Estimating Demand for Cellular Phone Service under Nonlinear Pricing

Huang, Ching-I

National Taiwan University

October 2007

Estimating Demand for Cellular Phone Service under Nonlinear Pricing

Ching-I Huang*

October 2, 2007

Abstract

Cellular phone carriers typically offer complicated nonlinear tariffs. Consumers make a discrete choice among several rate plans. Each plan has a nonlinear price schedule, and price is usually lower for in-network calls. I present an empirical framework to estimate demand under such nonlinear pricing schemes by using parsimonious data and apply the estimation method to analyze the cellular phone service market in Taiwan. Based on the estimated model, I evaluate the impacts of termination-based pricing schemes on the market structure. While the existence of in-network discounts causes considerable tipping effects on market shares, the effects come primarily from reducing the average prices, not from the difference between in-network and off-network prices. There is no evidence showing that termination-based pricing by itself has significant effects on market structure.

*Department of Economics, National Taiwan University, Taipei, Taiwan. E-mail: chingihuang@ntu.edu.tw. I would like to thank Aviv Nevo, John Panzar, Robert Porter, and William Rogerson for helpful comments and discussions. The Survey of Family Income and Expenditure was carried out by the Directorate General of Budget, Accounting, and Statistics of the Taiwan Government. The Center for Survey Research of Academia Sinica is responsible for the data distribution. I appreciate the assistance in providing data. Financial supports from Chiang Ching-kuo Foundation for International Scholarly Exchange, Center for the Study of Industrial Organization at Northwestern University and the National Science Council in Taiwan are gratefully acknowledged. All remaining errors are mine.

1 Introduction

Cellular phone carriers generally offer several rate plans at the same time. The price schedule differs across rate plans. Consumers select one of the rate plans if they want to use cellular phone service. Furthermore, the price schedule under a rate plan is typically nonlinear in quantity. A rate plan usually involves a fixed subscription fee and unit prices, which depend on both the total volume and the termination location of a phone call. The price of a call terminated within the caller's network (in-network call) is often lower than the price of a call terminated in other networks (off-network call). The in-network discounts reduce compatibility among different networks. As a result, consumers would prefer a large network for any given price schedule. Theoretical results of such termination-based pricing are sensitive to model specifications[1]. The effect of nonlinear pricing on market competition is thus an empirical issue. The motivation of this paper is to access the effects of termination-based pricing schemes on the market structure.

To capture the impact of the entire nonlinear price schedule on consumer behavior, I propose a preference-based structural model, which is conceptually similar to Miravete (2002). Consumers are heterogeneous in their marginal utilities of making phone calls, which is determined by their *ex ante tastes* and *interim random shocks*. The ex ante taste is known prior to the subscription decision and is private information. This asymmetric information induces firms to screen consumers by providing a menu of rate plans. After consumers subscribe to a rate plan from a carrier, there are carrier-level shocks on signal quality and consumer-level shocks on taste. Both types of shocks affect *ex post taste* of using cellular service. Consumers choose the volume that maximizes their surplus under the chosen rate plan, taking into account the realized interim shocks. But because only the distribution of the interim shocks, not the realized values, is known at the subscription stage, consumers select a rate plan according to their expected utilities. Standard nonlinear tariff theory ignores the time lag between the subscription decision and the volume choice, implying that the effective price scheme is the lower envelope of all available price schedules. In the telephone industry, however, the expected usage at the moment of subscription decision could differ from the actual usage because of the temporal separation. Therefore, the actual payment could be above

[1]For example, see Laffont, Rey, and Tirole (1998), Gans and King (2001).

the lower envelope.

While individual-level data on cellular phone consumption is preferred for this kind of empirical analysis, they are less available to researchers. I estimate consumer demand by combining monthly carrier-level aggregate output data with cross-sectional expenditure survey data. The market share of a carrier can be measured in two different ways, either by the number of its subscribers or by the total traffic volume. The first measure of market shares allows me to identify the discrete plan choice while the second measure identifies consumers' volume choice Distribution of iterim shocks is inferred from the difference between the two measures. Furthermore, I incorporate the expenditure distribution among consumers to identify the heterogeneity of their tastes. The estimation approach is to construct moment conditions from both data sources. These moment conditions are jointly used as constraints in the maximum likelihood estimation to obtain parameters in the behavior model.

I apply the model to study the cellular phone service market in Taiwan, where in-network discounts are large and common since the deregulation in 1998. In addition, the carrier of a phone number can be easily recognized from its prefix. Therefore, callers are aware of the discounts whenever they dial an in-network phone number. This feature allows consumers to make different volume choices based on the termination of a phone call.

The estimation finds significant heterogeneities on the taste of cellular service among consumers. For any given quantity of phone calls, the standard deviation of consumers' marginal utilities is 0.0736 Taiwan dollars per second.[2] Income variation can explain 9.38% of the taste variation. On the supply side, carriers are vertically differentiated in two aspects. First, carriers differ in their attractiveness at the subscription stage for any given level of expected surplus from making phone calls. The monetary value of the difference between the most attractive carrier and the least one is 447 Taiwan dollars a month. Second, carriers have different perceived signal qualities which affect consumers' quantity choices. The marginal utility of calling from the highest quality carrier is higher than from the lowest quality carrier by 0.0890 Taiwan dollars per second.

Although some simplification assumptions imposed on the model seem strong, an out-of-sample

[2]As a comparison, the median in-network and off-network prices among all rate plans are 0.07 and 0.13 Taiwan dollars per second, respectively.

test shows the estimated model can approximate the observed market reasonably well. I use the estimated model to predict monthly churn rates[3] for Chunghua Telecom and find the predicted rates are close to those observed in the data.

I perform two counterfactual simulations to evaluate the effects of termination-based pricing schemes on the market structure. In the first simulation, I eliminate all the discounts by setting in-network prices equal to the observed off-network prices. The simulation shows that in-network discounts have a large impact on the market structure, on average increasing the Herfindahl-Hirschman Index (HHI) by 218 points in this highly concentrated market. In the second simulation, I eliminate consumers' ability to recognize the carrier of a receiver from the phone number. As a result, consumers cannot make termination-specific quantity choices, essentially eliminating the substitution between in-network and off-network calls caused by termination-based pricing. The second simulation finds very tiny effects on the market structure. Combining these two simulations, I conclude that in-network discounts have a large effect on the market primarily because of reducing average prices, and the effects resulting from the price difference between in-network and off-network calls are almost negligible.

The rest of the paper is organized as follows. In the next section, I discuss the related literature. I then provide a brief background of the industry and describe the data in Section 3. The structural model is presented in Section 4, followed by my estimation approach in Section 5. I show the estimation results of the structural model in Section 6 and perform counterfactual simulations to evaluation the effects of termination-based pricing in Section 7. Conclusions are in the final section.

2 Related Literature

In this section, I briefly review some previous researches on demand estimation of the telecommunication industry and summarize my contributions over the previous works.

Because firms usually offer a collection of optional rate plans in the telecommunication market, a consumer needs to make a discrete choice over rate plans, followed by a continuous choice of the

[3] Churn rate, as is commonly used in the industry, is the proportion of subscribers who leave a carrier during the month.

volume.[4] Train, McFadden, and Ben-Akiva (1987) estimate a nested logit model in which plan choice and volume choice are simultaneous, and both are discrete. Hanemann (1984) provides a framework to estimate discrete/continuous models in which the discrete and continuous choices are linked by the same utility maximization problem. This framework can be used to analyze the simultaneous choices of brand and quantity, but does not account for the time lag between plan choice and volume choice. Miravete (2002) points out the importance of this time lag. His theoretical model provides a justification for a carrier to offer several rate plans with a nonlinear price schedule. He examines experimental data from a local telephone company in two cities in Kentucky. He concludes that the asymmetry of information between the firm and the consumers about both ex ante tastes and interim shocks is significant. The monopoly uses a menu of optional calling plans to screen consumers with respect to the ex ante tastes and nonlinear price schedule within each plan to screen them with respect to the interim demand shocks.

My model is close to that of Narayanan, Chintagunta, and Miravete (2007), who analyze demand for local telephone service. As in my model, they assume that interim shocks are observed after the plan choice. They use subscriber-level data on consumption choices to obtain model parameters, while my data are more aggregate. Economides, Seim, and Viard (2006) study local phone service in a competitive environment using phone bill information from a survey of residential customers in New York State. The moment conditions from the plan choice and from the volume choice are jointly estimated. However, they do not explicitly account for the time separation between plan choice and volume choice. Similarly, Iyengar (2004) uses subscriber-level billing records from a cellular phone carrier to study demand for wireless service. The difference between ex-ante optimal volume and ex-post actual volume is modelled as white noise, independent of other variables. In my framework, the difference results from interim shocks and is endogenously determined by a consumer's taste and the price schedule of the chosen rate plan.

Berry, Levinsohn, and Pakes (1995) propose a parsimonious empirical approach to analyze discrete choice with heterogeneous consumers using brand-level aggregate data. They recover the average utility level of each product from observed market shares. In their model, there is no

[4]Some earlier studies on cellular phone demand abstract away the volume choice by assuming all subscribers make the same amount of phone calls. (Parker and Röller, 1997; Hausman, 1997)

quantity choice. Consumers are assumed to purchase a single unit of one product. This is appropriate for the automobile market they study. Their approach has been adapted to study price discrimination with discrete quantity (or quality) choice in Broadway theatre (Leslie, 2004), paper towers (Cohen, 2001), and specialty coffee (McManus, 2006). Nonetheless, this approach has to be modified if consumers purchase different quantities and the quantity choice is on a *continuous* spectrum. Nair, Dubé, and Chintagunta (2005) account for the continuous quantity choice in the refrigerated juice market. As in the discrete/continuous choice model, the discrete brand choice and the continuous quantity choice are linked by specifying the utility function. Different from the telephone service market, however, consumers make these two choices simultaneously.

To my knowledge, there are very few pervious studies to quantify the effect of in-network discounts on market demand. By using reduced-form estimation, Kim and Kwon (2003) and Fu (2004) find that large networks are more attractive to consumers. However, it is difficult to separate the effect of in-network discounts from other factors such as reputation. By using carrier-level subscription data, Grajek (2003) proposes a structural model to estimate network effects in the Polish mobile phone industry. By comparing the network effects before and after in-network discounts are eliminated in the market, he finds a significant increase in compatibility among carriers.

3 The Cellular Phone Service in Taiwan

This section briefly illustrates the cellular phone service market in Taiwan and describes the data. The research period in the empirical part of this study is between May 2000 and June 2005.

3.1 Cellular Carriers

I focus on GSM carriers[5] since they dominate the wireless telephone service in Taiwan. The industry is regulated through licenses by the Directorate General of Telecommunications. During the research period, the number of GSM licences is fixed. The regulator divides Taiwan into North,

[5]GSM (global system for mobile communications) is a digital technology to transmit mobile voice and data. It is one of the second generation wireless systems and is the most widely used technology in the world for mobile telephones.

Table 1: Operational regions and market shares by carrier

	Operational Regions			Market Shares	
Carrier	North	Central	South	by Subscribers	by Volume
Chunghwa Telecom	×	×	×	0.308	0.345
Taiwan Cellular	×	×	×	0.256	0.249
Far Eastone	×	×	×	0.182	0.173
KG Telecommunication	×	×	×	0.148	0.169
Trans Asia			×	0.066	0.044
Mo Bi Tai		×		0.029	0.024

Notes: The market shares are the medians of monthly market shares between May 2000 and June 2005.

Central, and South regions.[6] There are four national carriers, Chunghwa Telecom (CHT), Taiwan Cellular (TCC), Far Eastone Telecommunications (FET), and KG Telecommunications (KGT), and two regional carriers, Trans Asia Telecommunications (TAT) and Mo Bi Tai Communications (MBT). See Table 1 for their operational regions and market shares. Besides GSM system, there are other types of wireless telephone systems in Taiwan, PHS and 3G. The number of their subscribers are both less than 4% of the number of GSM subscribers.[7]Expect for qualities, the products are essentially identical among the GSM carriers. Since their service is operated on the same wireless technology, consumers can switch between them without purchasing a new handset.[8]

Within the research period, the number of firms operating GSM service has fallen from six to three. Taiwan Cellular acquired a regional carrier, Trans Asia, in May 2001. Far Eastone acquired KG Telecommunications in January 2004. In August 2004, Taiwan Cellular acquired another

[6]The counties and cities included in each of the three regions are (1) North Region: Keelung, Taipei, Taoyuan, Hsinchu, Yilan, Hualien, and Lienchiang; (2) Central Region: Miaoli, Taichung, Changhua, Nantou, and Yunlin; (3) South Region: Chiayi , Tainan, Kaohsiung, Pingtung, Taitung, Penghu, and Kinmen. The proportion of the population is 45% in the North Region, 25% in the Central Region, and 30% in the South.

[7]PHS (personal handy-phone system) is generally considered inferior to GSM because of its lower power and smaller coverage area. First International Telecom, which began its PHS service in June 2001, is the only firm operating a PHS system. Its coverage area is limited to some metropolitan areas. 3G stands for the third generation wireless system. Five national 3G licenses were auctioned off by the Directorate General of Telecommunications in January 2002. Three of them were acquired by the incumbent GSM operators, Chunghwa Telecom, Taiwan Cellular, and Far Eastone. An entrant, Asia Pacific Broadband Wireless Communications, launched its 3G service in July 2003. Other carriers did not begin operating 3G service until July 2005. To be more precise, there is also an obsolete system during the research period, called CT2 (the second generation cordless telephony). Its market share has always been less than 0.2% and keeps decreasing during the research period.

[8]In particular, handsets are not locked to a specific carrier. Therefore, handsets are compatible with all GSM carriers. The compatibility substantially reduces switching costs among these carriers.

regional carrier, Mo Bi Tai. Nevertheless, these acquired carriers still operate as a separate brand in the market. In particular, their price schemes are different from the acquiring carriers' price schemes. Furthermore, in-network discounts apply to phone calls between the acquired network and the acquiring network only in some rate plans.

All cellular phone networks are interconnected with each other. They are also interconnected with other types of telephone services such as landline telephone networks. Therefore, a customer in one network can make a call to a receiver in any other network. Because the carrier of a receiver can be recognized by the caller from the prefix of the phone number, it is easy to make different consumption choices when the price depends on the receiver's network.

3.2 Output Data

Carrier-level output data come from *Monthly Statistics of Transportation and Communications* published by the Ministry of Transportation and Communications of the Taiwan government. The Directorate General of Telecommunications requires each GSM operator to report the number of active subscribers and the total volume of calls originated from the carrier every month since May 2000.[9] In addition, the numbers of landline telephone subscribers and PHS[10] subscribers are also reported in the monthly statistics. Nevertheless, there is no reliable monthly output data of 3G service before March 2006. The number of 3G subscribers is available only in the annual statistics.

3.3 Rate Plans

I collect all of the rate plans offered by GSM carriers during the research period. All carriers publicly announce their current rate plans on their websites. Previous rate plans are obtained through direct contacts and from reports on newspapers and magazines. Among these sources, a consumer magazine *Call: Fashion Communications Magazine* reports the rate plans of all carriers regularly since 2001.

[9]The volume of Far Eastone in the first two months (May and June, 2000) is substantially higher than that in the following months. I suspect that both incoming calls and outgoing calls were counted in the reported numbers. Therefore, I divide the reported values by two to correct the data. In addition, the volume of Chunghwa Telecom appears to have a one-month lag. I shift this series backward by one month.

[10]CT2 subscribers are included in the same category as PHS users. I do not treat them differently in the estimation because CT2 users only account a very small share in this category.

Table 2: Number of rate plans by carrier

Carrier	2000	2001	2002	2003	2004	2005
Chunghwa Telecom	5	10	10	10	11	11
Taiwan Cellular	5	9	9	10	9	14
Far Eastone	10	11	7	12	13	16
KG Telecommunications	8	10	9	10	11	8
Trans Asia	8	9	9	10	9	10
Mo Bi Tai	9	7	8	8	8	9

Notes: The numbers on the table are the numbers of rate plans in May of the year.

All prices are adjusted to 2001 Taiwan dollars (TWD) using the monthly consumer price index.[11] During the research period, the exchange rate as compared to U.S. dollars (USD) has been between 30.7 TWD and 35.1 TWD per USD.

Table 2 summarizes the number of the rate plans by carrier. National carriers always offer the same menu of rate plans regardless the region of a customer. Each carrier provides about 10 rate plans at a given month. There is a slowly increasing trend in the number of plans as more non-voice services are introduced into the market. In addition to the price of voice service, rate plans are differentiated in the price of non-voice service.

All rate plans have a structure similar to a two-part tariff. Once subscribing to a rate plan, a positive fixed monthly fee is charged in almost all plans. Consumers only pay for outgoing calls, but not incoming calls. Contrary to a typical two-part tariff, there are distinct marginal prices for in-network and off-network calls, respectively. In addition, there are generally thresholds in a rate plan such that, for volumes less than the thresholds, the total phone tariff is simply the flat monthly fee. The positive marginal prices are applied only to quantities above the thresholds. There are various forms of the thresholds. Some plans provide *free allowances*, which specify the time length of free usage. The amounts of the free allowance for in-network and off-network calls can be either combined or separated, depending on the plan design. Other plans specify the threshold in the dollar amount, called *deduction*. Only the portion of the usage charge above the deduction amount

[11] The price index is published by the Directorate-General of Budget, Accounting and Statistics. The consumer price level is very stable. The index has been between 98.8 and 103.4 during the research period.

Table 3: Average in-network discounts by carrier

Carrier	2000	2001	2002	2003	2004	2005
Chunghwa Telecom	0.466	0.441	0.441	0.441	0.468	0.468
Taiwan Cellular	0.373	0.463	0.463	0.440	0.463	0.483
Far Eastone	0.468	0.475	0.469	0.587	0.572	0.562
KG Telecommunications	0.515	0.497	0.534	0.527	0.514	0.469
Trans Asia	0.437	0.437	0.500	0.450	0.389	0.377
Mo Bi Tai	0.298	0.422	0.452	0.369	0.369	0.328

Notes: The discounts are computed from comparing the marginal price of an in-network call with that of a call terminated in a rival GSM network in May of the year.

is counted in the phone bill. Since all plans have only very limited off-peak periods, I ignore off-peak rates. This simplification causes an upward bias of the price.

Most rate plans charge a lower price for calls terminated within the own network. As Table 3 shows, in-network prices are close to 50% of off-network prices. The significant price differences between in-network and off-network calls provide consumers incentives to identify the carrier of the receiver while dialing a phone number.

3.4 Consumer Expenditure

The 2002 Survey of Family Income and Expenditure was conducted by the Directorate-General of Budget, Accounting and Statistics. The universal sampling rate is 0.20%, which is 13,681 households. The survey provides information on annual telecommunication expenditure and annual income at the household level. To account for variation of consumer tastes across regions, household income is used as a proxy to control the differences in socioeconomic status. Based on the survey data, I obtain the distribution of telecommunication expenditure conditional on income, which will be used in the estimation to identify the heterogeneity of consumer tastes.

4 Behavior Model

My model focuses on the demand for voice service in the cellular industry. Given a consumer's taste, this section derives her plan and quantity choices. Integrating the choices over all consumers, I obtain market shares for each carrier, measured in the number of subscribers and in the traffic volume.

4.1 Timeline of Events

The events in a billing period (a month) occur in the following order.

1. Each carrier announces a menu of rate plans. Consumers know their ex ante taste.
2. Consumers simultaneously subscribe to one (if any) of the rate plans available in their region. Carriers activate the service for consumers.
3. Random quality shocks for each carrier and random taste shocks for each consumer occur.
4. Consumers make phone calls and pay the tariff.

4.2 The Market Supply

The carriers of cellular phone service, determined by the regulator, vary across the three regions $R \equiv \{North, Central, South\}$. Let K_r denote the set of GSM brands operating in region r. Although some carriers are acquired by others, they still operate as a different network brand in the market. I will treat them as separate carriers in the estimation.

Rate plans are treated as exogenous in the model. I justify this assumption by the fact that changes on the plans have to be reported to the regulator and publicly announced before they take effect. As a consequence, firms cannot respond to interim shocks when the shocks are revealed. For any given carrier, it offers an identical menu of rate plans to all regions where it operates. Denote the set of rate plans offered by network k at time t as P_{kt}. For any carrier, the quality of service is the same regardless the chosen rate plan.

I simplify the tariff formula so that in-network and off-network usages are additively separable. *The payment of using q^I in-network minutes and q^O off-network minutes of plan p at time t* is

$$\bar{T}_{pt}(q^I, q^O) = MF_{pt} + p^I_{pt} \max\{q^I - a^I_{pt}, 0\} + p^O_{pt} \max\{q^O - a^O_{pt}, 0\}, \tag{1}$$

where a^I_{pt} and a^O_{pt} are free allowances for in-network and off-network calls, respectively; MF_{pt} is the monthly fee.[12] When the usage is less than free allowances ($q^I < a^I_{pt}$, $q^O < a^O_{pt}$), a customer faces zero marginal payment and pays the flat monthly fee MF_{pt}. Beyond the thresholds, the per-second marginal payment is p^I_{pt} for in-network calls and p^O_{pt} for off-network calls.

4.3 The Market Demand

Consumers in the market are all individuals in the economy. Let $\mathcal{C}_t$ denote the set of all consumers at time t. $POP_t \equiv |\mathcal{C}_t|$ is the population.[13]

The value of cellular phone service increases in the number of potential receivers. Since all networks are interconnected, the destination of a call can be either in a wireless network or in a landline network. Denote the set of all potential receivers at period t as $\mathcal{D}_t$, which includes subscribers of all telephone networks.

The cost of switching to a different rate plan or a different carrier in the next period is assumed to be zero.[14] Therefore, consumers make decisions independently over time. After I estimate the model, I will provide evidence on the restrictiveness of this assumption.

[12] For rate plans with other forms of thresholds, I divide the free allowances into a^I_{pt} and a^O_{pt} in proportion to the respective network sizes. This simplification causes a slightly upward bias of the tariff. In addition, I transform per-minute rates into per-second rates since most plans are based on per-second rates.

[13] I use the population registration data from the Ministry of the Interior.

[14] In practice, consumers can change to a different rate plan within the same carrier almost costless by calling the customer service line. However, the actual cost of switching to another carrier might be positive even though all carriers had reduced the activation fee to zero by 2002. A considerable proportion of customers have a one-year or two-year contract with their carrier in exchange for handset subsidy. In addition, number portability has not taken effect in Taiwan during the research period. The inconvenience of changing a phone number is also part of switching costs.

4.3.1 Consumer Preferences

Consumers are vertically differentiated in their utility of using cellular service. The taste of cellular service depends on (a) a consumer's *ex ante taste* θ_{it}, (b) an *interim taste shock* ν_{it}, and (c) the *signal quality of her carrier* η_{kt}. The singal quality is identical to all customers of a carrier.

The *surplus of consumer* $i \in \mathcal{C}_t$ *subscribing to rate plan* $p \in P_{kt}$ *of network* $k \in K_r$ *at time* t can be expressed as

$$\sum_{j \in \mathcal{D}_{it}} u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it}) - \alpha \bar{T}_{pt}(\mathbf{x}_{it}) + \delta_{kt} + \varepsilon_{ikt}, \quad (2)$$

where $\mathcal{D}_{it} \subset \mathcal{D}_t$ is a *consumer-specific set of receivers*, and $\mathbf{x}_{it} \equiv (x_{ijt} : j \in \mathcal{D}_{it})$ is the vector of i's *volume choice of phone calls to all receivers.* Each consumer has a balanced calling pattern[15]. In other words, the share of each network within $\mathcal{D}_{it}$ is the same as the market share in the entire economy $\mathcal{D}_t$.

In 2 $u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it})$ is the utility associated with calling a receiver $j \in \mathcal{D}_{it}$. It is additively separable across receivers. In the second term of (2), $\bar{T}_{pt}(\mathbf{x}_{it})$ is the total payment of making $\mathbf{x}_{it}$ calls under the rate plan and α is the *marginal disutility of payment.* Since expenditure on cellular phone services is a small proportion of the household income[16], it is reasonable to consider a quasi-linear model in which consumers are risk-neutral about the phone tariff variation. The third term δ_{kt} is a *fixed effect for subscription of network* k *at time* t, which is identical to all consumers. This term captures all carrier characteristics which do not affect the volume choice, such as advertisements, customer service, handset subsidies, reputation, ...etc. The final term ε_{ikt} is *consumer* i*'s idiosyncratic preference of carrier* k. It is i's private information and is independent of other observable variables. Incoming calls do not affect $u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it})$. However, their effects can be captured by the fixed effect δ_{kt}. This assumption implies the utility from incoming calls is identical for all subscribers in the same network.

The surplus in (2) can be decomposed into two parts: (i) *the surplus from making phone calls*, $\sum_{j \in \mathcal{D}_{it}} u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it}) - \alpha \bar{T}_{pt}(\mathbf{x}_{it})$ and (ii) *the surplus from subscription*, $\delta_{kt} + \varepsilon_{ikt}$. Only the first

[15]The assumption of a balanced calling pattern is used in most theoretical papers, such as Laffont et al. (1998) and Gans and King (2001). Equation (2) would understate the surplus of subscribing to regional carriers if the network shares in $\mathcal{D}_{it}$ are the regional market shares instead of national market shares.

[16]The average household expenditure on telecommunications is 1.88% of income in 2002.

one depends on the volume choice.

To obtain a tractable econometric model, I assume that consumer i's utility associated with making x_{ijt} seconds of calls from network k to receiver $j \in \mathcal{D}_{it}$ at period t is

$$u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it}) = \frac{1}{b} \left(\theta_{it} + \eta_{kt} + \nu_{it} + 1 - \log x_{ijt}\right) x_{ijt}.$$

It depends on the quantity x_{ijt} and the consumer's ex post taste, which is determined by ex ante taste, θ_{it}, and interim shocks, η_{kt} and ν_{it}. The marginal utility is

$$u'(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it}) = \frac{1}{b} \left(\theta_{it} + \eta_{kt} + \nu_{it} - \log x_{ijt}\right).$$

As a result, variation in taste shifts a consumer's marginal utility function vertically. I have normalized the utility of no consumption to zero for all consumers, $u(0; \theta_{it}, \eta_{kt}, \nu_{it}) = 0$ for all θ_{it}, η_{kt}, and ν_{it}.

The distribution of ex ante taste θ_{it} depends on household income I_i. In principle, I can add other demographic variables, but the number of parameters in the model will increase exponentially, resulting the curse of dimensionality in estimation. The variable I_i can be viewed as a proxy for individual i's overall socioeconomic status. Denote the conditional distribution function of θ_{it} by $F_{\theta|I}$. It is normal with mean $\mu_{\theta|I_i}$ and variance $\sigma^2_{\theta|I_i}$.

$$\theta_{it}|I_i \sim N\left(\mu_{\theta|I_i}, \sigma^2_{\theta|I_i}\right). \tag{3}$$

Since the income distribution varies across regions, the marginal distribution of θ_{it} differs across regions as well. Nonetheless, the income distribution is fixed over time in the model, implying the distribution of ex ante taste types θ_{it} is stable over time.

The random shocks, η_{kt} and ν_{it}, are revealed after a rate plan p has been chosen at the beginning of a month. The first shock η_{kt} is an index for the *perceived signal quality* of carrier k at time t. For instance, equipment failure in a network results in a lower realized value. Suppose the quality index has a joint normal distribution in every period,

$$\boldsymbol{\eta}_t \sim N(\bar{\boldsymbol{\eta}}_t, \Sigma_\eta), \tag{4}$$

where $\boldsymbol{\eta}_t \equiv (\eta_{kt} : k \in K)$ denotes the random vector of the quality indices; its mean is $\bar{\boldsymbol{\eta}}_t \equiv (\bar{\eta}_{kt} : k \in K)$ with $\bar{\eta}_{kt} = \eta_k^0 + \eta_t^0$. A carrier-specific parameter η_k^0 accounts for *heterogeneity of perceived qualities across carriers.* A time dummy η_t^0 captures *market-wide factors which influence the willingness to pay at time t.* The variance of the shock is assumed to be σ_η^2 for all carriers. The correlation coefficients of η_{kt} between any two carriers are assumed to be ρ_η. These random quality shocks η_{kt} are independent over time and independent of other variables.[17]

The second shock ν_{it} captures some unexpected personal events, such as being sick, which affect individual taste after committing to a rate plan. Its distribution is

$$\nu_{it} \sim N\left(0, \sigma_\nu^2\right). \tag{5}$$

It is independent of all other variables. In addition, it is also independent across individuals i and over time t.

Consumers may choose to stay away from any GSM network. Denote the outside option as $k = 0$. Let $K_r^0 \equiv K_r \cup \{0\}$ be the choice set in region r, including the outside option. Normalize the fixed effect of the outside option to be $\delta_{0t} = 0$. Hence, the surplus of no subscription is ε_{i0t}.

I assume that the idiosyncratic preferences ε_{ikt} follows a nested logit model. The first nest is the choice between *subscription to any carrier* and *no subscription.* The second nest after subscription is the choice among all carriers in a consumer's region. Finally, a consumer picks up the rate plan with the highest surplus from the chosen carrier. Specifically, the distribution function of (ε_{ikt}) is

$$F_\varepsilon(\varepsilon_{i0t}, \varepsilon_{i1t}, \varepsilon_{i2t}, \dots) = \exp\left(-\exp(-\varepsilon_{i0t}) - \left[\sum_{k\in K_r} \exp\left(-\frac{\varepsilon_{ikt}}{\sigma_\varepsilon}\right)\right]^{\sigma_\varepsilon}\right) \tag{6}$$

with $0 < \sigma_\varepsilon \leq 1$. The parameter σ_ε measures the degree of the differentiation among the rate plans

[17] For instance, higher market share will not cause congestion that lowers the quality.

relative to the on-off decision. When $\sigma_\varepsilon = 1$, this model becomes the standard multinomial logit model.

4.3.2 Volume Decision

As in any sequential game, I solve a consumer's choice problem backward. Consider the volume decision conditional on subscribing to rate plan p of network k at time t. The volume choices are determined by maximizing *the surplus from making calls*, which is the first two terms in the surplus function (2). Denote this part of the surplus as

$$\tilde{\mu}_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}, \mathcal{D}_{it}) \equiv \max_{\mathbf{x}_{it}} \sum_{j \in \mathcal{D}_{it}} u(x_{ijt}; \theta_{it}, \eta_{kt}, \nu_{it}) - \alpha \bar{T}_{pt}(\mathbf{x}_{it}). \tag{7}$$

Both the tariff schedule (1) and the utility of making phone calls are additively separable across receivers. In addition, consumers can recognize the carrier of a receiver. Therefore, *the volume choice x_{ijt} for an individual receiver j* can be expressed as

$$x_{ijt} = \begin{cases} x^I_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}, \mathcal{D}_{it}) & \text{if } j\text{'s network is eligible for in-network discounts;} \\ x^O_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}, \mathcal{D}_{it}) & \text{if } j\text{'s network is not eligible for in-network discounts.} \end{cases}$$

The volume choices solve the following maximization problem.

$$\begin{aligned} &\left[x^I_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}, \mathcal{D}_{it}), x^O_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}, \mathcal{D}_{it})\right] \equiv \\ &\arg\max_{[x^I, x^O]} \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N^I_{pt} u(x^I; \theta_{it}, \eta_{kt}, \nu_{it}) + \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N^O_{pt} u(x^O; \theta_{it}, \eta_{kt}, \nu_{it}) - \alpha T_{pt}\left(\frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N^I_{pt} x^I, \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N^O_{pt} x^O\right), \end{aligned} \tag{8}$$

where N^I_{pt} is *the total size of networks eligible for in-network discounts* and N^O_{pt} is *the size of all other networks*. The expected network sizes, N^I_{pt} and N^O_{pt}, are fulfilled at equilibrium.

The relative size of a consumer's receivers, $|\mathcal{D}_{it}|/|\mathcal{D}_t|$, cannot be separately identified from her ex ante taste θ_{it}. The surplus from calling conditional on rate plan p in (8) can be expressed as

$$\sum_{n=I,O} \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} \frac{N_{pt}^n}{b} \{[\theta_{it} + \eta_{kt} + \nu_{it} + 1 - \log x^n] x^n\} - \alpha T_{pt} \left(\frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N_{pt}^I x^I, \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} N_{pt}^O x^O \right)$$
$$= \sum_{n=I,O} \frac{N_{pt}^n}{b} \left\{ \left[\theta_{it} + \log\left(\frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|}\right) + \eta_{kt} + \nu_{it} + 1 - \log\left(\frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} x^n\right) \right] \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} x^n \right\} - \alpha T_{pt}\left(N_{pt}^I \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} x^I, N_{pt}^O \frac{|\mathcal{D}_{it}|}{|\mathcal{D}_t|} x^O \right).$$

When we compare the surplus and the total in-network and off-network volumes, there is no distinction between a type-θ_{it} consumer who makes (x^I, x^O) calls to a set of subscribers $\mathcal{D}_{it}$ and a type-$(\theta_{it} + \log(|\mathcal{D}_{it}|/|\mathcal{D}_t|))$ consumer who makes $((|\mathcal{D}_{it}|/|\mathcal{D}_t|)x^I, (|\mathcal{D}_{it}|/|\mathcal{D}_t|)x^O)$ calls to every subscriber in the economy. Therefore, I assume $\mathcal{D}_{it} = \mathcal{D}_t$ for all consumers and suppress $\mathcal{D}_{it}$ from the notation.

Because the tariff formula (1) has kinks when volumes equal to the free allowances a_{pt}^I and/or a_{pt}^O, the quantity choice functions have flat regions. The demand function of a type-θ_{it} consumer with shocks (η_{kt}, ν_{it}) is

$$x_{pt}^n(\theta_{it}, \eta_{kt}, \nu_{it}) = \begin{cases} \exp(\theta_{it} + \eta_{kt} + \nu_{it}), & \text{if } \eta_{kt} + \nu_{it} < A_1^n(\theta_{it}) \\ \frac{a_{pt}^n}{N_{pt}^n}, & \text{if } A_1^n(\theta_{it}) \leq \eta_{kt} + \nu_{it} < A_2^n(\theta_{it}) \\ \exp\left(\theta_{it} + \eta_{kt} + \nu_{it} - \alpha b p_{pt}^n\right), & \text{if } \eta_{kt} + \nu_{it} \geq A_2^n(\theta_{it}) \end{cases} \quad (9)$$

for $n = I, O$, where the boundaries are

$$A_1^n(\theta_{it}) \equiv \log\left(\frac{a_{pt}^n}{N_{pt}^n}\right) - \theta_{it} \quad \text{and} \quad A_2^n(\theta_{it}) \equiv \log\left(\frac{a_{pt}^n}{N_{pt}^n}\right) - \theta_{it} + \alpha b p_{pt}^n.$$

The total volume of calls originating from the consumer is[18]

$$\tilde{q}_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}) \equiv N_{pt}^I x_{pt}^I(\theta_{it}, \eta_{kt}, \nu_{it}) + N_{pt}^O x_{pt}^O(\theta_{it}, \eta_{kt}, \nu_{it}), \quad (10)$$

[18]The physical constraint, $\tilde{q}_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}) \leq 30 \times 24 \times 60 \times 60$ (the total seconds in a month), is abstracted away.

and the tariff is

$$
\begin{aligned}
&\tilde{T}_{pt}(\theta_{it},\eta_{kt},\nu_{it})\\
=&\bar{T}_{pt}\left(\, N^I_{pt}x^I_{pt}(\theta_{it},\eta_{kt},\nu_{it})\,,\; N^O_{pt}x^O_{pt}(\theta_{it},\eta_{kt},\nu_{it})\,\right)\\
=&MF_{pt} + \sum_{n=I,O}\left\{\mathbf{1}\{\eta_{kt}+\nu_{it}\geq A^n_2(\theta_{it})\}\, p^n_{pt}\left[N^n_{pt}\exp\left(\theta_{it}+\eta_{kt}+\nu_{it}-\alpha b p^n_{pt}\right)-a^n_{pt}\right]\right\}. \qquad (11)
\end{aligned}
$$

There is a closed-form formula for the surplus from calling,

$$
\begin{aligned}
\tilde{\mu}_{pt}(\theta_{it},\eta_{kt},\nu_{it}) = -\alpha MF_{pt} + \sum_{n=I,O}\Bigg\{&\mathbf{1}\{\eta_{kt}+\nu_{it}<A^n_1(\theta_{it})\}\left[\frac{N^n_{pt}}{b}e^{\theta_{it}+\eta_{kt}+\nu_{it}}\right]\\
&+\mathbf{1}\{A^n_1(\theta_{it})\leq\eta_{kt}+\nu_{it}<A^n_2(\theta_{it})\}\frac{a^n_{pt}}{b}\left[\theta_{it}+\eta_{kt}+\nu_{it}+1-\log\left(\frac{a^n_{pt}}{N^n_{pt}}\right)\right]\\
&+\mathbf{1}\{\eta_{kt}+\nu_{it}\geq A^n_2(\theta_{it})\}\left[\frac{N^n_{pt}}{b}e^{\theta_{it}+\eta_{kt}+\nu_{it}-\alpha b p^n_{pt}}+\alpha p^n_{pt}a^n_{pt}\right]\Bigg\}. \qquad (12)
\end{aligned}
$$

4.3.3 Discrete Choice of Rate Plans

At the beginning of a month, consumers choose one of the rate plans available in their home region or not to subscribe at all. The choice set includes all plans offered by carriers operating in the region, $\cup_{k\in K^0_r}P_{kt}$.

Because the value of the shocks (η_{kt} and ν_{it}) are unknown to consumers at the moment of subscription, consumers pick up the rate plan which maximizes their expected surplus.

$$
\max_{k\in K^0_r}\max_{p\in P_{kt}}\left\{E_{\eta,\nu}\left[\tilde{\mu}_{pt}(\theta_{it},\eta_{kt},\nu_{it})\right]+\delta_{kt}+\varepsilon_{ikt}\right\}.
$$

Under the normality assumption of η_{kt} and ν_{it}, I can compute closed-form expressions for *the expected surplus from calling* $E_{\eta,\nu}[\tilde{\mu}_{pt}(\theta_{it},\eta_{kt},\nu_{it})]$ from equation (12).

Let $\pi_{kt}(\theta_{it})\in P_{kt}$ denote the plan choice of a type-θ_{it} consumer who has subscribed to carrier k.

$$
\pi_{kt}(\theta_{it}) = \arg\max_{p\in P_{kt}}\{E_{\eta,\nu}\left[\tilde{\mu}_{pt}(\theta_{it},\eta_{kt},\nu_{it})\right]\}. \qquad (13)
$$

Thus, putting equations (10) and (13) together, the total volume of phone calls originating from the consumer is

$$q_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) = \tilde{q}_{\pi_{kt}(\theta_{it}),t}(\theta_{it}, \eta_{kt}, \nu_{it}).$$

Similarly, the tariff paid by the consumer is

$$T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) = \tilde{T}_{\pi_{kt}(\theta_{it}),t}(\theta_{it}, \eta_{kt}, \nu_{it}),$$

and the *surplus from calling* is

$$\mu_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) = \tilde{\mu}_{\pi_{kt}(\theta_{it}),t}(\theta_{it}, \eta_{kt}, \nu_{it}).$$

A taste-θ_{it} consumer in region r selects carrier $k \in K_r$ if and only if

$$E_{\eta,\nu}\left[\mu_{kt}(\theta_{it}, \eta_{kt}, \nu_{it})\right] + \delta_{kt} + \varepsilon_{ikt} \geq E_{\eta,\nu}\left[\mu_{k't}(\theta_{it}, \eta_{k't}, \nu_{it})\right] + \delta_{k't} + \varepsilon_{ik't}, \tag{14}$$

for any $k' \in K_r^0$. Given the nested logit assumption on the idiosyncratic preferences ε_{ikt}, the market share of carrier k among consumers with ex ante taste θ in region r is

$$s_{krt}(\theta) = \frac{\left[\sum_{k' \in K_r} \exp\left(\frac{E_{\eta,\nu}[\mu_{k't}(\theta,\eta,\nu)] + \delta_{k't}}{\sigma_\varepsilon}\right)\right]^{\sigma_\varepsilon}}{1 + \left[\sum_{k' \in K_r} \exp\left(\frac{E_{\eta,\nu}[\mu_{k't}(\theta,\eta,\nu)] + \delta_{k't}}{\sigma_\varepsilon}\right)\right]^{\sigma_\varepsilon}} \frac{\exp\left(\frac{E_{\eta,\nu}[\mu_{kt}(\theta,\eta,\nu)] + \delta_{kt}}{\sigma_\varepsilon}\right)}{\sum_{k' \in K_r} \exp\left(\frac{E_{\eta,\nu}[\mu_{k't}(\theta,\eta,\nu)] + \delta_{k't}}{\sigma_\varepsilon}\right)},$$

and the share of the outside option is

$$s_{0rt}(\theta) = \frac{1}{1 + \left[\sum_{k' \in K_r} \exp\left(\frac{E_{\eta,\nu}[\mu_{k't}(\theta,\eta,\nu)] + \delta_{k't}}{\sigma_\varepsilon}\right)\right]^{\sigma_\varepsilon}}.$$

The national market share is the weighted average over all regions. Let $\Pr(r|I)$ be the proportion of the population in region r conditional on the income I. Then,

$$s_{kt}(I, \theta) = \sum_{r \in R} \Pr(r|I) s_{krt}(\theta) \tag{15}$$

is the national market share for carrier k at time t conditional on income I and ex ante taste θ.

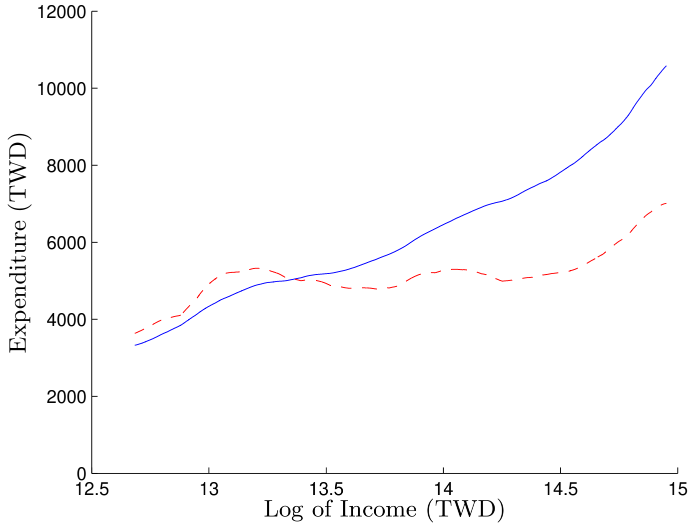
Table 4: Variable definition for the structural estimation

Name	Description
Carrier-Level Output Data	
SUB_{kt}	Number of subscribers in network k at time t
VOL_{kt}	Volume of calls originated from network k during period t
Household Survey Data	
$EXP_M(I)$	Mean of telecommunication expenditure condition on income I
$EXP_V(I)$	Variance of telecommunication expenditure condition on I
Other Data	
POP_t	Population at time t

5 Estimation Approach

Similar to the concept of Berry et al. (1995), I can compute the fixed effect for subscription δ_{kt} and the signal quality η_{kt} from the observed data by inversion. I then derive the likelihood function for the observed carrier-level volumes. The conditions imposed by the observed numbers of subscribers and by the distribution of household expenditure are used as constraints in the estimation. Table 4 summarizes the definitions for the observed variables.

I partition the parameters in the model into three sets ($\Delta\delta$,Θ,Φ). First, let $\boldsymbol{\delta}$ denote the vector of all carrier-time fixed effects for subscription $\{\delta_{kt} : k \in K, t \in T\}$. Second, I discretize the income space into a finite set $\mathcal{I}$. Let $\Theta \equiv \{\mu_{\theta|I}, \sigma^2_{\theta|I} : I \in \mathcal{I}\}$ denote the conditional mean and variance of ex ante taste types θ for each income level $I \in \mathcal{I}$. Third, use Φ to denote the remaining parameters in the model. My estimation strategy is to express the first parameter set $\boldsymbol{\delta}$ as a function of Θ and Φ from the condition implied by the observed numbers of subscribers SUB_{kt}, and then express the second parameter set Θ as a function of Φ from the condition implied by the expenditure distribution, $EXP_M(I)$ and $EXP_V(I)$. As a result, all the parameters can be expressed in term of the third parameter set Φ. The last step is to estimate Φ by maximizing the likelihood of the observed volumes VOL_{kt}.



Notes: The solid line is the mean expenditure. The dashed line represents the standard deviation

Figure 1: Mean and standard deviation of annual expenditure on telecommunications

5.1 Econometric Specifications

I consider only voice service of cellular phones. Although the percentage of revenue from non-voice service grows steadily, voice service (plus the fixed monthly fee) still accounts for the vast majority of revenue in the industry.[19]

In addition to GSM networks, the set of potential receivers $\mathcal{D}_t$ includes subscribers of landline phones and PHS phones. 3G users are ignored due to lack of reliable monthly data.[20] International calls are also excluded.[21] All calls are assumed to originate from the home region of a consumer. Roaming service is neglected.

The conditional mean and variance of telecommunication expenditures ($EXP_M(I)$ and $EXP_V(I)$), shown in Figure 1, are obtained by kernel regression.

Nonetheless, the expenditure survey reports the money amount spent by households on *all*

[19]For example, the proportion of revenue from non-voice services was below 5% for Chunghua Telecom every month between September 2001 and June 2005. See *Operation Data for Most Recent 12 Months* of Chunghua Telecom (`http://www.cht.com.tw/CompanyCat.php?CatID=274`).

[20]There is only one 3G carrier and its market share is small during the research period.

[21]Calls terminated outside Taiwan account for a small portion of the telephone traffic in terms of outgoing minutes although the ratio keeps growing (2000: 1.1%, 2001: 1.7%, 2002: 2.7%, 2003: 4.3%). See Directorate Generate of Telecommunications (2004).

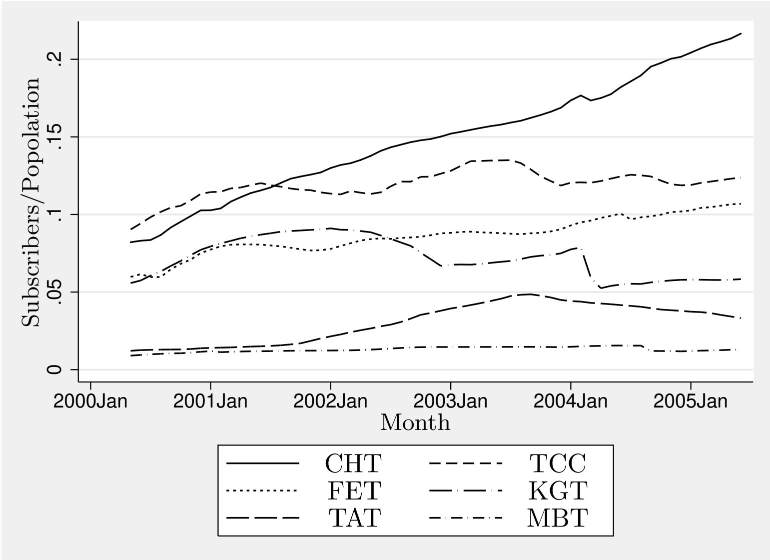


Figure 2: Number of subscribers by carrier

telecommunication services, not just cellular phone. I assume the expenditure on cellular phone service is a constant fraction λ (to be estimated) of the telecommunication budget for all individuals[22].

Carrier-level output data from the Directorate General of Telecommunications include both residential users and business users while the expenditure survey only covers the former ones. I assume that each carrier has the same proportion of residential users among their subscribers. In addition, the proportion of the volume originated from residential users is the same as the the proportion of residential subscribers. This proportion can be computed for each December between 1999 and 2004 by comparing the number of wireless subscribers in the Directorate General of Telecommunications output data[23] with that in the annual family survey data. For other months, the proportion is obtained by linear interpolation. The median proportion of residential subscribers is 0.47. The output variables, SUB_{kt} and VOL_{kt}, refer to residential users in the market. Figures 2 and 3 shows the observed series of these two variables normalized by the population.

[22]A sufficient condition to obtain a constant share of the expenditure on cellular phone is that (a) all consumers have the same homothetic preferences between cellular phone service and other telecommunications services and (b) prices are linear.

[23]Directorate Generate of Telecommunications (2005) provides the total number of wireless subscribers, including GSM, PHS, and 3G, at the end of each year.

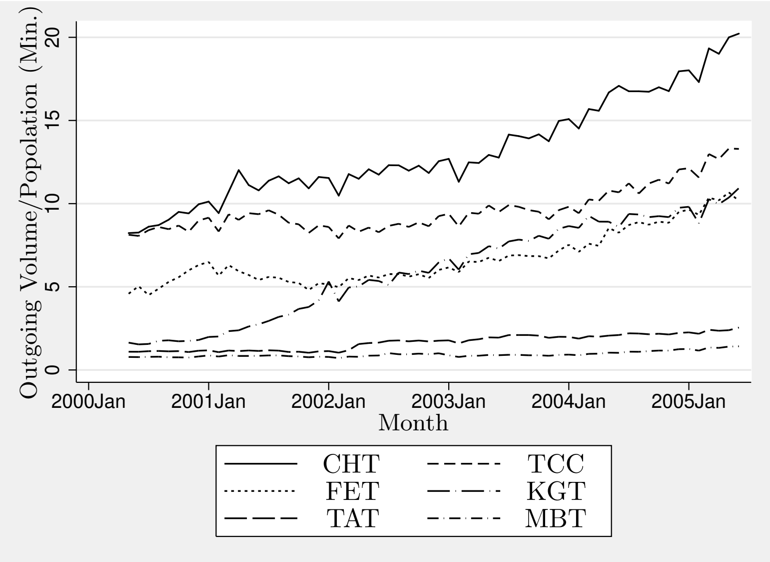


Figure 3: Outgoing volume by carrier

5.2 The Condition on Numbers of Subscribers

For any given parameters Θ and Φ, I use numbers of subscribers SUB_{kt} to recover the carrier-time fixed effects for subscription δ_{kt}. By equating the observed number of subscribers (normalized by the population) to the number predicted in the model, I have

$$\frac{SUB_{kt}}{POP_t} = \iint s_{kt}(I, \theta; \boldsymbol{\delta}_t, \Theta, \Phi)\, dF_{\theta|I}\, dF_I, \qquad \forall k, t. \tag{16}$$

For each period, I have a system of equations. The value of the vector $\boldsymbol{\delta}_t(\Theta, \Phi) = \{\delta_{kt}(\Theta, \Phi) : k \in K\}$ can be inverted from these equations for each t.[24] Similar to Berry et al. (1995, p. 865), I can construct a contraction mapping to solve for $\boldsymbol{\delta}_t$ recursively. The contraction mapping also implies $\boldsymbol{\delta}_t$ is well-defined for any given observed value of SUB_{kt}.

In principle, I can stop here and estimate the demand model by the generalized method of moments as in Berry et al. (1995) if I have enough valid instruments for carrier characteristics.

[24]If switching costs are positive (for instance, a long-term contract with their carrier) for some consumers, the fixed effects δ_{kt} might be overestimated. Nonetheless, this bias depends on the correlation of preferences over time. If preferences are similar over time, most consumers would choose the same carrier and switching costs have little effect. I will use the observed churn rates to evaluate the restrictiveness of assuming zero switching costs in Section 6.2.

Unfortunately, this approach requires a huge number of instruments in my model. Furthermore, identification of the quantity choice and taste heterogeneity only relies on the functional form assumption, not the observed data. Next, I show how to overcome the shortcomings by incorporating data on the expenditure and on the volumes.

5.3 The Condition on Expenditure Distribution

Heterogeneities among consumers are identified from cross-sectional survey data. Average taste strength determines the mean expenditure. Similarly, dispersion of taste affects the variance of expenditure. Therefore, I invert the first and second moments of expenditure to obtain the parameter set Θ, i.e. the mean $\mu_{\theta|I}$ and the variance $\sigma^2_{\theta|I}$ of ex ante taste for any given income level I.

The mean expenditure in the year 2002 conditional on income I is

$$\begin{aligned}
\lambda EXP_M(I) &\equiv \frac{1}{\#\{i : I_i = I\}} \sum_{\{i:I_i=I\}} \sum_{t\in 2002} \sum_{k\in K} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}; \Theta, \Phi) \\
&\xrightarrow{p} E_{\varepsilon,\theta,\nu} \left[\sum_{t\in 2002} \sum_{k\in K} \mathbf{1}\{\pi_{it} = p\} T_{kt}(\theta, \eta_{kt}, \nu; \Theta, \Phi) \middle| I \right] \\
&= \sum_{t\in 2002} \sum_{k\in K} E_\theta \left[s_{kt}(I, \theta; \Theta, \Phi) E_\nu [T_{kt}(\theta, \eta_{kt}, \nu; \Theta, \Phi)] \middle| I \right] \\
&\xrightarrow{p} \sum_{t\in 2002} \sum_{k\in K} E_\eta \left[E_\theta \left\{ s_{kt}(I, \theta; \Theta, \Phi) E_\nu [T_{kt}(\theta, \eta_{kt}, \nu; \Theta, \Phi)] \middle| I \right\} \right], \qquad (17)
\end{aligned}$$

where $\mathbf{1}\{\kappa_{it} = k\}$ is an indicator function of consumer i's carrier choice, which equals 1 if and only if i subscribes to carrier k at period t. The limit in the second line holds in probability when the number of individuals with income I goes to infinity. The equality in the third line follows the independence of θ_{it}, ν_{it}, and ε_{ikt}, . The limit in the last line applies the Law of Large Numbers to $\{\eta_{kt}\}$. To ease the notation, I have substituted the carrier-time fixed effect by the function $\boldsymbol{\delta}_t(\Theta, \Phi)$ and suppressed it in the market share function, $s_{kt}(I, \theta; \Theta, \Phi) = s_{kt}(I, \theta; \boldsymbol{\delta}_t(\Theta, \Phi), \Theta, \Phi)$.

The second moment condition comes from the variance of the expenditure on cellular phone service. To ease the notation, denote the average expenditure of a consumer with income I in period t by

$$MT_t(I;\Theta,\Phi) = \sum_{k\in K} E_\eta\left[E_\theta\left\{s_{kt}(I,\theta;\Theta,\Phi)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)]\big|I\right\}\right].$$

Because the observe variance is computed from *annual* expenditure, I need to account for the serial correlation of ex ante taste θ_{it} over different months. Similar to the arguments used in deriving (17), I have[25]

$$\begin{aligned}\lambda^2 EXP_V(I) = E_\theta\Bigg\{ &\sum_{t\in 2002}\sum_{k\in K^0} s_{kt}(\theta,I;\Theta,\Phi)E_{\eta,\nu}\left[(T_{kt}(\theta,\eta,\nu;\Theta,\Phi) - MT_t(I;\Theta,\Phi))^2\right] \\ &+ c_\theta \sum_{\substack{t,t'\in 2002\\ t\neq t'}}\Bigg[\Bigg(\sum_{k\in K^0} s_{kt}(\theta,I;\Theta,\Phi)E_\nu[T_{kt}(\theta,\eta,\nu;\Theta,\Phi) - MT_t(I;\Theta,\Phi)]\Bigg)\times \\ &\Bigg(\sum_{k'\in K^0} s_{k't'}(\theta,I;\Theta,\Phi)E_{\eta,\nu}[T_{k't'}(\theta,\eta,\nu;\Theta,\Phi) - MT_{t'}(I;\Theta,\Phi)]\Bigg)\Bigg]\Bigg| I\Bigg\}\end{aligned} \tag{18}$$

for some parameter $c_\theta \in [0,1]$ to be estimated. This parameter increases in the serial correlation of consumer's ex ante tastes θ_{it}.[26]

For each income level $I \in \mathcal{I}$, there are two moment conditions as described in (17) and (18). This can be done for all grid points in the discretized income space, so I have $2|\mathcal{I}|$ conditions. Each condition contains the parameter sets Θ and Φ on the right hand side. Fix the value of the parameter set Φ and solve for the parameter Θ from the system of these $2|\mathcal{I}|$ equations. Given the observed expenditure distribution, I can express the solution as a vector-valued function $\Theta(\Phi)$.

5.4 The Condition on Total Volumes

The total volume of calls originated from carrier k in period t (normalized by the population) is

$$\begin{aligned}\frac{VOL_{kt}}{POP_t} &= \iiint s_{kt}(I,\theta;\boldsymbol{\delta}_t(\Theta(\Phi),\Phi),\Theta(\Phi),\Phi)q_{kt}(\theta,\eta_{kt},\nu;\Theta(\Phi),\Phi)\,dF_\nu\,dF_{\theta|I}\,dF_I \\ &\xrightarrow{p} \iint s_{kt}(I,\theta;\boldsymbol{\delta}_t(\Theta(\Phi),\Phi),\Theta(\Phi),\Phi)E_\nu\left[q_{kt}(\theta,\eta_{kt},\nu;\Theta(\Phi),\Phi)\right]dF_{\theta|I}\,dF_I\end{aligned} \tag{19}$$

[25] The computational details are relegated to Appendix.

[26] By applying linear approximation to equation (18), the parameter $c_\theta \approx \sum_{t,t'\in 2002,t\neq t'}\rho_\theta^{|t-t'|}/\sum_{t,t'\in 2002,t\neq t'} 1$ where ρ_θ is the monthly serial correlation of the series of ex ante tastes θ_{it}.

The above limit holds in probability when the number of consumers goes to infinity. Note that all parameters can now be expressed in terms of Φ. The condition 19 implicitly defines the perceived signal index as a function of the observed volume VOL_{kt} and the parameter set Φ, $\eta_{kt} \equiv G_{kt}(VOL_{kt}/POP_t; \Phi)$.

It is easy to shows that G_{kt} is a well-defined, increasing function for any $VOL_{kt} > 0$. First, $E_\nu[q_{kt}(\theta, \eta_{kt}, \nu; \Phi)]$ is a strictly increasing function in the quality index η_{kt}. Second, the market share $s_{kt}(I, \theta; \Phi) > 0$ does not depends on it. As a result, the right-hand side of (19) is a monotonic function of η_{kt}. Furthermore, $E_\nu[q_{kt}(\theta, \eta_{kt}, \nu)] \to +\infty$ as $\eta_{kt} \to +\infty$ and $E_\nu[q_{kt}(\theta, \eta_{kt}, \nu)] \to 0$ as $\eta_{kt} \to -\infty$. Therefore, for any $VOL_{kt} > 0$, there is a unique solution of η_{kt} to equation (19).

5.5 Likelihood Function

Given the above results, now I can compute *the cumulative distribution function of the total volume originated from carrier k (normalized by the population).*

$$\Pr\left(\frac{VOL_{kt}}{POP_t} \leq Q_k; \Phi\right) = \Pr(\eta_{kt} < G_{kt}(Q_k; \Phi)),$$

where G_{kt} is the monotonic function implicitly defined by equation (19). Recall that $\boldsymbol{\eta}_t \sim N(\bar{\boldsymbol{\eta}}_t, \Sigma_\eta)$. Define the vector functon $\boldsymbol{G}_t(\boldsymbol{G}; \Phi) \equiv (G_{kt}(Q_k; \Phi) : k \in K)$. The density function for the total volume at period t is

$$l_t(\boldsymbol{Q}; \Phi) \equiv (2\pi)^{-\frac{|K|}{2}} |\Sigma_\eta|^{-\frac{1}{2}} \exp\left(-\frac{1}{2}\left[\boldsymbol{G}_t(\boldsymbol{Q}; \Phi) - \bar{\boldsymbol{\eta}}_t\right]' \Sigma_\eta^{-1} \left[\boldsymbol{G}_t(\boldsymbol{Q}; \Phi) - \bar{\boldsymbol{\eta}}_t\right]\right) |\nabla \boldsymbol{G}_t(\boldsymbol{Q}; \Phi)|, \quad (20)$$

where $\nabla \boldsymbol{G}_t$ is the Jacobian of the vector function $\boldsymbol{G}_t$.

The parameter Φ is estimated by

$$\hat{\Phi} = \arg\max_\Phi \sum_t \log l_t \left(\left\{\frac{VOL_{kt}}{POP_t} : k \in K\right\}; \Phi\right). \quad (21)$$

Other parameters are subsequently obtained through $\hat{\Theta} = \Theta(\hat{\Phi})$ and $\hat{\boldsymbol{\delta}} = \boldsymbol{\delta}(\Theta(\hat{\Phi}), \hat{\Phi})$.

5.6 Identification

On important difference between my estimation approach and the standard method proposed in Berry et al. (1995) is the endogeneity of prices. All the fixed-effects of subscription δ_{kt} are treated as parameters and estimated from data. We do not need to worry about endogenous price change resulting from unobservable carrier characteristics. Moreover, since shocks of signal qualities η_{kt} are revealed after the pricing stage, price tariffs are independent of the shocks.

Identification of the model parameters is a subtle issue because they are interdependent through the structural model. I now provide intuitions of how variations in the data identify the parameters. For the first parameter set $\boldsymbol{\delta}$, the carrier-time fixed effect of subscription δ_{kt} is identified from the number of subscribers in network k for a given level of surplus from making calls. Identification of the second parameter set Θ has been mentioned in Subsection 5.3. The distribution of telecommunication expenditure in the cross-sectional data is used to recover the distribution of ex ante tastes across consumers.

The third parameter set Φ is identified as follows. The marginal disutility of expenditure α is mainly identified from the sensitivity of demand with respect to changes in flat monthly fees. Marginal price varies within a rate plan and across rate plans. Changes in market shares in response to these price variations identify the scale parameter of the utility b. The parameters for the distribution of the signal quality indices are identified from the variation of *average volumes per customer* across carriers and over time. For a given tariff formula, more calls originating from a carrier imply better perceived signal quality. Identification of the substitution parameter in the nested logit model σ_ε comes from change in the share of outside good relative to changes in market shares across carriers in response to price variation. The percentage of the expenditure on cellular service λ is identified from the difference between the average payment imputed from the tariff formulas and the average telecommunication expenditure found in the household survey. Similarly, the parameter for the serial correlation of ex ante tastes c_θ is identified from the variance of the tariffs imputed from the monthly output data relative to the observed variance of annual expenditure in the survey.

Finally, since there are no data on an individual consumer's choice in a single period, the variance of individual interim shock σ_ν^2 can only be identified through functional form assumptions. This does not affect the estimation result too much because there is only a second order effect of these individual shocks in the aggregate level.

6 Estimation Results

In this section, I presents the empirical findings on the Taiwanese cellular phone service market by using the method described in the previous section. After showing the estimated parameters and their implications, I compute the switching behavior predicted by the estimated model with the observed behavior. This comparison suggests that the assumption of zero switching costs is innocuous. In the final part of this section, I compute demand elasticities for this market.

6.1 Estimated Parameters

The estimation results of the parameter set Φ are reported on Table 5.

Two different specifications are presented here. The mean of signal quality index η_t^0 is assumed to be a yearly dummy in column I.

$$\eta_t^0 = \eta_{year}^0 \mathbf{1}[t \in year],$$

where I normalize η_{2002} to be zero. In column II, I assume the mean value is a quadratic function over time,

$$\eta_t^0 = \gamma_1(t-30) + \gamma_2(t-30)^2,$$

where I normalize the value for the 30th period (October 2002) to be zero. There is no significant difference on most parameter estimates under these two specifications. The following discussions are based on the estimates under specification II since its likelihood is higher.

Most parameters are significantly different from zero at the 5% significance level. The marginal disutility of payment α is positive as expected. The utility from making cellular calls is positive since the scale parameter $\hat{b} > 0$. The estimated share of expenditure on cellular phone service among telecommunication budget is 55.25%. The substitution parameter in the nested logit model

Table 5: Parameter estimates of the structural model

Parameter	Description	I	II
1000α	Marginal disutility of payment	7.3258 (0.8219)	7.2109 (0.6367)
$0.001b$	Scale parameter of utility	0.6034 (0.0652)	0.5386 (0.0601)
λ	Share of cellular expenditure	0.5770 (0.0152)	0.5525 (0.0121)
σ_ε	Substitution parameter	0.4957 (0.1867)	0.5448 (0.1959)
c_θ	Correlation of θ over time	0.8731 (0.0591)	0.8682 (0.0526)
η^0_{TCC}	Quality index of TCC	-0.0537 (0.0124)	-0.0274 (0.0090)
η^0_{FET}	Quality index of FET	0.0226 (0.0339)	0.0198 (0.0291)
η^0_{KGT}	Quality index of KGT	-0.2301 (0.0236)	-0.2249 (0.0190)
η^0_{TAT}	Quality index of TAT	-0.3429 (0.0439)	-0.3457 (0.0372)
η^0_{MBT}	Quality index of MBT	-0.3370 (0.0290)	-0.3242 (0.0377)
η^0_{2000}	Quality index of 2000	0.2486 (0.0570)	
η^0_{2001}	Quality index of 2001	0.0696 (0.0318)	
η^0_{2003}	Quality index of 2003	-0.1087 (0.0195)	
η^0_{2004}	Quality index of 2004	0.0125 (0.0131)	
η^0_{2005}	Quality index of 2005	0.1350 (0.0318)	
$1000\gamma_1$	Time trend of quality index		-0.6856 (0.7422)
$1000\gamma_2$	Squared term of time trend		0.2937 (0.0508)
σ^2_η	Variance of quality shock	0.1307 (0.0137)	0.1247 (0.0140)
ρ_η	Correlation of quality shock	-0.0483 (0.0286)	-0.0245 (0.0560)
Log-Likelihood		-1735.6	-1730.4

Notes: Standard errors are in parentheses. There are 372 observations. Estimates for the variance of individual demand shocks are close to zero ($\hat{\sigma}_\nu = 1.9 \times 10^{-4}$) and insignificant. The number of grid points on the quantile space is 11×11.

Table 6: Signal quality difference between carriers

	CHT	TCC	EFT	KGT	TAT
TCC	-0.0071				
	(0.0024)				
FET	0.0051	0.0122			
	(0.0075)	(0.0075)			
KGT	-0.0579	-0.0508	-0.0630		
	(0.0048)	(0.0033)	(0.0080)		
TAT	-0.0890	-0.0819	-0.0941	-0.0311	
	(0.0098)	(0.0080)	(0.0118)	(0.0064)	
MBT	-0.0835	-0.0764	-0.0886	-0.0256	0.0055
	(0.0099)	(0.0087)	(0.0114)	(0.0079)	(0.0084)

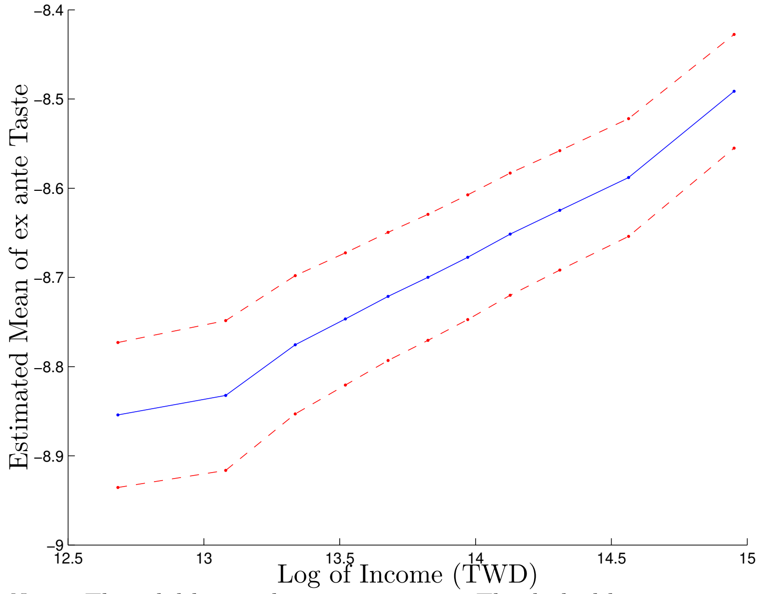
Notes: The number in entry (i, j) is the monetary value of the marginal utility of subscribing to carrier i relative to carrier j at any given quantity. Standard errors are in parentheses. Unit: TWD/second.

is $\hat{\sigma}_{\varepsilon} = 0.5448$, which is significantly different from one, implying that the substitution among carriers significantly differs from the on-off substitution. The estimated parameter of correlation $\hat{c}_{\theta} = 0.8682$ is large but significantly differs from one. This value suggests that the monthly serial correlation of ex ante tastes is approximately 0.9670 for a given consumer.

Conditional on subscription, perceived signal quality indices differ significantly across carriers and over time. Because the marginal utility of consuming a given quantity x_{ijt} can be expressed in the following monetary value (TWD per second)

$$\frac{\theta_{it} + \eta_{kt} + \nu_{it} - \log x_{ijt}}{\alpha b}, \tag{22}$$

quality differences can be expressed by the monetary value of the difference in marginal utility for any fixed quantity x_{ijt}. Table 6 reports the difference between any pair of carriers. The estimated quality indices tend to be positively correlated with market shares. Far Eastone and Chunghua Telecom provide the highest marginal utility values without significant difference between them. They are followed by Taiwan Cellular. KG Telecommunication is the next. The two regional networks, Mo Bi Tai and Trans Asia, give consumers the lowest marginal values on phone calls. Furthermore, the mean signal quality index also changes over time. It declines 0.0405 Taiwan dollars per second between December 2000 and December 2002 before the index rebounds 0.0465



Notes: The solid line is the point estimate. The dashed lines represent the 95% confidence interval.

Figure 4: Mean of ex ante taste conditional on income

Taiwan dollars between December 2002 and December 2004. Comparing to marginal prices, quality differences across carriers and over time are both considerable.[27]

Interim quality shocks are important in the volume decision. The estimated variance of the quality shock, $\hat{\sigma}_\eta^2 = 0.1247$, is significantly positive. By using the measure defined in (22), a positive shock with one standard deviation would increase the marginal utility by 0.0909 Taiwan dollars per second. Equivalently, the volume would raise 42.4% under linear pricing.[28]

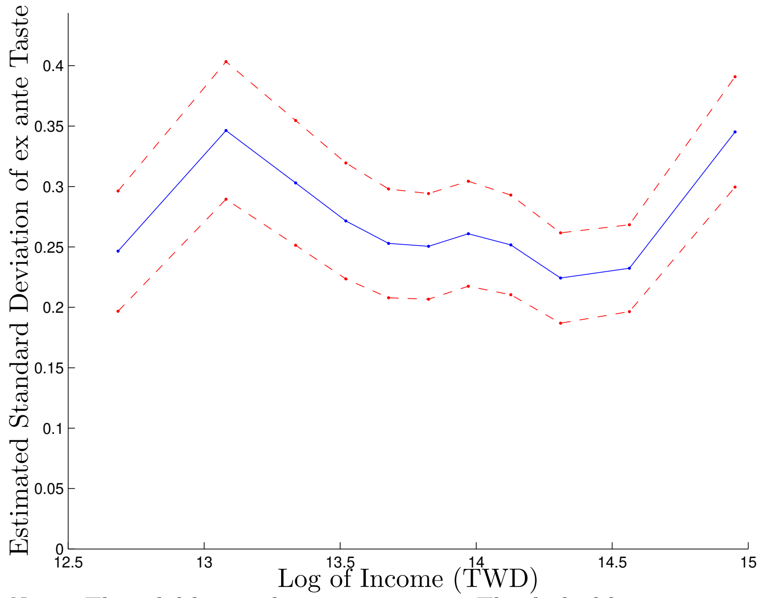
The parameters for the conditional distribution of ex ante tastes θ is obtained from $\hat{\Theta} = \Theta(\hat{\Phi})$ (defined in Section 5.3).

The estimated conditional means $\hat{\mu}_{\theta|I}$, are shown in Figure 4.[29] As expected, the conditional mean increases in income I. A consumer in a wealthy household tends to use more cellular phone service, ceteris paribus. Specifically, an individual in a 90% income percentile household on average

[27] The median in-network and off-network prices among all plans are 0.07 and 0.13 Taiwan dollars per second, respectively.

[28] In practice, because the tariff formula has kinks, the increase in volume could be much smaller.

[29] The magnitude of the ex ante taste type θ_{it} can be interpreted in terms of marginal utility. Suppose the interim shocks, η_{kt} and ν_{it}, are both zero. The mean of θ_{it} is -8.6324 at the median income, which means the marginal utility is 0.0721 Taiwan dollars per second for a consumer who makes 50 minutes of calls in the entire month of October 2002.



Notes: The solid line is the point estimate. The dashed lines represent the 95% confidence interval.

Figure 5: Standard deviation of ex ante taste conditional on income

values a second of cellular service 0.0629 Taiwan dollars more than a person in a 10% income percentile household. This difference would imply 27.7% more calling volume under linear pricing. Furthermore, after controlling for the household income, consumers still differ in their calling taste.

Figure 5 presents the estimated standard deviations conditional on income. The estimated standard deviations $\hat{\sigma}_{\theta|I}$ are significantly positive, but there is no clear relationship between the standard deviations and income. There is substantial variation of ex ante tastes among consumers. The variance among all consumers is 0.0818, which implies the standard deviation of marginal utility is 0.0736 Taiwan dollars per second for any given quantity. Income variation can accounts for 9.38% of the taste variation.

Finally, the carrier-time fixed effects for subscription can be obtained from $\hat{\boldsymbol{\delta}}_t = \boldsymbol{\delta}_t(\Theta(\hat{\Phi}), \hat{\Phi})$ (defined in Section 5.2).

In Figure 6, the estimated fixed effects are expressed in their monetary values $\hat{\delta}_{kt}/\hat{\alpha}$. Relative to the outside option, the median *surplus from subscription* is about -1166 Taiwan dollars. As a result, for a consumer who does not want to make any outgoing phone call, the hassle cost of connecting to a GSM network (e.g. the cost of buying a handset) outweighs its value (e.g. receiving incoming

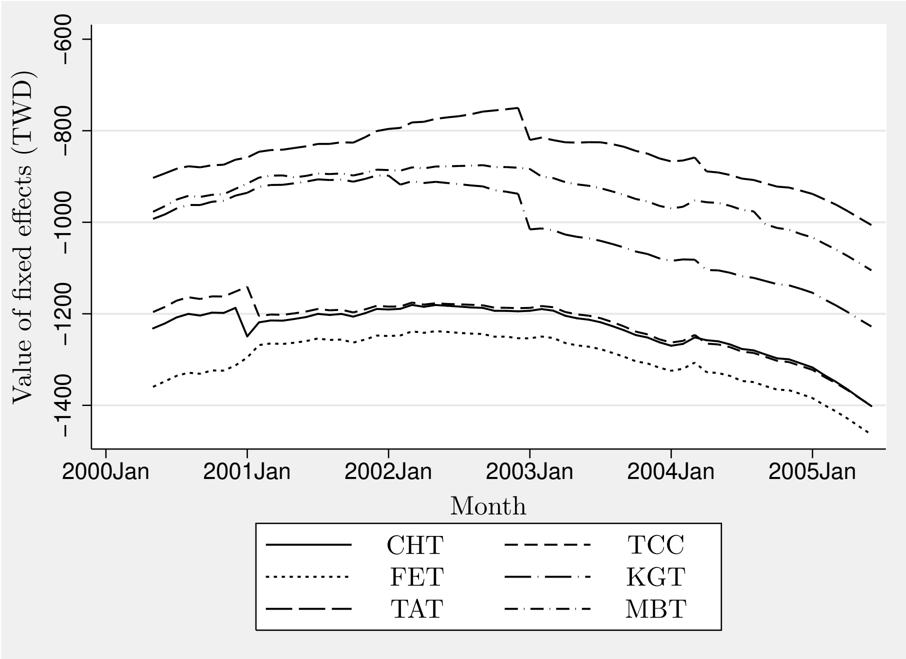


Figure 6: Carrier-time fixed effects for subscription

phone calls) when the value of outside choice is normalized to zero. The value of this fixed effect generally increases between 2000 and 2002. This is consistent with the time when carriers reduced activation fees to zero. On the contrary, the decline in the second half of the research period may reflect the effect due to entry of non-GSM wireless phone services (PHS and 3G). Note that while Far Eastone has the highest signal quality index η^0_{FET} and Trans Asia has the lowest index η^0_{TAT}, the order is reversed for the fixed effects δ_{FETt} and δ_{TATt}. The median surplus of subscribing to Far Eastone is -1290 Taiwan dollars, while that of subscribing to Trans Asia is -843 Taiwan dollars.

6.2 Validation Test: Churn Rates

A potentially crucial assumption imposed on my estimation model is that consumers incur no switching costs from one period to another. One way to evaluate the restrictiveness of the assumption is to perform an out-of-sample test. I compare the churn rates predicted by the simulated model with the churn rates observed in the market. This is a very rigorous test because my estimation does not use any information about churn rates in the market.

The estimated parameter c_θ suggests the monthly serial correlation of ex ante tastes is 0.9670,

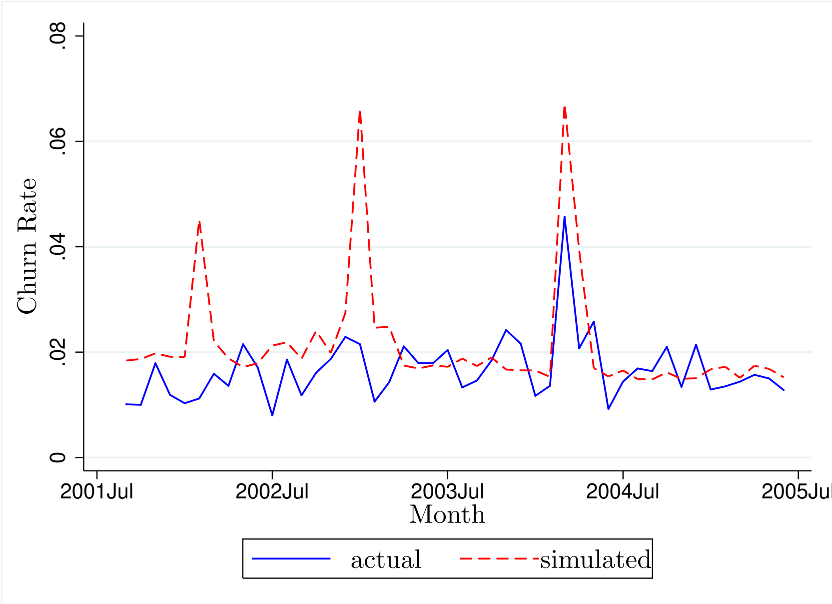


Figure 7: Monthly churn rates for Chunghua Telecom

but my estimation does not give any information on the serial correlation of a consumer's idiosyncratic preferences over various carriers. To compute the churn rates from the estimated model, I assume the preferences are fixed over time ($\varepsilon_{ikt} = \varepsilon_{ikt'}$) for all individuals.

Figure 7 shows the observed and simulated monthly churn rates for Chunghua Telecom.[30] The predicted and observed churn rates are very close. The two series are very similar in magnitude, overall shape, and month-to-month variation, especially toward the end of the research period. My estimation generates these churn rates reasonably well. Consequently, the assumption of zero switching costs seems innocuous. The intuition behind the result is the following. Switching costs have no effect if a consumer does not want to switch. Since consumer tastes are highly correlated over time, only very few of them want to change their carriers from one month to another. Therefore, by imposing the simplification of zero switching costs, I can use the static model to approximate the real world with little bias and avoid solving a complicated dynamic problem.

[30] I have detailed data on monthly churn rates only for this carrier. The data are obtained from *Operation Data for Most Recent 12 Months* on the Chunghua Telecom website (`http://www.cht.com.tw/CompanyCat.php?CatID=274`). The data are available since September 2001.

Table 7: Median own- and cross-price elasticities

	CHT	TCC	FET	KGT	TAT	MBT
Number of Subscribers						
CHT	-6.1833	2.0250	1.5163	0.8312	0.1887	0.1453
TCC	2.6116	-6.2190	1.4236	0.8643	0.2127	0.1430
FET	2.5408	1.9042	-6.9853	0.8514	0.2189	0.1413
KGT	1.9465	1.5319	1.1093	-5.9524	0.2482	0.1358
TAT	1.0932	1.0569	0.7411	0.6123	-4.2726	0.0000
MBT	1.6494	1.6294	1.1573	0.8024	0.0000	-5.9762
Total Volume						
CHT	-6.5359	2.1548	1.6414	0.8135	0.1747	0.1444
TCC	3.0040	-6.9363	1.5860	0.8412	0.1806	0.1452
FET	2.8856	2.0747	-7.7912	0.8518	0.1927	0.1427
KGT	2.3720	1.7760	1.2682	-6.5036	0.2204	0.1365
TAT	1.2545	1.2224	0.8428	0.6736	-4.9977	0.0000
MBT	2.0764	1.8892	1.4045	0.8437	0.0000	-6.7509

Note: Cell entries (i, j), where i indexes row and j column, give the percentage change in network i with respect to a 1% proportional price change of network j. Each entry represents the median of the elasticities from 62 periods.

6.3 Demand Elasticities

I use the estimated model to compute demand elasticities. Since pricing schemes are nonlinear, the payments are determined by several elements: in-network and off-network prices and free allowances as well as monthly fees. To compute demand elasticities, I consider a proportional increase in the tariff formula, holding free allowances fixed. The median industry-wide demand elasticity over time for a proportional change in price schemes is -1.1217 for the number of subscribers and -1.3394 for the total volume. Because increase in price would reduce the number of subscribers and the usage of the remaining customers, the latter elasticity is greater than the former one (in absolute value). My estimated elasticities are close to the results found in previous researches on the U.S. market.[31]

The demand elasticities for each carrier are presented in Table 7. The demand is elastic for all carriers. While all other carriers have similar own-price elasticities, Trans Asia has a substantial lower elasticity. This suggests the service of Trans Asia is more differentiated away from the other

[31] For example, Parker and Röller (1997) estimate the elasticity at -2.46 in a linear regression model for U.S. cellular market between 1984 and 1988, but volume choice is abstracted away in their study. Narayanan et al. (2007) find the usage elasticity in a *monopolistic landline telephone* market ranges between -1.76 and -1.92, depending on their models.

five carriers. Besides, price change of a large network has a stronger impact on rival networks than that of a small network. This is primary due to network effects.

7 Counterfactual Simulations

Based on the behavior model, I perform two counterfactual simulations to evaluate the effects of termination-based pricing on the market structure. The first one consider the overall effects of in-network discounts. The second one quantifies the effects caused by the substitution between in-network and off-network calls resulting from the price difference. Nonetheless, one needs to be cautious in interpreting these results. Carriers may respond to policy changes by adjusting their tariffs, so the market equilibrium may change. This response is ignored in the following simulations.

7.1 Evaluation of Intra-Network Discounts

For a given percentage of in-network discounts, the average price of a rate plan in a large network reduces more than that in a small network because there is a higher probability of making an in-network call. Consumers are more likely to subscribe to a rate plan offered by a large carrier.

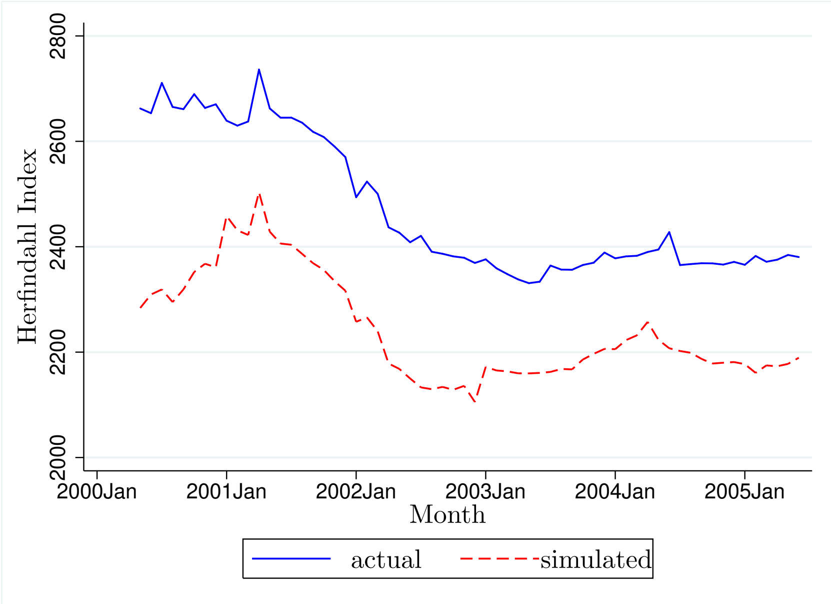
The first column of Table 8 is the actual outcome in October of 2002. Suppose in-network discounts are not allowed and all calls (exceeding the free allowance thresholds) are priced at the observed off-network rate. The simulated result is on the second column of the table. While the average price goes up, the average consumption goes down. Consumer surplus reduces by 8.8%. There are large impacts on the relative market shares. The variation of network sizes among the carriers becomes much less when the in-network discounts are eliminated. For instance, the largest carrier, CHT, loses 23% of its subscribers, but the smallest one, MBT, gains 32%. Meanwhile, the revenue of CHT decreases by 20%, but that of MBT increases by 38%. The market shares of the four national carriers become much close.

Figure 8 shows the HHI measured in total volume for each period. The difference between the two curves reflects the effect of in-network discounts. When in-network discounts are eliminated, the median change in the indices is −218 points. The quartiles are −257 and −184 points. Although there is no clear guidance to interpret the change in HHI due to price discrimination, the U.S.

Table 8: Counterfactual simulation on no in-network discount

	Actual	Simulated
Average Usage (minutes)	35.641	33.343
Average Expenditure (TWD)	258.261	254.821
Average Expected Consumer Surplus (TWD)	170.121	155.228
Number of Subscribers (millions)		
CHT	3.325	2.570
TCC	2.796	2.535
FET	1.927	1.928
KGT	1.694	1.856
TAT	0.795	0.892
MBT	0.326	0.429
Total	10.862	10.210
Aggregate Volume (million minutes)		
CHT	276.325	204.716
TCC	199.680	183.162
FET	129.511	129.033
KGT	134.292	157.011
TAT	39.846	45.125
MBT	22.135	31.036
Total	801.788	750.083
Revenue (billion TWD)		
CHT	1.908	1.534
TCC	1.371	1.335
FET	0.955	1.002
KGT	1.031	1.195
TAT	0.376	0.436
MBT	0.168	0.231
Total	5.810	5.733

Note: Calculated for October of 2002.



Note: Intra-network discounts are eliminated in the simulation.

Figure 8: Simulated market concentration rates without discounts

Department of Justice (1994)'s horizontal merger guidelines says "Where the post-merger HHI exceeds 1800, it will be presumed that mergers producing an increase in the HHI of more than 100 points are likely to create or enhance market power or facilitate its exercise." The change in HHI is large according to this standard. The median change of the concentration rate due to in-network discounts is equivalent to a horizontal merger between two firms with 10.4% market shares.

7.2 Evaluation of Carrier Recognizability

I now consider the case in which consumers cannot recognize the carrier of a receiver from the phone number. For example, after number portability is introduced into the market, consumers can switch to a different cellular carrier without changing the phone number.[32] The prefix of a phone number is not a valid indicator for the carrier. Alternatively, if phone numbers are not assigned to carriers with easily distinguishable prefixes, such as in the U.S. cellular service market, it is difficult for consumers to know the carrier of a receiver from the phone number.

[32] Here, number portability is interpreted as jeopardizing the ability to recognize the carrier of a phone number. The main objective of this policy, however, is to reduce consumer's switching costs among carriers. I do not consider switching costs in this paper.

By eliminating the ability to recognize the carrier of a receiver, it is impossible to choose calling volumes according to the termination of a phone call. Consumers cannot substitute between in-network and off-network calls. The price difference between in-network and off-network calls does not affect consumption. Only the average price matters. Without loss of generality, assume $a^I_{pt}/N^I_{pt} \geq a^O_{pt}/N^O_{pt}$. Let $N_t = N^I_{pt} + N^O_{pt}$ be the total number of receivers. The demand function of a type θ_{it} consumer with shocks (η_{kt}, ν_{it}) for a give plan p becomes

$$x_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}) = \begin{cases} \exp\left(\theta_{it} + \eta_{kt} + \nu_{it}\right), & \text{if } \eta_{kt} + \nu_{it} < B_1(\theta_{it}) \\ \frac{a^O_{pt}}{N^O_{pt}}, & \text{if } B_1(\theta_{it}) \leq \eta_{kt} + \nu_{it} < B_2(\theta_{it}) \\ \exp\left(\theta_{it} + \eta_{kt} + \nu_{it} - \alpha b \bar{p}^O_{pt}\right), & \text{if } B_2(\theta_{it}) \leq \eta_{kt} + \nu_{it} < B_3(\theta_{it}) \\ \frac{a^I_{pt}}{N^I_{pt}}, & \text{if } B_3(\theta_{it}) \leq \eta_{kt} + \nu_{it} < B_4(\theta_{it}) \\ \exp\left(\theta_{it} + \eta_{kt} + \nu_{it} - \alpha b \bar{p}_{pt}\right), & \text{if } \eta_{kt} + \nu_{it} \geq B_4(\theta_{it}) \end{cases},$$

where $\bar{p}_{pt} = (N^I_{pt} p^I_{pt} + N^O_{pt} p^O_{pt})/N_t$, $\bar{p}^O_{pt} = N^O_{pt} p^O_{pt}/N_t$ and the boundaries are

$$B_1(\theta_{it}) \equiv \log\left(\frac{a^O_{pt}}{N^O_{pt}}\right) - \theta_{it}\,, \qquad B_2(\theta_{it}) \equiv \log\left(\frac{a^O_{pt}}{N^O_{pt}}\right) - \theta_{it} + \alpha b \bar{p}^O_{pt}\,,$$

$$B_3(\theta_{it}) \equiv \log\left(\frac{a^I_{pt}}{N^I_{pt}}\right) - \theta_{it} + \alpha b \bar{p}^O_{pt}\,, \text{ and} \qquad B_4(\theta_{it}) \equiv \log\left(\frac{a^I_{pt}}{N^I_{pt}}\right) - \theta_{it} + \alpha b \bar{p}_{pt}\,.$$

Both in-network and off-network prices enter demand function only indirectly through their averages. The tariff is

$$\begin{aligned} \tilde{T}_{pt}(\theta_{it}, \eta_{kt}, \nu_{it}) = {} & MF_{pt} \\ & + \mathbf{1}\{B_2(\theta_{it} \leq \eta_{kt} + \nu_{it} < B_3(\theta_{it})\} \left[\bar{p}^O_{pt} N_t e^{\theta_{it} + \eta_{kt} + \nu_{it} - \alpha b \bar{p}^O_{pt}} - p^O_{pt} a^O_{pt}\right] \\ & + \mathbf{1}\{B_3(\theta_{it} \leq \eta_{kt} + \nu_{it} < B_4(\theta_{it})\} \bar{p}^O_{pt} N_t \left(\frac{a^I_{pt}}{N^I_{pt}} - \frac{a^O_{pt}}{N^O_{pt}}\right) \\ & + \mathbf{1}\{\eta_{kt} + \nu_{it} \geq B_4(\theta_{it})\} \left[\bar{p}_{pt} N_t e^{\theta_{it} + \eta_{kt} + \nu_{it} - \alpha b \bar{p}_{pt}} - p^O_{pt} a^O_{pt} - p^I_{pt} a^I_{pt}\right]. \end{aligned}$$

The surplus from calling is

$$\begin{aligned}\tilde{\mu}_{pt}(\theta_{it},\eta_{kt},\nu_{it}) = &-\alpha MF_{pt} + \mathbf{1}\{\eta_{kt}+\nu_{it} < B_1\}\left[\frac{N_t}{b}e^{\theta_{it}+\eta_{kt}+\nu_{it}}\right] \\ &+ \mathbf{1}\{B_1 \leq \eta_{kt}+\nu_{it} < B_2\}\frac{N_t a_{pt}^O}{bN_{pt}^O}\left[\theta_{it}+\eta_{kt}+\nu_{it}+1-\log\left(\frac{a_{pt}^O}{N_{pt}^O}\right)\right] \\ &+ \mathbf{1}\{B_2 \leq \eta_{kt}+\nu_{it} < B_3\}\left[\frac{N_t}{b}e^{\theta_{it}+\eta_{kt}+\nu_{it}-\alpha b\bar{p}_{pt}^O} + \alpha p_{pt}^O a_{pt}^O\right] \\ &+ \mathbf{1}\{B_3 \leq \eta_{kt}+\nu_{it} < B_4\}\left[\frac{N_t a_{pt}^I}{bN_{pt}^I}\left(\theta_{it}+\eta_{kt}+\nu_{it}+1-\log\left(\frac{a_{pt}^I}{N_{pt}^I}\right)\right) - \alpha N_t \bar{p}_{pt}^O\left(\frac{a_{pt}^I}{N_{pt}^I}-\frac{a_{pt}^O}{N_{pt}^O}\right)\right] \\ &+ \mathbf{1}\{\eta_{kt}+\nu_{it} \geq B_4\}\left[\frac{N_t}{b}e^{\theta_{it}+\eta_{kt}+\nu_{it}-\alpha b\bar{p}_{pt}} + \alpha\left(p_{pt}^O a_{pt}^O + p_{pt}^I a_{pt}^I\right)\right].\end{aligned}$$

Table 9 compares the actual outcome with the simulated one for October 2002. The differences are small. Consumers are slightly worse off when they cannot recognize the carrier of a phone receiver. The average expected consumer surplus drops by 0.8%. The market shares are more evenly distributed among carriers. Chunghua Telecom loses 1.6% of subscribers while Mo Bi Tai gains 2.1%.

As Figure 9 shows, there is little change on the HHI over the entire research period.[33] The median change in HHI over time is marely -3.1 points.

Compare this simulation with the previous one. Most of the "tipping effects" on the market shares due to intra-network discounts can be attributed to lowering the average prices. To quantify the effect directly from the price difference, I eliminate the substitution between in-network and off-network calls in the second counterfactual simulation. There is little effect on the market structure resulting directly from the price difference.

8 Conclusion

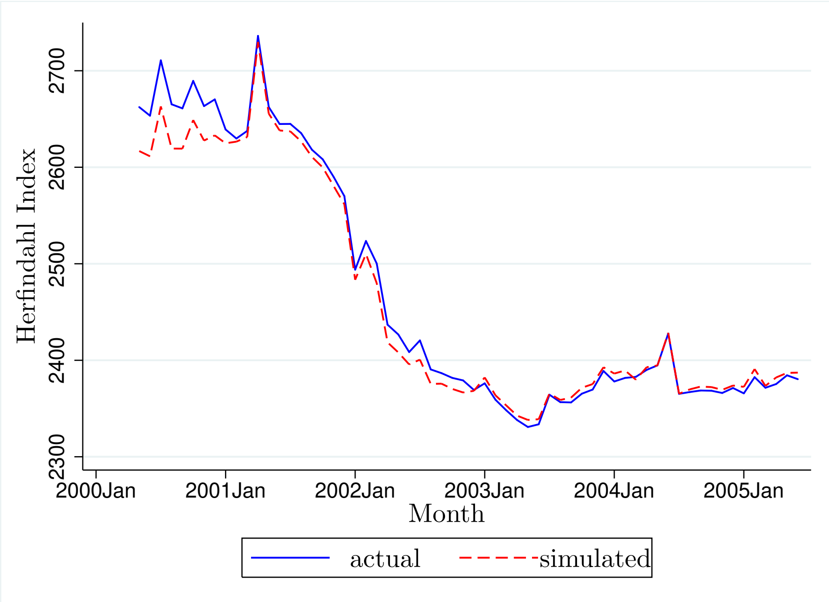
In the telecommunications industry, firms often provide a menu of optional rate plans. Because plan choice and volume choice are temporally separated, consumers can adjust their behaviors

[33]Because of interim shocks, the HHI measured in total volumes may increase even when the HHI measured in the number of subscribers decreases. In fact, the latter index always decreases when carriers are not recognizable from phone numbers.

Table 9: Counterfactual simulation on carrier recognizability

	Actual	Simulated
Average Usage (minutes)	35.641	35.538
Average Expenditure (TWD)	258.261	258.818
Average Expected Consumer Surplus (TWD)	170.121	168.779
Number of Subscribers (millions)		
CHT	3.325	3.272
TCC	2.796	2.786
FET	1.927	1.923
KGT	1.694	1.694
TAT	0.795	0.795
MBT	0.326	0.333
Total	10.862	10.803
Aggregate Volume (million minutes)		
CHT	276.325	273.008
TCC	199.680	200.185
FET	129.511	129.014
KGT	134.292	134.711
TAT	39.846	39.833
MBT	22.135	22.729
Total	801.788	799.480
Revenue (billion TWD)		
CHT	1.908	1.891
TCC	1.371	1.380
FET	0.955	0.959
KGT	1.031	1.041
TAT	0.376	0.379
MBT	0.168	0.172
Total	5.810	5.822

Note: Calculated for October 2002.



Note: Consumers cannot recognize the carrier of a phone receiver in the simulation.

Figure 9: Simulated market concentration rates with carrier recognizability

after learning new information. This paper develops a framework to analyze such an environment by using carrier-level data. Because consumers choose different quantity of the service, market shares measured by the number of subscribers differ from those computed from the traffic volume. I combine these two measures of market shares in the estimation to identify consumers' two-stage decisions on plan and volume. Moreover, household survey data are incorporated to identify consumer heterogeneities. Estimation is based on a preference-based structural model. I apply the method to analyze the cellular phone service market in Taiwan. Although switching costs are abstracted away in my model, the estimated model predicts churn rates similar to those observed in the real world. I use the estimated results to evaluate the effect of termination-based pricing schemes on the market structure. Intra-network discounts substantially increase the concentration rate in this highly concentrated market. However, the effects are primarily caused by lower average prices. The effects of the discounts *per se* are very small. Even though my counterfactual analysis only considers the demand side and is not an equilibrium analysis, the small effects imply that carriers would only change their tariffs slightly if termination-based pricing schemes is prohibited.

This paper focuses on consumer demand, taking price schedules as given. A more comprehensive analysis including carriers' pricing decision is important for future research. In addition, even though my empirical results suggest that switching costs only have modest effects on the subscription decisions, a dynamic model is needed to formally quantify the effects. Another important future extension is to relax the assumption of balanced calling pattern so that a group of consumers who often make calls to each other may coordinate their subscription decisions to take advantage of in-network discounts.

A Appendix: The Condition on the Variance of Expenditure

I will show that the condition on the conditional expenditure variance can be expressed as

$$\lambda^2 EXP_V(I) = E_\theta \Bigg\{ \sum_{t\in 2002} \sum_{k\in K^0} s_{kt}(\theta, I; \Theta, \Phi) E_{\eta,\nu}\left[(T_{kt}(\theta,\eta,\nu) - MT_t(I))^2\right] + c_\theta \sum_{\substack{t,t'\in 2002 \\ t\neq t'}} \Bigg[\sum_{k\in K^0} s_{kt}(\theta, I) E_\nu[T_{kt}(\theta,\eta,\nu) - MT_t(I)]\Bigg]\Bigg[\sum_{k'\in K^0} s_{k't'}(\theta, I) E_{\eta,\nu}[T_{k't'}(\theta,\eta,\nu) - MT_{t'}(I)]\Bigg] \Bigg| I \Bigg\} \tag{23}$$

for some parameter c_θ to be estimated. This parameter is increasing in the serial correlation of consumer's ex ante taste θ_{it}.

In this appendix, I will consider two extreme cases. The first one is the case with fully correlated ex ante taste, $\theta_{it} = \theta_i$ for all t in the year 2002. The parameter $c_\theta = 1$ in this case. In the second case, the ex ante taste is assumed to be independent over time. Then, $c_\theta = 0$. In general, the correlation of ex ante taste is between the two extreme cases, and I have $c_\theta \in (0, 1)$.

A.1 Case One

When the interim taste shock ε_{ikt} is independent over t, I have

$$\Pr(\kappa_{it} = k, \kappa_{it'} = k'|\theta_i) = \Pr(\kappa_{it} = k|\theta_i) \times \Pr(\kappa_{it'} = k'|\theta_i), \qquad \text{for any } k,\ k' \text{ and } t \neq t'.$$

By the definition conditional variance, for an income level I,

$$\lambda^2 EXP_V(I) \equiv \frac{1}{\#\{i : I_i = I\}} \sum_{\{i:I_i=I\}} \left[\sum_{t\in 2002} \sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) - \lambda EXP_M(I) \right]^2 .$$

Recall that $MT_t(I) = \sum_{k\in K} E_\eta[E_\theta\{s_{kt}(I,\theta) E_\nu[T_{kt}(\theta, \eta_{kt}, \nu)] | I\}]$ denotes the expected expenditure of a consumer with income I at period t. Plugging in the condition on expenditure mean (17), I obtain

$$\begin{aligned}
\lambda^2 EXP_V(I) &= \frac{1}{\#\{i : I_i = I\}} \sum_{\{i:I_i=I\}} \left\{ \sum_{t\in 2002} \left[\sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) - MT_t(I) \right] \right\}^2 \\
&= \frac{1}{\#\{i : I_i = I\}} \sum_{\{i:I_i=I\}} \left\{ \sum_{t\in 2002} \left[\sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) - MT_t(I) \right]^2 \right. \\
&\quad \left. + \sum_{\substack{t,t'\in 2002 \\ t\neq t'}} \left[\sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\cdot) - MT_t(I) \right] \left[\sum_{k'\in K^0} \mathbf{1}\{\kappa_{it'} = k'\} T_{k't'}(\cdot) - MT_{t'}(I) \right] \right\}.
\end{aligned}$$

As the number of consumers with income level I goes to infinity, the above equation converge in probability to

$$\begin{aligned}
&E_{\theta,\nu,\varepsilon} \left\{ \sum_{t\in 2002} \left[\sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\theta_{it}, \eta_{kt}, \nu_{it}) - MT_t(I) \right]^2 \right. \\
&\quad \left. + \sum_{\substack{t,t'\in 2002 \\ t\neq t'}} \left[\sum_{k\in K^0} \mathbf{1}\{\kappa_{it} = k\} T_{kt}(\cdot) - MT_t(I) \right] \left[\sum_{k'\in K^0} \mathbf{1}\{\kappa_{it'} = k'\} T_{k't'}(\cdot) - MT_{t'}(I) \right] \middle| I \right\}
\end{aligned}$$

Because of the independence of ε_{ikt}, θ_{it}, and ν_{it}, it equals

$$\begin{aligned}
&E_\theta \left\{ \sum_{t\in 2002} \sum_{k\in K^0} s_{kt}(\theta, I) E_\nu \left[(T_{kt}(\theta, \eta_{kt}, \nu) - MT_t(I))^2 \right] \right. \\
&+ \left. \sum_{\substack{t,t'\in 2002 \\ t\neq t'}} \left[\sum_{k\in K^0} s_{kt}(\theta, I) E_\nu[T_{kt}(\cdot) - MT_t(I)] \right] \left[\sum_{k'\in K^0} s_{k't'}(\theta, I) E_\nu[T_{k't'}(\cdot) - MT_{t'}(I)] \right] \middle| I \right\} \qquad (24)
\end{aligned}$$

The following lemma shows that the Law of Large Numbers can be applied to equation (24).

Lemma 1. *Suppose η_{kt} is independent over time t. As $|T|$ goes to infinity,*

$$\frac{1}{|T|^2}\left\{\sum_{t\in T}\sum_{k\in K^0} s_{kt}(\theta,I)E_\nu\left[(T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I))^2\right]\right.$$
$$\left.+\sum_{\substack{t,t'\in T\\ t\neq t'}}\left[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\right]\left[\sum_{k'\in K^0}s_{k't'}(\theta,I)E_\nu[T_{k't'}(\theta,\eta_{kt},\nu)-MT_{t'}(I)]\right]\right\} \quad (25)$$

converges in probability to

$$\frac{1}{|T|^2}\left\{\sum_{t\in T}\sum_{k\in K^0} s_{kt}(\theta,I)E_\eta E_\nu\left[(T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I))^2\right]\right.$$
$$\left.+\sum_{\substack{t,t'\in T\\ t\neq t'}}\left[\sum_{k\in K^0}s_{kt}(\theta,I)E_\eta E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\right]\left[\sum_{k'\in K^0}s_{k't'}(\theta,I)E_\eta E_\nu[T_{k't'}(\theta,\eta_{kt},\nu)-MT_{t'}(I)]\right]\right\}. \quad (26)$$

Proof. The second term in (1) can be expressed as

$$\sum_{\substack{t,t'\in T\\ t\neq t'}}\left[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\right]\left[\sum_{k'\in K^0}s_{k't'}(\theta,I)E_\nu[T_{k't'}-MT_{t'}(I)]\right]$$
$$=\left[\sum_{t\in T}\left[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\right]\right]^2-\sum_{t\in T}\left[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\right]^2$$

By the independence of η_{kt} over t, the Law of Large Numbers implies

$$\frac{1}{|T|}\sum_{t\in T}\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu\left[(T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I))^2\right]$$
$$\xrightarrow{p}\frac{1}{|T|}\sum_{t\in T}\sum_{k\in K^0}s_{kt}(\theta,I)E_\eta E_\nu\left[(T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I))^2\right],$$

$$\frac{1}{|T|}\sum_{t\in T}\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\xrightarrow{p}\frac{1}{|T|}\sum_{t\in T}\sum_{k\in K^0}s_{kt}(\theta,I)E_\eta E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)],$$

and

$$\frac{1}{|T|}\sum_{t\in T}\Big[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\Big]^2\xrightarrow{p}\frac{1}{|T|}\sum_{t\in T}\Big[\sum_{k\in K^0}s_{kt}(\theta,I)E_\eta E_\nu[T_{kt}(\theta,\eta_{kt},\nu)-MT_t(I)]\Big]^2.$$

Combining the above results, the probability limit stated in this lemma can be obtained after algebraic simplification. □

Using the result in Lemma 1, I obtain the following condition.

$$\lambda^2 EXP_V(I)=E_\theta\Bigg\{\sum_{t\in 2002}\sum_{k\in K^0}s_{kt}(\theta,I)E_{\eta,\nu}\left[(T_{kt}(\theta,\eta,\nu)-MT_t(I))^2\right]$$
$$+\sum_{\substack{t,t'\in 2002\\ t\neq t'}}\Big[\sum_{k\in K^0}s_{kt}(\theta,I)E_\nu[T_{kt}(\theta,\eta,\nu)-MT_t(I)]\Big]\Big[\sum_{k'\in K^0}s_{k't'}(\theta,I)E_{\eta,\nu}[T_{k't'}(\theta,\eta,\nu)-MT_{t'}(I)]\Big]\Big|I\Bigg\}. \quad (27)$$

A.2 Case Two

Next, consider the other extreme case. Suppose ex ante taste θ_{it} is independent over time t. The reasoning is similar to the previous case. However, because

$$E_{\theta_t,\theta_{t'}}\Bigg\{\Big[\sum_{k\in K^0}s_{kt}(\theta_t,I)E_\nu[T_{kt}(\theta_t,\eta,\nu)-MT_t(I)]\Big]\Big[\sum_{k'\in K^0}s_{k't'}(\theta_{t'},I)E_{\eta,\nu}[T_{k't'}(\theta_{t'},\eta,\nu)-MT_{t'}(I)]\Big]\Big|I\Bigg\}$$
$$=E_{\theta_t}\Bigg\{\sum_{k\in K^0}s_{kt}(\theta_t,I)E_\nu[T_{kt}(\theta_t,\eta,\nu)-MT_t(I)]\Big|I\Bigg\}E_{\theta_{t'}}\Bigg\{\sum_{k'\in K^0}s_{k't'}(\theta_{t'},I)E_{\eta,\nu}[T_{k't'}(\theta_{t'},\eta,\nu)-MT_{t'}(I)]\Big|I\Bigg\}$$
$$=0$$

for any $t\neq t'$, the second term on the right hand side of the equation (27) disappears in this case. The condition becomes

$$\lambda^2 EXP_V(I)=E_\theta\left[\sum_{t\in 2002}\sum_{k\in K^0}s_{kt}(\theta,I)E_{\eta,\nu}\left[(T_{kt}(\theta,\eta,\nu)-MT_t(I))^2\right]\Big|I\right].$$

References

Berry, S., J. Levinsohn, and A. Pakes (1995). Automobile prices in market equilibrium. *Econometrica 63*, 841–890.

Cohen, A. (2001). Package size and price discrimination in paper towels. Mimeo. University of Virginia.

Department of Justice (1994). *Horizontal Merger Guidelines.* Washington, DC: Department of Justice.

Directorate Generate of Telecommunications (2004). *2003 Annual Report.* Taipei, Taiwan: Directorate Generate of Telecommunications.

Directorate Generate of Telecommunications (2005). *2004 Annual Report.* Taipei, Taiwan: Directorate Generate of Telecommunications.

Economides, N., K. Seim, and B. V. Viard (2006). Quantifying the benefits of entry into local phone service. Mimeo. New York University and Stanford University.

Fu, W. W. (2004). Termination-discriminatory pricing, subscriber bandwagons, and network traffic patterns: The Taiwanese mobile phone market. *Telecommunications Policy 28*, 5–22.

Gans, J. S. and S. P. King (2001). Using 'bill and keep' interconnect arrangement to soften network competition. *Economic Letters 71*, 413–420.

Grajek, M. (2003). Estimating network effects and compatibility in mobile telecommunications. Discussion Paper SP II 2003 - 26, Wissenschaftszentrum Berlin, Germany.

Hanemann, M. W. (1984). Discrete/continuous models of consumer demand. *Econometrica 52*, 541–561.

Hausman, J. A. (1997). Valuing the effect of regulation on new services in telecommunications. *Brookings papers on economic activity. Microeconomics 1997*, 1–54.

Iyengar, R. (2004). A structural demand analysis for wireless services under nonlinear pricing schemes. Mimeo. University of Pennsylvania.

Kim, H.-S. and N. Kwon (2003). The advantage of network size in acquiring new subscribers: A conditional logit analysis of the Korean mobile telephony market. *Information Economics and Policy 15*, 17–33.

Laffont, J.-J., P. Rey, and J. Tirole (1998). Network competition: II. Price discrimination. *RAND Journal of Economics 29*, 38–56.

Leslie, P. (2004). Price discrimination in Broadway theatre. *RAND Journal of Economics 35*, 520–541.

McManus, B. (2006). Nonlinear pricing in an oligopoly market: The case of specialty coffee. *RAND Journal of Economics*, forthcoming.

Miravete, E. J. (2002). Estimating demand for local telephone service with asymmetric information and optional calling plans. *Review of Economic Studies 69*, 943–971.

Nair, H., J.-P. Dubé, and P. Chintagunta (2005). Accounting for primary and secondary demand effects with aggregate data. *Marketing Science 24*, 444–463.

Narayanan, S., P. K. Chintagunta, and E. J. Miravete (2007). The role of self selection, usage uncertainty and learning in the demand for local telephone service. *Quantitative Marketing and Economics 5*, 1–34.

Parker, P. M. and L.-H. Röller (1997). Collusive conduct in duopolies: Multimarket contact and cross-ownership in the mobile telephone industry. *RAND Journal of Economics 28*, 304–322.

Train, K. E., D. L. McFadden, and M. Ben-Akiva (1987). The demand for local telephone service: A fully discrete model of residential calling patterns and service choices. *RAND Journal of Economics 18*, 109–123.