac{M f_{\theta}(\beta) \beta_m}{L - \lambda(y)\gamma} \right] \left( \frac{L}{N} \right) \\ &= \frac{-PM}{N(L, p)} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(Ln\beta_m - \mu)^2} \frac{q_m}{L - \lambda\gamma} \end{aligned}$$

$$\begin{aligned} \eta_p^Q &= -\eta_p^{q_j} + \frac{q_m}{Q} \eta_p^N \\ &= -\frac{p}{\lambda\alpha - p} + \frac{\beta_m(\alpha - p/\lambda)}{[Q(L, p)/N(L, p)]} \eta_p^N \end{aligned}$$

where  $q_m = \beta_m(\alpha - p/\lambda)$

## Appendix B. The Computation of $\mu$ and $\sigma$

$nlp = N$ :	telephone penetration rate
$qbar = Q$ :	calling units per capita per month
$mc = L$ :	fixed monthly charge
$p$ :	per calling unit charge
$a = \alpha$ :	the utility derived from the first call
$gamma = \gamma$ :	the value of having telephone service when no outgoing calls are made
$bm = \beta$ :	the taste parameter of various groups of subscribers
$\mu = \mu$ :	the mean of $\ln\beta$
$sigma = \sigma$	
$(sigma)^2 = \sigma^2$ :	the variance of $\ln\beta$

The purpose of this computer programme is to calibrate  $\mu$  and  $\sigma$ . In this calibration, we have the data series as follows:

$$nlp = 0.355$$

$$qbar = 98$$

$$mc = 26.5$$

$$p = 0.125$$

$$a = 0.4727$$

$$gamma = 8.365$$

$$bm = 2(mc - gamma) / (a - p)^2 = 300.012$$

```
f[mu_,sigma_] := 1-Integrate[Exp[-((x-mu)^2)/(2 (sigma)^2)]/
  (sigma Sqrt[2 Pi]),{x,0,Log[bm]}]
```

```
g[mu_,sigma_] := Integrate[(a-p) Exp[-((Log[x]-mu)^2)/(2
  (sigma)^2)]/(sigma Sqrt[2 Pi]),{x,bm,5000}]
```

```
FindRoot[{f[mu,sigma] == nlp, g[mu,sigma] == qbar},
  {mu,{5.3,5.4}},{sigma,{1.1,1.2}}]
```

```
{mu -> 5.2697, sigma -> 1.16742}
```

## Appendix C. The Calculation of The Optimal Two-Part Tariff of Beijing

First, we transform the equation (1) listed in Section 5.1 as follows:

$$(1) \quad N = [1 - F_{\theta}(\beta_m)] = \int_{Ln\beta_m}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2} dx$$

We rewrite this equation using the error function  $erf[z]$ , which is the integral of the Gaussian distribution (Wolfram, 1993:787), given by  $Erf[z] = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2} dt$

$$\text{Let } z = \frac{x-\mu}{\sigma\sqrt{2}} \Rightarrow F_{\theta}(\beta_m) = \frac{1}{2} Erf\left[\frac{-\mu}{\sigma\sqrt{2}}, \frac{Ln\beta - \mu}{\sigma\sqrt{2}}\right] \Rightarrow$$

$$N = 1 - F_{\theta}(\beta_m) = 1 - \frac{1}{2} Erf\left[\frac{-\mu}{\sigma\sqrt{2}}, \frac{Ln\beta - \mu}{\sigma\sqrt{2}}\right] \quad \text{where } \beta = \frac{2(L-\gamma)}{(\alpha-p)^2}$$

Based on the four parameter  $\alpha, \gamma, \mu, \sigma$  and the above equation, together with the equation (2), (3), (4) presented in Section 5.1, we vary the monthly fixed charge (mc) from 12 to 28 yuan, the per calling unit charge (p) from 0.1 to 0.25 yuan to calculate the penetration rate (N), the calling units per capita per month (Q), the net profit per capita per month ( $\pi$ ) and the consumer welfare per capita per month (W). The calculation is presented in this appendix.

The following computation presents different values of N, Q,  $\pi$ , W in sequence, given the ascending value of mc, p. In the bracket, the first number refers to the monthly fixed charge (mc), the second refers to the per calling unit charge (p), the third refers to the penetration rate (N), the fourth refers to the calling units per capita per month (Q), the fifth number refers to the net profit per capita per month ( $\pi$ ), and the sixth number refers to the consumer welfare per capita per month (W) in a row.

Table[{mc,

p,

(1)  $1 - \text{Erf}[-\mu/(\sigma \sqrt{2})], (\text{Log}[2 (mc - \gamma)/((a-p)^2)] - \mu)/(\sigma \sqrt{2})]/2$

(2)  $\text{NIntegrate}[(a-p) (1/(\sigma \sqrt{2 \text{Pi}})) \text{Exp}[-((\text{Log}[x] - \mu)^2)/(2 (\sigma)^2)], \{x, 2(mc - \gamma)/((a-p)^2), 5000\}],$

(3)  $(mc - 3.52) (1 - \text{Erf}[-\mu/(\sigma \sqrt{2})], (\text{Log}[2 (mc - \gamma)/((a-p)^2)] - \mu)/(\sigma \sqrt{2})]/2) + (p - 0.06) \text{NIntegrate}[(a-p) (1/(\sigma \sqrt{2 \text{Pi}})) \text{Exp}[-((\text{Log}[x] - \mu)^2)/(2 (\sigma)^2)], \{x, 2(mc - \gamma)/((a-p)^2), 5000\}] - 16.1,$

(4)  $\text{NIntegrate}[(\gamma + (a-p)^2 (x/2) - mc) (1/(x \sigma \sqrt{2 \text{Pi}})) \text{Exp}[-(\text{Log}[x] - \mu)^2/(2 (\sigma)^2)], \{x, 2(mc - \gamma)/((a-p)^2), 5000\}], \{mc, 12, 28, 0.5\}, \{p, 0.1, 0.25, 0.025\}]$

{{{12, 0.1, 0.869465, 133.993, -3.36724, 21.8188},

{12, 0.125, 0.842529, 124.478, -0.864286, 18.5877},

{12, 0.15, 0.809776, 114.841, 1.10262, 15.596},

{12, 0.175, 0.770023, 105.047, 2.51015, 12.847},

{12, 0.2, 0.721952, 95.0479, 3.32885, 10.3453},

{12, 0.225, 0.664187, 84.7899, 3.52263, 8.09675},

{12, 0.25, 0.595472, 74.2094, 3.04939, 6.10851}},

{{{12.5, 0.1, 0.844581, 133.474, -3.17671, 21.3917},

{12.5, 0.125, 0.814475, 123.851, -0.735688, 18.1749},

{12.5, 0.15, 0.778362, 114.085, 1.15736, 15.2003},

{12.5, 0.175, 0.73517, 104.137, 2.47762, 12.4721},

{12.5, 0.2, 0.683764, 93.9606, 3.19469, 9.99536},

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