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INTERNET QUALITY OF SERVICE MARKET ANALYSIS WITH PEERING AND USAGE-SENSITIVE PRICING: A GAME THEORETIC AND SIMULATION APPROACH

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Introduction

After the commercialization of the Internet in 1995, the demand for various Internet services diversified; new real-time and business-critical data applications require improved levels of services, or 'QoS (Quality of Service)' from the network. One of the major areas for research and investment related to the Internet is the provision of QoS.

In the summer of 2001, large service providers like AT&T and WorldCom announced that they would provide Internet "Class of Service" (CoS) to their customers. The CoS consists of four classes according to the priority level: Platinum, Gold, Silver, and Bronze. Since QoS interconnection policies have yet to be established, this CoS capability is limited to traffic that is contained completely in the provider's own network. To address this limitation, BellSouth's Florida Multimedia Internet Exchange (FMIX) announced a plan in 2001 to be the first NAP[1] (Network Access Point) to support QoS interconnection using MPLS (Multi-Protocol Label Switching). Some of the challenges (that were not in the announcement) will be exactly how class matching between providers will be achieved, and how to disclose needed network information for an end-to-end quality guarantee without compromising the competitive position of the interconnecting parties.

Despite these difficulties, we remain confident that, in the not-to-distant future, QoS will be introduced not only in private networks but in the whole Internet. We take the backbone market leaders' movement toward QoS and the emergence of QoS enabled NAP as strong signs of this shift. Other features of this new network include:

(1) *Product Diversification* With QoS, there are two services in the Internet market: a BE service and a QoS service. Since the QoS service includes the BE service as its lowest class of service, the new markets will feature vertical product differentiation.

(2) *Operational Transition* Traditionally, Internet Access Providers (IAPs[2]) in the U.S. provided flat-rate access plans, and later performed a limited amount of usage metering. Previous research (MacKie-Mason and Varian, 1995) indicates that, in the absence of price-based differentiation, users will choose the highest quality level regardless of traffic type. Thus, it is reasonable to expect a change in pricing and billing practices toward usage-sensitive pricing with metering.

The QoS Internet with these new features lets IAPs have several options for their strategies besides network capacity. New strategies are chosen for their profit maximization, which is dependent on not only my own strategies but also the other's strategies. With the QoS Internet scenario, we build an Internet QoS Game model

In this dissertation, we make two different assumptions of data distribution for users' willingness-to-pay: (1) uniform distribution and (2) empirical distribution. According to the different assumptions, we use different demand functions. For the demand

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[1] A NAP is where Internet interconnection among different providers occurs.

[2] A company that provides access to the Internet IAPs generally provide dial-up access through a modem and PPP connection, though companies that offer Internet access with other devices, such as cable modems or wireless connections, could also be considered IAPs. The term IAPs and ISPs are often used interchangeably, though some people consider IAPs to be a subset of ISPs. (Source: **www.webopedia.com/TERM/I/IAP.html**)

function of empirically distributed data, which comes from the U.S. General Accounting Office (U.S. GAO) survey for Internet usage, we use a two-stage RNG (Random Number Generator) simulation and linear regression. Based on the above demand functions and a cost function made by the data found in the real market, we establish a profit function. Then, we try to find an equilibrium point when both IAPs maximize their profits simultaneously. The research purpose of this study is to provide a foundation of policy framework for the QoS connectivity in the future Internet access market.

Internet QoS Game Model

We apply Cournot duopoly theory to our game model, describing two IAPs (IAP1 and IAP2) in a rural area. In Cournot duopoly game model, firms' output level is a strategic variable and its main assumptions are product homogeneity and no entry. In the game model of this dissertation, we use the same assumptions and make an extended duopoly game model. Each IAP has four strategic choices: technology (BE or QoS), pricing scheme (flat-rate pricing or two-part tariff), investment in network capacity (1K, 2K, or 3K[3]), and interconnection method (peering or transit). While these four choices are assumed to be long-term strategies, output level is supposed to be a short-term strategy.

Table 1. Internet QoS Game Model in Detail

				Transit									Peering								
				BE			QoS						BE			QoS					
				Flat			Flat			Two-Part			Flat			Flat			Two-Part		
				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Transit	BE	Flat	1	Case 1			Case 2			Case 3											
			2																		
			3																		
	QoS	Flat	1				Case 5			Case 4											
			2																		
			3																		
		2-Part	1							Case 6											
			2																		
			3																		
Peering	BE	Flat	1										Case 7								
			2																		
			3																		
	QoS	Flat	1													Case 9			Case 8		
			2																		
			3																		
		2-Part	1																Case 10		
			2																		
			3																		

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[3] "K" means 1,000. For example 1K (2K, 3K) means an IAP can support up to 999 (1999, 2999) users. Because we assume 5,000 potential users in the market, network capacity for 3,999 or 4,999 users means negative profit to the IAPs.

Table 1 presents an overall game structure. There are unique 10 cases considering interconnection, pricing, and technology strategies. Because of symmetric characteristic, there are duplicates of Case 2, 3, 4, and 8. Peering is only possible for the two IAPs with the same technology to make an agreement for. Every case has 9 cells (3x3), which are characterized by its network capacity (1K, 2K, or 3K). There are a total of 90 cells in this model (= 9 cells * 10 cases). In each cell, both IAPs try to maximize their profit by choosing an optimal output level, which is determined by interactions between them through the strategic variables.

Demand Function

There are two demands in the Internet access market: (1) access demand and (2) usage demand. The demand for access means how much the subscriber would pay for the right to be connected to an IAP's network and the demand for usage means how many hours he would connect at whatever price is charged for usage. (Wenders, 1987)

The following two demands equations can be expressed as the access demand for the number of users (Q) in [Eq-1], and the usage demand for the number of QoS usage hours (h_{QoS}) in [Eq-2]:

$Q = A_0 - A_1*F - A_2*r$ . . . . [Eq-1]
$h_{QoS} = B_0 - B_1*r$ . . . . [Eq-2]

where Q is the number of users (BE and QoS), h_{QoS} is the number of QoS connection hours, F is the fixed access price, which is assumed to be P_{BE}, and the r is the hourly usage rate for QoS connection. The relationships between quantity (Q, h_{QoS}) and price factors (F, r) are assumed to be negative, i.e., increasing prices means decreasing quantity. According to the industry and market data, we estimate the coefficients of demand functions as follows:

Table 2. Values of Coefficients

Coefficients	**A_0**	**A_1**	**A_2**	**B_0**	**B_1**
Values	5,000	100	500	100	33.3

Based on the above demand functions, we apply production differentiation theory (Gal-Or, 1983, 1985) for BE and QoS. The following are the three estimated demand functions:

$P_{BE} = [0.01* (5000 - Q_{QoS} - Q_{BE})]$ . . . . [Flat-rate BE]
$P_{BE} = [0.01* (5000 - Q_{QoS} - Q_{BE})] - 5*r$ . . . . [Two-part BE]
$P_{QoS} = P_{BE} + [0.01*(5000 - {}_{QqoS})]$ . . . . [QoS]

where $Q_{BE} = q1_{BE} + q2_{BE}$ and $Q_{QoS} = q1_{QoS} + q2_{QoS.}$

Revenue Function

The revenue function of each IAP is assumed to have generally two components: (1) the revenue obtained from the subscribers and (2) those received from the advertisers that present their announcements in the IAP's web pages. In our analysis these two revenues will be calculated on a monthly basis. The following table summarizes revenue function in the game model.

Table 3. Revenue Functions

	BE	**QoS (flat-rate)**	**QoS (two-part)**
Subscription Revenue	$Q_{BE}*P_{BE}$	${}_{QqoS}*P_{QoS}$	$Q_{QoS}*P_{BE} + Q_{QoS}*h_{QoS}*r$
Advertising Revenue	$Q_{BE}*8$	$Q_{QoS}*8$	$Q_{QoS}*8$

Cost Function

The cost structure of the Internet industry is characterized by large, up-front sunk costs and near zero, short run marginal traffic cost. In our model, the measuring unit of cost is not traffic but a subscriber, i.e. the cost is calculated by the number of subscribers. The basic assumptions of the cost structure in the model are (1) large, up-front, irreversible sunk cost and (2) low constant marginal cost for additional subscriber. Under these assumptions, the duopolists must cover the following three types of costs to be able to provide their services: capital (c_c), interconnection (transit:c_t or peering:c_p), and operation costs (c_o). Table 4 summarizes cost functions of the IAP1 used in the game model. The same cost function is applied to the IAP2.

Table 4. Cost Functions

Category		Parameter	BE-IAP	QoS-IAP (flat-rate)	QoS-IAP (two-part)
Capital		c_c / 1,000 subscribers	*k1**9,000	10,000+ *k1**6,000	10,000+ *k1**6,000
Inter-conne-ction	**Transit**	c_t / 1,000 subscribers	*k1**1,000	*k1**$2,000	*k1**2,000
	Peering	c_p / 1,000 subscribers	Max{*k1,k2*}*150	2*Max{*k1,k2*}*150	2*Max{*k1,k2*}*150
Operation		c_o / subscriber	$\$1*q1_{BE}$	$\$1*q1_{BE}+(q1_{QoS})$^1.5	$\$1*q1_{BE}+(q1_{QoS})$^1.6
Total		Transit	$\$1*q1_{BE}+k1*10{,}000$	$\$1*q1_{BE}+(q1_{QoS})$^1.5 +10,000+*k1**8000	$\$1*q1_{BE}+(q1_{QoS})$^1.6 +10,000+n1*8000
		Peering	$\$1*q1_{BE}+5{,}000$ +*k1**6,000 +Max{*k1,k2*}*150	$\$1*q1_{BE}+(q1_{QoS})$^1.5 +10,000+*k1**6000+ 2*Max{*k1,k2*}*150	$\$1*q1_{BE}+(q1_{QoS})$^1.6 +10,000+*k1**6000+ 2*Max{*k1,k2*}*150

Equilibrium Analysis of Uniform Distribution

According to the demand functions based on the uniform distribution, we make 10 cases with a combination of three strategies, (1) technology choice, (2) pricing scheme, and (3) interconnection method. Each IAP has three investment options for its network capacity, 1K, 2K, or 3K. A payoff function of each case is defined by a profit function, which is gross revenue minus total cost. The shaded cells in table 5 show equilibrium points of each case.

The following are conclusions of equilibrium analysis of each case:

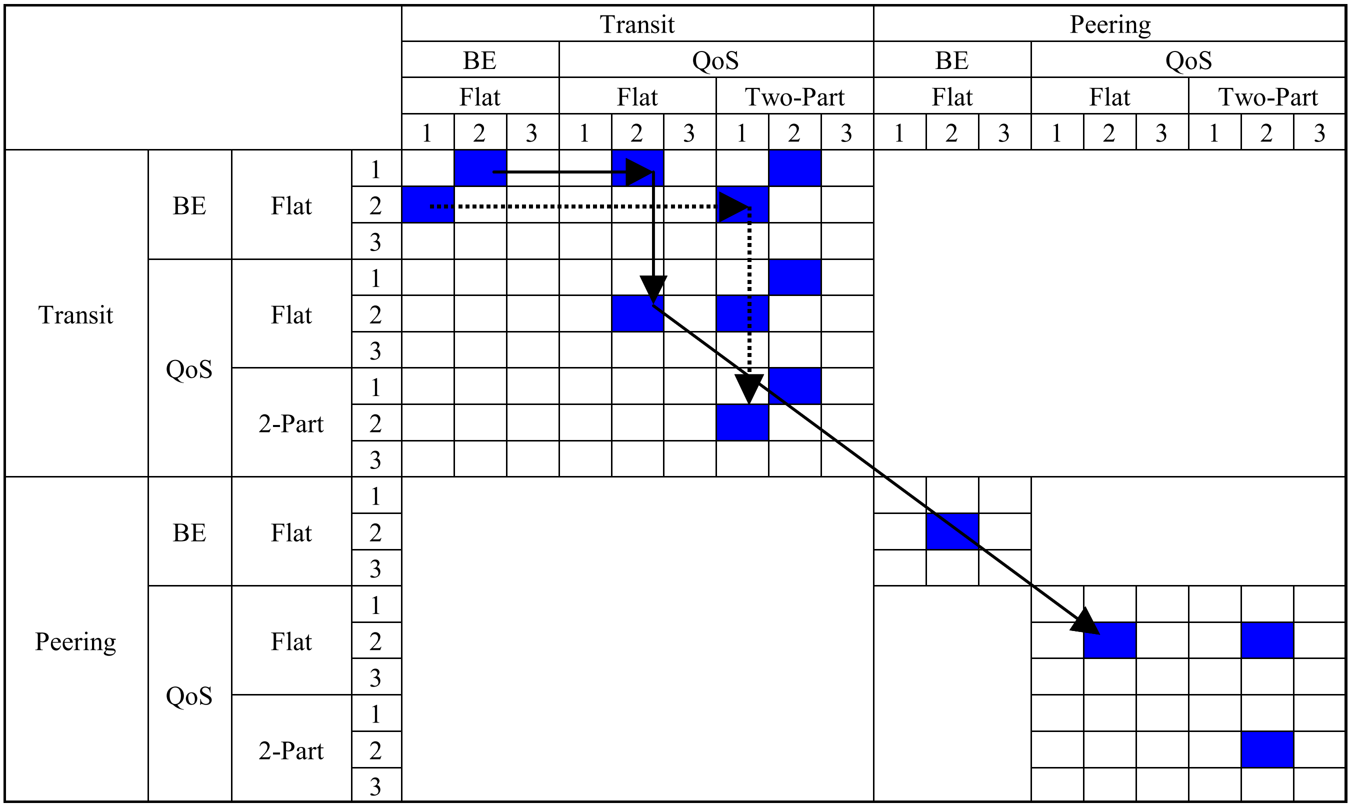
- In Case 1, being a larger network capacity (*2K*) earlier than the other (*1K*) will pay off.
- In Case 2, QoS-IAP will have a better market position than a BE-IAP when they exist in the same market and upgrading to QoS technology earlier than the other will pay off.
- In Case 3, even a BE-IAP can have a better market position when it chooses larger network capacity (*2K*) than a QoS-IAP with two-part tariff (*1K*).
- In Case 4, larger QoS-IAP (*2K*) will be a better market position regardless of pricing scheme.

In Cases 5, 7, 9, and 10, both IAPs' dominant strategy is 2K, therefore there is one equilibrium, [2K, 2K]. At this equilibrium, every strategy is symmetric between two IAPs, i.e., the same strategy set of two IAPs, {QoS, flat-rate, transit/peering, 2K}. So, there is a possibility for the two identical providers to collude, i.e., to reduce the network capacity from 2K to 1K, and to get a higher profit than at the equilibrium point.

In Case 6, when both IAPs produce QoS services with a two-part tariff, large QoS-IAP (*2K*) will pay off.

In Case 8, even though they make an investment of the same network capacity, QoS-IAP with two-part tariff has a higher profit than QoS-IAP with flat-rate pricing.

Table 5. Equilibrium and Progressive Paths



				Transit									Peering								
				BE			QoS						BE			QoS					
				Flat			Flat			Two-Part			Flat			Flat			Two-Part		
				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Transit	BE	Flat	1		■			■			■										
			2	■						■											
			3																		
	QoS	Flat	1								■										
			2					■		■											
			3																		
		2-Part	1								■										
			2							■											
			3																		
Peering	BE	Flat	1																		
			2											■							
			3																		
	QoS	Flat	1																		
			2														■			■	
			3																		
		2-Part	1																		
			2																	■	
			3																		

If we combine equilibrium points of all ten cases, we can suggest progressive paths of IAPs' market equilibrium from BE Internet to QoS Internet. We can classify the above ten cases into three categories: (1) current BE Internet: Case 1, (2) Internet in transition: Cases 2, 3, and 7, and (3) future QoS Internet: Cases 4, 5, 6, 8, 9, and 10. From the equilibrium points in Case 1, we can find a progressive path of market equilibrium when the technology changes from BE to QoS and the interconnection method changes from transit to peering. The decision making rules of transition from one equilibrium to another, when a new strategy is introduced, are (1) whether the profit of new equilibrium point is higher than the previous one and (2) increasing network capacity is possible but decreasing is impossible because network capacity is assumed to be classified into the irreversible sunk cost. This transition is also based on the assumption that the other's strategy set does not change.

Social Welfare Analysis

Among social welfares of 90 points, the highest social welfare values in the model lie in Case 5 and Case 9. This means that the strategy set of {QoS, flat-rate, transit/peering, 2K/3K} is a socially desirable one. These points (Case 5 and 9) are different from the destination points of market equilibrium evolutionary paths (Case 6 and 10), which suggests that market equilibrium does not mean socially desirable points.

Analyses Based on the Empirically Distributed Data

In the previous chapters we use the theoretical uniform distribution for the customers' willingness-to-pay. In this chapter, instead of the uniform distribution, we use an empirical distribution from a survey of Internet usage (U.S. GAO report, 2001), on which we draw an estimated demand function by simulation and linear regression. We expect the empirical distribution to make the game model close to the real market situation.

The estimated demand function for BE is presented in figure 1. The kinked line represents a demand curve from the simulation and the straight line represents a demand curve from the linear regression, which is "$P = 44.55 - 0.00855*Q$." We estimate a QoS demand function by applying the product differentiation theory as we did in the uniform distribution case.

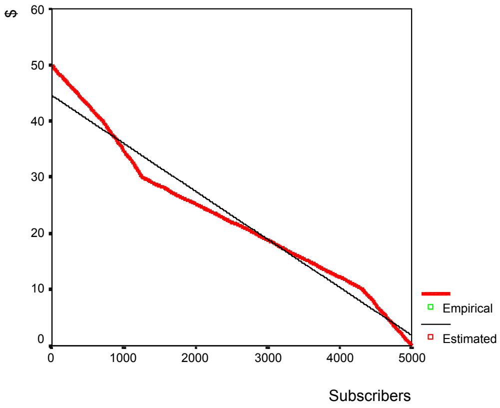


Figure 1. Demand Curves for Empirical Distribution

Based on this empirically estimated demand function, we analyze the 10 cases and the overall model as we did in the uniform distribution. The empirical distribution has the same equilibrium network capacity as the uniform distribution does except for Case 7.[4] We try to find market evolutionary paths from the equilibrium points of Case 1 as we did in the uniform distribution. There are identical, two market equilibrium evolutionary paths as in the uniform distribution. In conclusion, there is no significant difference in the results of equilibrium analyses between two distributions, thus uniform distribution assumption is reasonable in this game model.

We calculate social welfares of all 90 points (= 9 cells * 10 cases) in the empirical distribution as we did in the uniform distribution. If we consider social welfares of equilibrium of each case, the highest social welfares are [2K, 2K] of Case 5 and Case 9, which are the same as in the uniform distributions. In the both distributions, social welfares of peering cases (Cases 7 ~10) are higher than that of transit cases (Case 1~6), which means that peering is socially more desirable than transit.

Conclusion

The Internet has become an important social and business tool. The market has been quite dynamic since it was privatized. By studying rural markets where the market structure is simpler, we are able to construct reasonable economic model. In this dissertation, we show that the unique cost and revenue structure of the Internet access market has a significant influence on the equilibrium results. The analyses let us know the following:

- QoS technology will be introduced with {two-part tariff, transit/peering} or (flat-rate, peering},
- Network capacity is an important strategy to determine the market equilibrium in the future as well as in the current,
- A peering arrangement will provide higher social welfare than transit will in the QoS Internet, and
- A BE service will survive in the QoS Internet and will contribute a considerable portion to the IAPs' revenue.

Therefore, new technology (QoS), new pricing scheme (two-part tariff), and larger capacity pay off in the future Internet market Even if you are not the first mover toward QoS and two-part tariff, a second mover will pay off.

We conclude that there is no single dominant strategy to win in the Internet access market. Technology strategy alone or pricing strategy alone is not enough to dominate the Internet access market. The winning strategy set is a combination of multiple strategies and it is different according to the other's strategy set. Introducing new technology does not always guarantee social

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[4] Case 7's equilibrium network capacity: [2K, 2K] in the uniform distribution and [1K, 2K] and [2K, 1K] in the empirical distribution.

welfare improvement. If cost of new technology is larger than benefit or if demand of new technology is not enough to cover the cost, it would make social welfare worse than before.

A policy maker's goal for the Internet industry is continuing growth and innovation. To achieve this goal, they are trying to encourage competition and to give incentives for ongoing investment and deploying new technology, which will give benefit to consumers in the Internet market. The Internet policy makers should deliberate how to induce the rural IAPs to move into the other equilibrium points in the future without market distortion.

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