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A Game Theoretic Modeling and Analysis for Internet Access Market

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Abstract

In this paper, we study the local dial-up Internet access market using a game theoretic model. In particular, we consider the Nash equilibrium of the service providers and examine their behavior on investment and output level. We calibrate this model to fit the industry structure and data found in rural markets. In the first part of the paper, we examine the Internet industry structure and its characteristics. In the latter part of the paper, we create an abstract Cournot duopoly model, in which real world cost and revenue projection will be used to find an Internet access market equilibrium and its social welfare. These analyses allow us to explain the motivation for the ISPs' behavior, such as over-subscription and under-investment. Finally, we will present an analytical framework for the Internet industry policy maker.

1. Introduction

It is well known that the cost characteristics of Internet capacity provisioning include large, up front sunk costs and near zero short run marginal cost of traffic. Another well-known characteristic of Internet industry is that the Internet dial-up access product is almost homogeneous. These two features are significant determinants in the analysis of the Internet industry.

ISPs in this industry are competitors and cooperators simultaneously: On one hand they are competitors for their market shares but on the other they are cooperators that provide universal, global connectivity, that is to say, one ISP's decision has an influence to other ISP's decision.

Therefore, ISPs in the Internet industry have a strong dependence with each other. This unique characteristics make the Internet suitable to game theoretic situation, i.e., each player in the game model is a competitor in a market and there are interactions according to their strategic decision.

There are many ISPs in the access market, most of which are concentrated on urban metropolitan area. Some of them are big companies and they are equipped with financial power and high level of technology, but many of them are small-sized, family-operated, rural ISPs. From the universal connectivity point of view, they are very important to give Internet accessibility to a whole nation. Our model in this paper will focus on small ISPs in the rural area.

With the above assumptions, we can apply the Cournot duopoly model to ISPs in the rural downstream market. The research purpose in this paper is to provide to the Internet industry policy makers a framework that they have to take a consideration for small, rural ISPs when they make a future Internet industry policy.

The paper is structured as follows. Section 2 presents the current Internet industry structure focusing on ISPs and IBPs. Section 3 analyzes Internet access market using a Cournot duopoly model and Section 4 refines this model using realistic data. Finally, we conclude in the section 5.

2. The Internet Industry

2.1 Introduction

The Internet is a system that makes it possible to send and receive information, among all the individual and institutional computers associated with it. Like telephone and radio, the Internet eliminates the need for the communicating entities to be in the same place. Like mail, it does not require that the communicating entities coincide in time and it makes it possible to retain records of what is being communicated. These “mail services” are provided by the Internet in a much shorter time and a lower cost. Finally, the Internet also can be used to provide services similar to those provided by the mass media.

The Internet industry integrates the equipment, software, and organizational infrastructure required for Internet communications. As a rough approximation it can be said it is divided into two components: IBPs[1] that transfer communications in bulk among network exchange points, and ISPs[2] that (1) receive communications from individuals or institutions and transfer them to an IBP's network**,** and (2) receive communications from IBP and transfer them to their destination. Generally speaking, the Internet industry has a vertical structure: Upstream IBPs provide an intermediate good and downstream ISPs using this input sell connectivity to the their customers. Therefore, the relationship between IBPs and ISPs is that of wholesalers and retailers.

In reality the Internet is much more complex. The ISPs themselves are networks of users that may directly exchange information among each other. In addition, the IBPs may provide services directly to users[3] and also may interconnect with other IBPs. In this sense, the Internet is a network of networks that is accessible in many parts of the world. Since the telephone industry is tightly intertwined with the Internet industry, we begin by with its examination.

2.2 Telephone Industry

Public Switched Telephone Network (PSTN) was designed and optimized for the transmission of the human voice. In the U.S., telephone service is divided into two industries: (1) local telephone service provided by Local Exchange Carriers (LECs) and (2) long distance telephone service provided by Interexchange Carriers (IXCs). This structure creates a vertical hierarchy: Upstream IXCs provide the connection between LECs, and the downstream LECs have direct access to telephone users.

Traditionally, a LEC was a monopoly that served a specific geographic region without competition. Even after deregulation, LECs are still considered by many to be a local monopoly, especially for residential customers. In the U.S., the local telephone services provided under flat-

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[1] IBPs are used to refer to NSPs (Network Service Providers or National Service Providers).

[2] ISPs are used to refer to any company who can offer Internet connectivity. Some people use ISPs as a general term including IBPs. Some people argue that ISPs can be differentiated from other types of online information services, such as CompuServe or American On Line, because ISPs do not provide content but they focus only on providing Internet connectivity.

[3] IBPs like AT&T WorldNet, Broadwing, CAIS, Epoch, Netaxs, Savvis Communications, XO also support dial-up access customers in the downstream market. (http://www.boardwatch.com/isp/bb/n_america.htm)

rate billing, that is, a telephone user can originate local calls as many times and as long as he wishes with only monthly flat rate. This type of billing system has been a great influence on the growth of Internet access market.

The long distance market is now generally considered to be a very competitive market, though it too was a monopoly at one time. Users can use a long distance calling with pre-selected IXC through their LEC. Any IXC that wishes to handle calls originating in a local service area can build a switching office, called a Point of Presence (POP), there. The function of the POP is to interconnect networks so that now any site where networks interconnect is may be referred to as a POP.

2.3 Internet Backbone Providers

With some simplification, it can be said that the IBPs receive communications in bulk from POPs or NAPs (Network Access Points) and distribute them to other POPs or NAPs close to the destination. NAPs are public interconnection points where major providers interconnect their network and consist of a high-speed switch or network of switches to which a number of routers can be connected for the purpose of traffic exchange. The function of NAPs is similar to major airport hubs; all ISPs and IBPs are gathered at the NAPs to connect each other.

Before the Internet privatization, the NSF (National Science Foundation) was responsible for the operation of the Internet. The NSF backbone ceased operation in late 1994 and was replaced by the four NAPs[4] (Minoli, 1998, pp27-28). There are probable around 50 major NAPs[5] world-wide in the Internet, most of which are located in the U.S. (Moulton, 2001, p551). As the Internet continued to grow, the NAPs suffered from congestion because of the enormous traffic loads. Because of the resulting poor performance, private direct interconnections between big IBPs were introduced, called peering points.

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[4] 4 NAPs are Chicago NAP (Ameritech), San Francisco NAP (Pacific Bell), New York NAP (Sprint), and Washington D.C. NAP (Metropolitan Fiber Systems).

[5] Sometimes NAPs are known by names such as Commercial Internet Exchange (CIX), Federal Internet Exchange (FIX), and Metropolitan Area Exchange (MAE).

To make the Internet a seamless network, the IBPs have multiple POPs distributed over the whole world. Most frequently they are located in large urban centers. These POPs are connected each other with owned or leased optical carrier lines. Typically, these lines are 622 Mbps (OC-12) or 2.488 Gbps (OC-48) circuits or more, as defined by the SONET[6] hierarchy. These POPs and optical carrier lines make up the IBP backbone network. The IBP's POPs, are also connected with the POPs of many ISPs. The relationship between an ISP's POP and IBP's POP is the same as that of ISPs and IBPs.

There are two types of interconnections among the IBPs: peering and transit. The only difference among theses types is in the financial rights and obligation that they generate to their customers. The peering type of interconnection is used mainly by the big, equal-sized IBPs for reception and distribution of the information that each one of them receives. From the interconnection perspective, NAPs are the place for public peering. Anyone who is a member of NAP can exchange traffic based on the equal cost sharing. Members pay for their own router to connect to the NAP plus the connectivity fee charged by the NAP. On the other hand, the direct interconnection between two equal sized IBPs is bilateral private peering, which takes place at the mutually agreed place of interconnection. With transit agreements, usually small IBPs are able to receive and send communications using the facilities of large IBPs, and must pay a fee for these services. A concern related to transit is that while small IBPs do not have to pay in the case of peering through NAPs, they must pay a transit fee if they directly connect to one of the large IBPs. Before the commercialization of the Internet, carriers interconnected without a settlement fee, regardless of their size. However, after the Internet's commercialization, the large IBPs announced their requirements for a peering arrangement, and any carrier who could not meet those terms would be required to pay a transit fee in addition to the interconnection costs.

According to Erickson (2001), the North American backbone market had around 36 IBPs[7] in the first quarter of 2001. However, these numbers misinterpret the Internet backbone market structure because this market is highly concentrated. There were 11,888 transit interconnections between backbone and access markets in April 2000. (McCarthy, 2000) Counting by the number

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[6] SONET stands for Synchronous Optical Networking. The capacity of OC-x is based on that of OC-1 (51.84 Mbps). For example, the capacity of OC-3 is 3 times of OC-1. (155.52 Mbps = 3*51.84 Mbps)

[7] These numbers are based on North America Region.

of connections to downstream market, MCI/Worldcom is a dominant player in the backbone market with 3,145 connections and Sprint is the second largest backbone provider with 1,690 connections and AT&T (934 connections) and C&W (851 connections) are the third and the fourth.

Several of the large IBPs are subsidiaries of large telephone companies such as AT&T, MCI/WorldCom, Sprint, etc. Since these companies own the infrastructure needed for telephone services, they are very favorably positioned to provide the facilities and equipment required by the IBPs. In addition, due to their size, they are able to offer large volume discount rates or bundling agreements of both telephone and Internet lines for the services they provide. This is possible because the Internet industry is lightly, if at all, regulated. In particular, there are no regulations with respect to the tariffs that can be charged for the services provided. From these observations it follows that the large IBPs, supported by the large telephone companies, are in a position to capture large shares of the upstream market.

According to the Carlton and Perloff (1999, p247), the most common measure of concentration in an industry is the share of sales by the four largest firms, called the ‘C4’ ratio. Generally speaking, if the C4 ratio is over 60, the market is considered a tight oligopoly. For the upstream backbone market this ratio[8] is 73, which shows high concentration in the market. The entry barrier is also high because there is a large sunk cost for nationwide backbone lines and switching equipment. The number of IBPs for the past three years shows just how high the entry barrier in the backbone market is: 43 (1999), 41(2000), and 36 (2001)[9]. The slight reduction for last three years is caused by mergers and acquisitions[10] and reclassification[11]. According to the number of players, we conclude that the overall backbone market is stable. In addition there are significant economies of scale and the rapid pace of technological change generates a large amount of uncertainty about the future return on investments. It is not easy to enter this market without large investments and high technology.

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[8] Source: TeleGeography, Inc. The calculation is based on the data of 1999 U.S. backbone revenue (Worldcom 38%, Genuity 15%, AT&T 11%, Sprint 9%)

[9] The Boardwatch magazine’s annual survey for ISPs.

[10] AT&T and Time Warner, GTE and Bell Atlantic, Concentric and NextLink, Qwest and US West, etc

[11] The backbone section was divided into backbone provider and data center provider from 2001 survey.

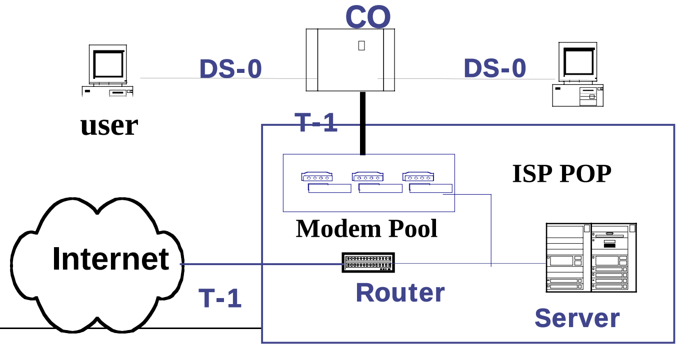
The interconnection price is usually determined by the provider's relative strength and level of investment in a particular area (Halabi, 2000, 42p). It is certain T-1 transit price has been decreased continuously. In 1996, the Internet connectivity for T-1 was $3,000 per month with $1000 setup fee (Halabi, 1997, 40p). According to Martin (2001), the average price of T-1 connection in 1999 was $1,729. In 2000, it was $1,348. In 2001, it is $1,228. One of reasons for decreasing T-1 interconnection price is advent of substitute services for T-1 line, such as wireless Internet access technology[12], digital subscriber line (DSL) technology, and cable-modem technology, which exert a downward pressure on T-1 prices.

2.4 Internet Service Providers

An ISP's product is public access to the Internet, which includes login authorization, e-mail services, some storage space, and possibly personal web pages. There are several Internet access technologies including dial-up, cable-modem, DSL, and wireless. According to U.S.GAO (United States General Accounting Office) report (2001), the dominant technology is dial-up access (87.5%) in 2000[13]; so we restrict our analysis to that technology.

The following diagram illustrates the components of dial-up access ISP and its environment. The DS-0 line (Digital Signal level 0)[14] is a normal telephone local loop. The T-1[15] line between CO and ISP's modem pool is dedicated line for the ISP's customer traffic from a particular CO to their modem pool. Another T-1 line is needed to connect to the Internet, which runs from the ISP's router to the IBP's POP.

[Figure-1: ISP Business Environment]



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[12] LMDS (Local Multiple Distribution System) and satellite based Internet service
[13] Dial-up (87.5%), Cable modem (8.9%), DSL telephone (3.2%), and Wireless (0.4%)
[14] DS-0 is the basic digital signal converted from analog voice (64 Kbps).
[15] T-1 line has 1.544 Mbps capacity, which is the same as 24 DS-0 (64Kbps) telephone lines.

The ISP's coverage area is usually determined by the existence of an ISP's POP within the local telephone area. ISPs are classified as local, regional, and national according to the scope of their service coverage. The distribution of ISPs is presented in the Table-1.

Among 307 telephone area codes in U.S., the largest ISP covers 282 area codes and the smallest covers only 1 area code. The ISPs with 1 to 10 area codes constitute 79.81% of the total number of ISPs. This explains that most of ISPs in the downstream market are small, local companies. Some of these small ISPs are subsidiaries or affiliates of CLECs (Competitive Local Exchange Carriers), which are small telephone companies established in the 1990s as a result of telephone industry deregulation.

[Table-1: Distribution of ISPs by their coverage]

Telephone area codes covered by ISP	Percentage	Type
1	35.14%	Local
2-10	44.67%	Local / Regional
11-24	4.11%	Regional
25-282	16.08%	National

- **Source: The 13th edition of the Directory of Internet Service Providers, Boardwatch magazine (www.ispworld.com/isp/introduction.htm)[16]**

AOL-Time Warner is a dominant player in the dial-up access market. According to Fusco (2001), AOL-Time Warner had 22.7 million subscribers in the 1st Quarter of 2001. The Table-2 shows top 10 dial-up ISPs ranked by the number of paying users.

[Table-2: Top 10 U.S. Fee-based ISPs (Dial-up only)][17]

Rank & ISP	Paying User	Market Share	Rank & ISP	Paying User	Market Share
(1) AOL	22.7M	46%	(6)Gateway.net	1.7M	3%
(2) MSN	5.0M	10%	(7)AT&T WorldNet	1.3M	3%
(3)EarthLink	4.8M	10%	(8)NetZero+Juno Online	1.0M	2%

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[16] Total number of registered ISPs to this survey is 7,288 at March, 2001

[17] Total number of customers of paid dial-up ISPs is 49.6 M at the first quarter of 2001 according to the Telecommunications Report International Inc. We calculated market share of each companies and the rest of ISPs' market share except top 10 ISPs is expected as 11%.

(4) Prodigy	3.1M	6%	(9) Verizon	0.9M	2%
(5)CompuServe	3.0M	6%	(10) Bell South	0.8M	2%

- **Source: www.isp-planet.com/research/rankings/usa.html**

In the downstream access market the C4 ratio[18] is 72, which is also highly concentrated. However, the entry barrier in the downstream market is much lower than in the backbone market. Since subscribers can utilize the PSTN line to connect ISPs' modems and ISPs purchase business telephone lines from a LEC, ISPs do not have to invest in access lines to individual subscribers. They can build POPs to link to the PSTN and other ISPs. Since a T-1 lines prices and telecom equipment prices are currently dropping quickly, a large number of small ISPs are possible, especially in the less densely populated areas. The number of North American ISPs for the past several years is an evidence of low entry barrier in the downstream market: 1447 (February 1996), 3640 (February 1997), 4470 (February 1998), 5078 (March 1999), 7463 (April 2000), and 7288 (March 2001)[19].

In summary, considering market concentration and entry barriers, IBPs have more market power than ISPs in the Internet industry. The Table-3 compares the IBP and ISP markets presented above.

[Table-3: Comparison of Access and Backbone Markets]

	No. of companies	Dominant Company	C4	Entry Barrier
Backbone Market	36	MCI/WorldCom (UUNET[20])	73	Higher
Access Market	7,228	AOL TimeWarner	72	Lower

- **Sources: TeleGeography, Inc., Internet.com Magazine, and Boardwatch Magazine**

Most ISPs provide unlimited Internet access with a monthly flat rate. For major national ISPs, the price ranges generally from $0 to $25 per month[21]. Some ISPs provide Internet access service

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[18] Source: www.isp-planet.com/research/rankings/usa.html

[19] Source: www.ispworld.com/isp/images/NA_ISPs_chart.gif. At the time of July 2001, the number of ISPs is over 8,000.

[20] UUNET is a subsidiary of MCI/WorldCom

[21] Telecommunications International Inc.'s Quarterly Online Census at March 31, 2000

with zero monthly subscription fees to their customers[22]; their revenues depend completely on Internet advertising income. According to Zigmont (2000), the cost of startup ISP is roughly $12 per subscriber including $7 for management/maintenance cost plus $5 for marketing. For this paper, we assume the price of dial-up Internet access to be $20 per month.

ISPs are free to make local peering arrangements with other ISPs. Cremer and Tirole (2000, p445) call this local secondary peering. The Pittsburgh Internet Exchange (PITX) is an example of local peering arrangement. Without this local peering, all network traffic passing from one Pittsburgh network to another has to be sent through Washington, D.C., Chicago, or New York City[23]. The sending and receiving networks pay an unnecessary cost for this inefficient handling of data that should remain local. Participants in this local exchange point reduce their costs and improve performance and reliability for their local Internet traffic with the equal basis of cost recovery. However, this kind of peering is confined to only local traffic. Outbound traffic to other areas still has to depend on the IBP's transit service.

2.5 Relationship among Telephone Industry and Internet Industry

Dial-up access using PSTN is the most universal form of Internet access. In the U.S., such a modem call is typically a local call without a per-minute charge. ISP's lines are treated as a business telephone user not as a carrier, so they are not required to pay the measured Common Carrier Line Charge (CCLC[24]). The switching system in LEC's CO connects calls between Internet users and ISP's modem pool so the LECs' facilities support dial-up Internet communications. In addition, IBPs and large ISPs often construct their backbone networks by leasing lines from IXCs and LECs. As a result, we can say that telephone industry provide basic infrastructure for the Internet industry.

The following diagram explains the overall Internet connections from end user to LEC's CO, ISP, IBP, and NAP. In this diagram, the local ISP's POP connected to AT&T POP is located in

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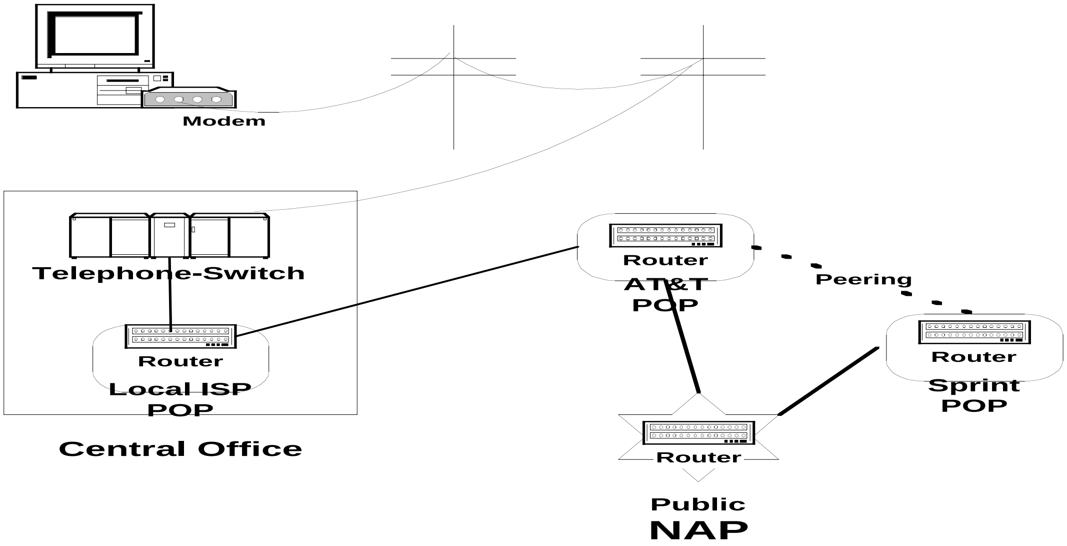
[22] AltaVista, FreeInternet.com, NetZero, FreeLane, Source: www.ispworld.com/introduction.htm,
[23] Source: http://www.pitx.net/about.html
[24] LECs have traditionally been charging IXCs $.03/minute at each end for originating and terminating calls. This CCLC recovers part of the cost of the local loop not already recovered by the Subscriber Line Charge (SLC).

the LEC's CO. The AT&T and Sprint POPs are connected two ways: (1) through the public NAP and (2) through a private peering line.

[Figure-2: Relationship among CO, POPs, and NAP]



3. Duopoly Game Model in the Internet Access Market

3.1 Rationale for the Cournot Duopoly Model

The presentation below emphasizes the study of the downstream market, especially in a local rural area. We chose the Cournot model because the product is homogeneous. Each ISP produces a homogeneous Internet access service and the sum of their products equals the market output (Q): $Q = q_i + q_j$ where ISP_i produces q_i and ISP_j produces q_j.

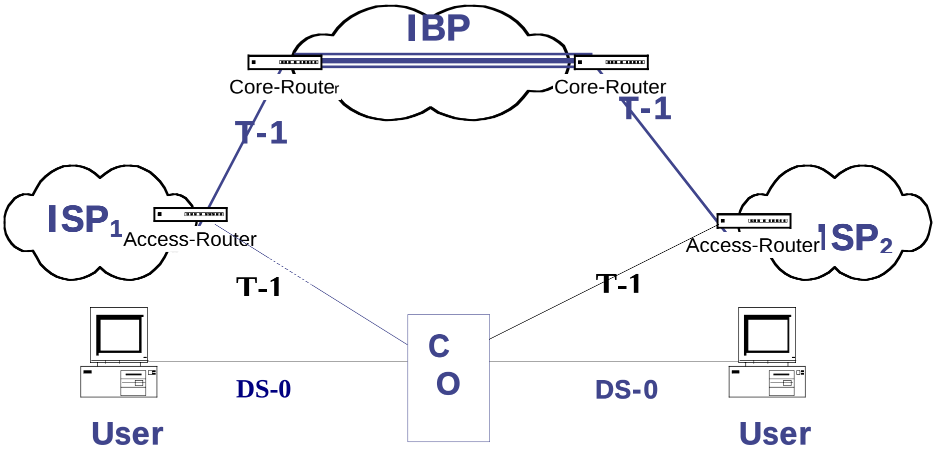
The duopoly game model is a useful first approximation for the analysis of an industry with limited competition. According to Greenstein (1999), 2069 counties (66%) out of 3139 in the U.S. had two or less ISPs in the fall of 1998; 87% of these 2069 counties are rural. While national ISPs usually concentrate in major urban areas and moderate density suburban and rural areas, low-density rural areas are usually served by local providers. In these low density areas, the national ISPs do not have local POPs so their customers would be forced to use measured service via a toll free number[25]. Thus, users of national ISPs have to pay a usage-based data communication fee in addition to the ISP's subscription fee. An important competitive advantage of local ISPs is the lower cost of access for the local population. (Greenstein, 1999) Thus, the duopoly model in the local Internet access market is reasonable in this context and can provide a foundation for the analysis of more complex markets.

3.2 Model Components and Basic Assumptions

In this model it is assumed that there are 2 duopolists (denoted ISP_1 and ISP_2) in the downstream market without the possibility of new entrants. Their objective is to maximize their profits, which are equal to its gross revenue minus its costs.

The following diagram illustrates components of the model and their connections. In this diagram, each ISP has two T-1 connections: one with CO and the other with the IBP.

[Figure-3: Components and Connections of the Model]



According to McCarthy (2000), 71% ISPs offer 56 Kbps dial-up service. We assume that ISP_1 and ISP_2 sell only 56 Kbps dial-up Internet access to their customers and the quality of their product is homogenous so that the users are indifferent to which ISP they use. We characterize the revenue and cost functions of each ISP below.

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[25] For example, AOL's usage price for 1-800 number (28.8Kbps) is 10 cents / minute.

3.3 The Revenue Functions of the Duopolists

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

We adopt the standard assumptions in the study of duopolistic competition with respect to the revenue generated from the subscribers: each subscriber pays a price (p_s) for the subscription, and that this price decreases with the number of subscribers. Following the Cournot model, the selling price of subscription of the two ISPs is the same and is determined by the market demand (Q), which is the sum of ISP$_i$'s demand (q_i) and ISP$_j$'s demand (q_j). Aassuming linearity, the demand function can be expressed as:

$$Q = b_0 - b_1 * p_s \qquad (1)$$

where $Q = q_i+q_j$, q_i = number of subscribers to ISP$_i$, i = 1,2,
p_s = price a subscriber pays, and b_0, b_1 = parameters.

Usually, the demand for Internet access service is considered to be insensitive to price. The reasons for price-insensitivity are:

(1) The communications demand consists of access and usage demand. Demand for access is considered less sensitive than demand for usage. Under flat rate pricing, the user's price includes both the usage and access price. But precisely speaking, because the quantity that users can consume is unbounded, there is no usage demand and the usage price is zero. (Wenders, 1987, p46). Therefore, Internet access service itself is insensitive to the price.

(2) The network externality effect. A potential user has a tendency to subscribe to the same ISP as her friends and family for better and reliable communications between them. Even if the monthly price is higher than she is willing to pay, she prefers to choose the ISP with as many acquaintances as possible.

(3) Customer lock-in effect. If someone wants to change his current ISP, he has to tolerate the inconvenience of notifying his correspondents of his new e-mail addresses. That is the

same as the local number portability[26] issue in the telephone industry, though services such as *hotmail*, *yahoo* and others minimize this effect by offering addresses that are not associated with ISPs.

If we make an inverse function of equation (1), the price for each subscriber to either of the two duopolists can be expressed as:

$$p_s = a_0 - a_1*(q_i+q_j) \qquad (2)$$

where $a_{0,}\ a_1$ = are scaling parameters and $a_0 = b_0/b_1$, $a_1 = 1/b_1$.

As a result, the subscription revenue of ISP_i is a product of p_s and q_i, i.e., p_s*q_i for i= 1,2.

The advertisement revenue is similar to that of newspaper and broadcasting industries. In reality, the number of hits on a specific advertisement in web pages determines payment for that advertisement, but in our model we simply assume that the monthly advertisement revenue per subscriber (p_a) is constant. This means that it can be simply characterized with the expression p_a*q_i for i= 1,2, and where p_a is the average monthly money per subscriber that advertisers pay to ISP_i.

The sum of the subscription and advertisement revenues is the total revenues of each of duopolists, which can be expressed as:

$$\begin{aligned} \text{total\_revenue}_i &= \text{subscription\_revenue}_i + \text{advertsement\_revenue}_i \\ &= p_s*q_i + p_a*q_i \\ &= [a_0 - a_1*(q_i+q_j)]*q_i + p_a*q_i \end{aligned}$$

for i = 1,2; j = 1,2; i ≠ j

3.4 The Cost Functions of the Duopolists

The cost structure of the Internet industry is characterized by large, up front sunk costs and near zero short run marginal traffic cost. It is well known that with congestion-free network the cost to carry or process an additional minute of Internet traffic approaches zero, because the

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[26] With the advent of local competition, telephone subscribers do not have to change their telephone number when they move from one local telephone company to another (2001,Moulton, p101)

incremental cost is near zero. (Frieden, 1998) 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. Two basic assumptions of the cost structure in our model are (1) large, up front 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), transit (c_t) and operation costs (c_o). Capital and transit costs are evaluated in similar ways, and are characterized simultaneously. Operating costs are treated differently and will be discussed below.

The capital costs are consist predominantly of the equipment that an ISP needs to provide its services, that is, mail-server, access layer router[27], and modem pool. The transit costs are payments by an ISP to an IBP for the right to use the IBP's facilities to transmit the communications of the ISP's subscribers. Although the price of bandwidth is decreasing substantially and the demand for T-3[28] lines and optical links are increasing, T-1 service still dominates in the market[29]. We assume that the IBP sells only T-1 connections to two ISPs, which is reasonable given that these are small ISPs serving a rural area.

It is assumed here that these two types of costs increase in equal steps. This means that an ISP to provide services to 0 to n–1 subscriber(s) must purchase equipment worth \$$c_c$ and must pay \$$c_t$ to an IBP for transit capabilities. For n to $2*n$-1 subscribers the cost increases to $2*(c_c+c_t)$, and so on. When the number of subscribers of duopolist i ranges between $k*n$ and $(k+1)*(n-1)$, the costs of the duopolists are $(k+1)*(c_c+ c_t)$.

The operating costs are assumed to be proportional to the number of subscribers. The operating cost includes the set-up cost for network connectivity such as login account, allocation of storage, user registration, etc. and maintenance costs for a single user of the network. These

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[27] There is three-layers router hierarchy: access layer, distribution layer, and core layer. Access layer routers have a function of access server connecting remote users to internetworks. Distribution layer routers are used to separate slow-speed local traffic from the high-speed backbone. Core layer is the backbone layer.

[28] The bandwidth of T-3 line is 45.736 Mbps, which equals to that of 28 T-1 lines.

[29] At year 2000, T-1:1.2 million, T-3:58,000, Ocx:14,000, Source: Gartner/Dataquest

types of costs increase as the number of users increase. This means that they can be represented with $c_o * q_i$, for i= 1,2.

3.5 The Profit Functions of the Duopolists

The equations presented above make it possible to express in the following way the profit functions for the duopolists:

$$f_i[q_i, q_j]=[a_0 - a_1*(q_i+q_j)]*q_i + p_a*q_i - (k+1)*(c_c+c_t) - c_o*q_i \qquad (3)$$

for $i = 1,2; j = 1,2; i \neq j$ and $k*n \leq q_i < (k+1)*n$,

where n is the number of subscribers to be accommodated by a set of equipment and one T-1 line.

3.6 Equilibrium Analysis

We can now rewrite each ISP's profit functions (from equation (3)):

$$f_1[q_1, q_2]=[a_0 - a_1*(q_1+q_2)]*q_1 + p_a*q_1 - (k+1)*(c_c+c_t) - c_o*q_1 \qquad (4)$$

$$f_2[q_1, q_2]=[a_0 - a_1*(q_1+q_2)]*q_2 + p_a*q_2 - (k+1)*(c_c+c_t) - c_o*q_2 \qquad (5)$$

Assuming that each duopolist determines q_i in maximizing profits, the first order conditions for optimization forms a system of two equations with two unknowns. The solution of this system gives the Nash equilibrium[30] quantities that the duopolists should produce. The following table shows the Nash equilibrium point and its corresponding profit. The equilibrium point and its profit of each ISP are the same as those of the other ISP because the payoff functions for the two duopolists are symmetric.

[Table-4: Equilibrium Point and its profit]

	Equilibrium Quantity	**Equilibrium Profit**
ISP$_i$	$q_i^* = (a_0 - c_o + p_a)/ 3a_1$	$f_1^* [q_i, q_j] = (1/9a_1)\{(a_0^2 - 9a_1(c_c+c_t)(1+k) - 2a_0(c_o - p_a) + (c_o - p_a)^2\}$

3.7 Sensitivity Analysis

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[30] A set of strategies is called a Nash equilibrium if, holding the strategies of all other firms constant, no firm can obtain a higher payoff (profit) by choosing a different strategy (1999, Carlton and Perloff, p157).

The Table 5 shows the derivatives of equilibrium quantity and profit for each parameter. The equilibrium quantity of each ISP increases according to the following rules: (1) the larger the number of potential users in a coverage area of each ISP ($\partial q_i^*/\partial a_0 > 0$), (2) the larger the advertisement revenue per subscriber ($\partial q_i^*/\partial p_a > 0$), and (3) the smaller the operation cost per subscriber ($\partial q_i^*/\partial c_o < 0$). The parameters such as c_c , and c_t do not give any influence to the equilibrium quantity, but as they increase, the equilibrium profit decreases ($\partial f_i^*/\partial c_c < 0$, $\partial f_i^*/\partial c_t < 0$).

[Table-5: Derivatives of Equilibrium Quantity and Profit]

Parameters	**Derivatives of Equilibrium Quantity**	**Derivatives of Equilibrium Profit**
a_0	$1/3a_1$	$\{2a_0-2(c_o-p_a)\}/9a_1$
a_1	$(-a_0+c_o-p_a)/3a_1^2$	$-(c_c+c_t)(1+k)/a_1 - (1/9a_1^2)\{a_0^2-9a_1(c_c+c_t)(1+k)-2a_0(c_o-p_a)+(c_o-p_a)^2\}$
c_c	N/A	$-(1+k)$
c_o	$-1/3a_1$	$(1/9a_1)\{-2a_0+2(c_o-p_a)\}$
c_t	N/A	$-(1+k)$
p_a	$1/3a_1$	$(1/9a_1)\{2a_0-2(c_o-p_a)\}$

4. Numerical Example

4.1 Parameters' Values

We apply numbers to the above model based on the demographics of the markets that we are studying. The following table presents the values of the parameters of the model.

[Table-6: Values of parameters]

Revenue Functions		**Cost Functions**	
Parameter	Value	Parameter	Value
a_0	50	c_c	\$9,000
a_1	0.01	c_t	\$1,000
p_a	\$8	c_o	\$1
p_s	$50 - 0.01*(q_1+q_2)$	n	1,000

The detailed explanation will be offered below.

4.2 Values of Revenue Parameters

According to Greenstein (1999), in 1996 the ISPs in rural counties with under 50,000 population were overwhelmingly local or regional, and in the Fall of 1998 the equivalent figure was 30,000. Extrapolating from this trend, we assume that the population in our model market is 25,000. On average, 20% of the population subscribe to dialup service -- the estimated number of dial-up users was 60 million[31] in 2001, compared with the population of the U.S. population of 280 million. Applying this percentage to our model market, we compute the number of potential user to be 5,000, which is the value of a_0.

The assumed price range of dial-up Internet access in the model is $0 to $50 per month. Some ISPs provide free Internet access service in exchange for viewing advertisements, so $0 per month is the lower bound. We further assume that the upper price limit is the monthly price ($50) of DSL Internet access service, which is superior to dialup. If the price of dial-up access is over $50 per month, a rational user would choose DSL service instead of dial-up service. Therefore, in our model, there are two specific points: $0 with 5,000 subscribers and $50 without users, which we use to determine the demand function.

Based on the above assumptions, we can write a market demand function like “Q =5,000 – 100P.” This demand function expresses that $1 increasing for local Internet access causes 100 users off from the Internet. Therefore, the value of a_1 is 100 with this demand function. This value is rather price sensitive, which conflicts a general idea of insensitivity of Internet access service. However, there are two supporting ideas for our assumption that the demand function that is rather sensitive to price:

(1) According to MacKie-Mason and Varian (1995), there are two types of users. One has a very high value for the service, but only wants to use a little of it, i.e. ASCII e-mail. The other user has a low willingness-to-pay for the service but wants to consume a very large

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[31] Including free users (10 millions) and paid users (49.6 millions) at the first quarter of 2001, Source: Telecommunications Report International Inc.

amount of it, i.e, teenager's downloading MTV videos. The demand function for high value users is insensitive to the price but the demand function for low value users is sensitive to the price because they are marginal users. After the advent of broadband Internet access service, the high value users for dial-up Internet access have been moving to the broadband market. Therefore, as times go by, the ratio of low value users in the dial-up Internet access market is increasing, which means the demand function is becoming more sensitive to the price.

(2) The U. S. GAO (2001, pp26-27) reports that the largest percentage of users (35%) indicates that price is the basis for their choice of dial-up ISP. But among the broadband users, the most common reason is that they selected their ISP because it was the company that provided the features and applications of most interest to them (23%), which means price is not a top priority to choose their broadband ISP.

For the value of p_a, in our model we simply assume \$8 per subscriber. According to the AOL's annual report year 2000, the advertisement revenue was \$2,000 million. If we assume that the number of AOL's subscribers at year 2000 is 20 million[32], the average monthly advertisement revenue was approximately \$8 per subscriber. Therefore, each ISP earns $\$8*q_i$ per month as an advertisement revenue. From this point of view, the number of subscribers is an important factor for the advertisement revenue of ISPs. This type of revenue can justify increase of capacity with a lower price of Internet access service to acquire more subscribers. In an extreme case, subscription price per month may be reduced to zero and have only the advertisement revenue source of income for an ISP.

The following graph shows the revenues of ISP_1 when the ISP_2's quantity is assumed to be fixed at $q_2 = 1{,}000$. The straight line displays the revenue from advertisement (p_a*q_1), and the lower curve displays the revenue from subscription (p_s*q_1) and the upper curve displays the total revenue ($p_a*q_1+ p_s*q_1$). The negative subscription revenue over 4,000 subscribers occurs because the price of subscription is negative because the total number of subscribers of both ISPs becomes greater than 5,000 at this point.

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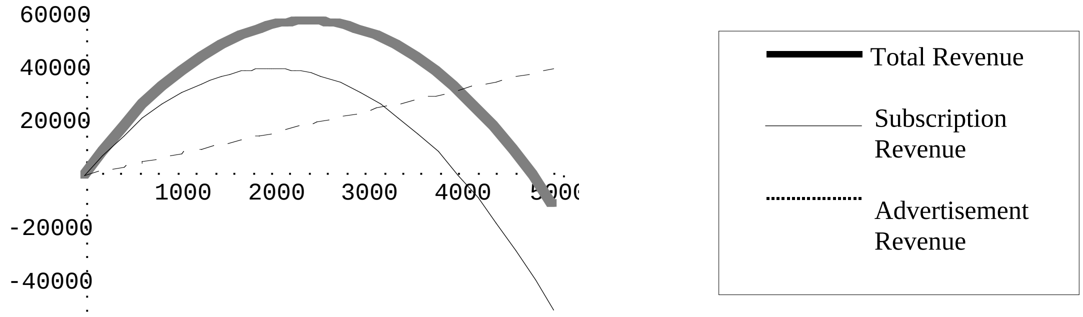
[32] This number is estimated from the fact that the number of subscriber at first quarter of 2001 is 22.7 millions.

[Graph-1: ISP-1's revenues when q2=1000]



4.3 Values of Cost Parameters

We assume that the value *n* is 1,000 subscribers. The calculation of 1,000 subscribers per one set of equipment and one T-1 line is made under the following assumptions:

(1) The capacity between CO and ISP modem pool is determined by a concentration ratio of 1:10 (the number of modems to the number of subscribers). That means 100 modems are enough to accommodate 1,000 subscribers.

(2) The capacity between the ISP and the IBP is determined by several factors. We already assume T-1 line and 56 Kbps modems as a basic connection, and we add 1:6 bandwidth ratio to this assumptions. The bandwidth ratio occurs because a user does not consume 56 Kbps for the duration of the connection. Therefore 162 (= 27*6) users[33] can access the Internet simultaneously at one time. Peak load time is used to calculate the Internet traffic capacity; the standard duration of peaks in the industry is assumed to be 4 hours a day. If we assume the average holding time per user is 30 minutes, the number of users[34] using the Internet during 4 peak hours is 1,296 users (=27*6*8). From a network engineering point of view, ISPs try to plan to have at least 20% excess capacity at their peak times, and therefore 1,000 subscribers per T-1 line is reasonable number.

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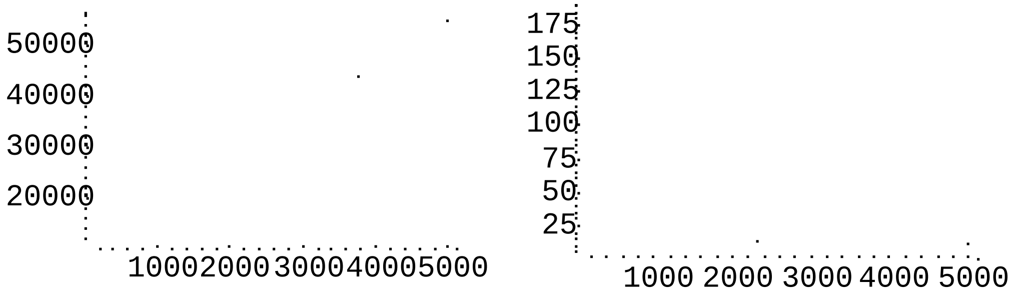
[33] 27 =1.544Mbps / 56 Kbps and 6 = 1:6 Bandwidth Ratio

[34] 8 = 240 minutes / 30 minutes

(3) It is assumed that the value of the equipment (c_c) is $9,000[35], which comes from the retail price of an access router, a server, and 100 modems in 2001. The value of transit cost (c_t) is assumed to be $1,000[36]. The operation cost (c_o) per subscriber is assumed to be $1. In summary, the ISP will spend $10,000 of capital and transit costs for the first 1,000 subscribers before it start its business and it will spend $1 for every subscriber. When the number of subscribers reaches 1,000, the ISP will spend another $10,000. Therefore, $10,000 can be viewed as a lump sum cost which is independent of q_1 and q_2.

The following graphs show total cost (=operation+capital+transit) and average cost (=total cost / number of subscribers). The marginal cost curve consists of two parts: At the points of 0, 1000, 2000, 3000, 4000 the marginal cost is vertical and the other point is marginal cost is horizontal with a value of $1.

[Graph-2: Total Cost and Average Cost]



4.4 Profit Functions with real numbers

The following mathematical forms are the numerical payoff functions of the ISP_1. The same format is applied to those of ISP_2 with the change of q_1 and q_2.

$$
f_1[q_1,q_2] = \begin{cases} q_1*(p_s + 8) - (1*q_1 + 1*10{,}000) \text{ if } 0 =< q_1 < 1{,}000 \\ q_1*(p_s + 8) - (1*q_1 + 2*10{,}000) \text{ if } 1{,}000 =< q_1 < 2{,}000 \\ q_1*(p_s + 8) - (1*q_1 + 3*10{,}000) \text{ if } 2{,}000 =< q_1 < 3{,}000 \\ q_1*(p_s + 8) - (1*q_1 + 4*10{,}000) \text{ if } 3{,}000 =< q_1 < 4{,}000 \\ q_1*(p_s + 8) - (1*q_1 + 5*10{,}000) \text{ if } 4{,}000 =< q_1 < 5{,}000 \end{cases}
$$

---

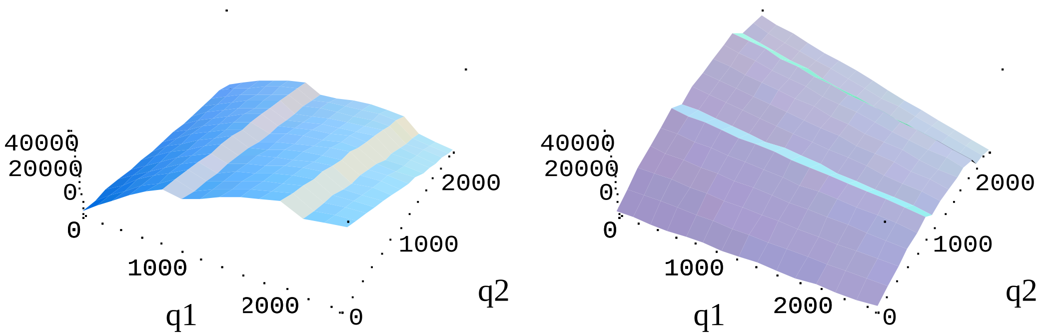
[35] A low-end access router ($3,000) + a low-end mail server with software ($3,000) + 100 Modems ($3000)

[36] The average price of T-1 transit service is $1,288 per month (www.ispworld.com/isp). The big IBP's price of T-1 is close to $2,000 per month and small provider's T-1 price is less than $1,000 per month

where $p_s = 5{,}000 - Q$ and $Q = q_1 + q_2$.

The following two 3D graphs show the profits of $ISP_1$and ISP_2 with the change of q_1 ($0 \leqq q_1 < 2{,}500$) and q_2 ($0 \leqq q_2 < 2{,}500$).

[Graph-3: Profits of ISP_1 and ISP_2]



If we see the profit graphs in detail, we can find that the graphs are not smooth at the points of 1,000 and 2,000, which are the points for additional investment needed.

4.5 Equilibrium Analysis

We assumed that each ISP maximizes profits for any number of subscribers that the other ISP is able to serve. This means that the maximum of the functions in $f_1[q_1,q_2]$ and $f_2[q_1,q_2]$ have to be obtained with respect to q_1 and q_2. Since the functions are not continuous at the quantities 0, 1000, 2000, etc., the maximization has to be obtained within each cost interval. This is done using the Kuhn-Tucker conditions for maximization with inequality constraints. These conditions are applied in two stages. In the first stage, the standard first order conditions of elementary calculus are used. In the second stage it is analyzed if the inequality constraints are satisfied, and if this is not the case, corrections are introduced.

Using the first order conditions for the maximization of each ISP's profit functions with the assumption that the number of subscribers of the other ISP is fixed, one obtains a system of two equations and two unknowns. The maximization values of q_1 and q_2 are obtained solving this system of equations.

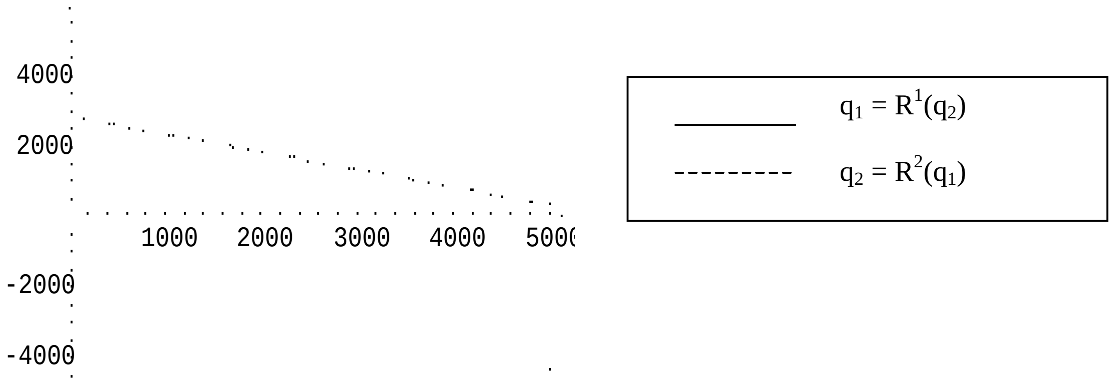
If we solve the above two equations ($f_1[q_1,q_2]$ & $f_2[q_1,q_2]$) simultaneously, the equilibrium quantity and its profit are:

$q_1^* = q_2^* = 1{,}900$ subscribers and

$f_1^* = f_2^* = \$16{,}100$

with reaction functions of $q_1 = -50*(-57+ q_2/100)$ and $q_2 = -50*(-57+ q_1/100)$. The following graph shows two reaction functions: (1) $R^1[q_2] = 2850 - 0.5*q_2$, and (2) $R^2[q_1] = 2850 - 0.5*q_1$. These two reaction functions satisfy the stability condition in the Cournot model, which is $|\partial q_i/\partial q_j| < 1$. In our reaction functions this value is $|\partial q_1/\partial q_2| = 0.5$. Therefore, the Nash equilibrium quantity exists in our model. The intersection point of two reaction functions is the equilibrium point, $(q_1^*, q_2^*) = (1900, 1900)$. However, that equilibrium point is only meaningful in the second cost intervals of each ISPs ($1000 \leqq q_1, q_2 < 2000$), because a 1,900 is one of the points of second cost interval and continuity is guaranteed only within this interval.

[Graph-4: Reaction Functions]



For other cost intervals, we used computational method based on the definition of Nash equilibrium, i.e., (1) fix q_1 value from n_0 to n_{999} ($n_0 \leqq q_1 < n_{999}$) and find the best response value of q_2 at each fixed q_1, and (2) do the same thing for q_2, i.e. fix q_2 value from m_0 to m_{999} ($m_0 \leqq q_2 < m_{999}$) and find the best response value of q_1 at each fixed q_2. (3) If n is equal to m, i.e., two ISPs stay in the same cost interval, the response values of two ISPs are always same because the profit functions are symmetric. For example, in the first cost interval ($0 \leqq q_1, q_2 < 999$), we find, whatever the value of q_1 and q_2 in this cost interval, the best response values of q_2 and q_1 are always 999. Therefore, the equilibrium point in this cost interval is $(q^1{}_1{*}, q^1{}_2{*}) = (999, 999)$. The superscript in this equilibrium point expresses the order of cost interval. (4) In the case of $n \neq m$, i.e., there are multiple response values. In this case, the way to find an equilibrium point is to compare the best response values of q_1 from (1) and the best response values of q_2 from (2), and then find the intersection point. The detailed data for finding equilibrium points are given in the appendix.

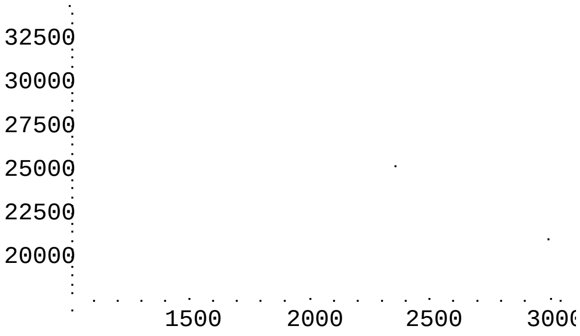
By this method, we obtain the following equilibrium table (Table 7)

[Table-7: Equilibrium points at each cost interval]

ISP$_2$ **ISP$_1$**	**< 1,000**	**< 2,000**	**< 3,000**	**< 4,000**	**< 5,000**
< 1,000	**999, 999**	999, 1999	999, 2350	999, 3000	850, 4000
< 2,000	1999, 999	**1900, 1900**	1850, 2000	1350, 3000	1000, 4000
< 3,000	2350, 999	2000, 1850	**2000, 2000**	2000, 3000	2000, 4000
< 4,000	3000, 999	3000, 1350	3000, 2000	**3000, 3000**	3000, 4000
< 5,000	4000, 850	4000, 1000	4000, 2000	4000, 3000	**4000, 4000**

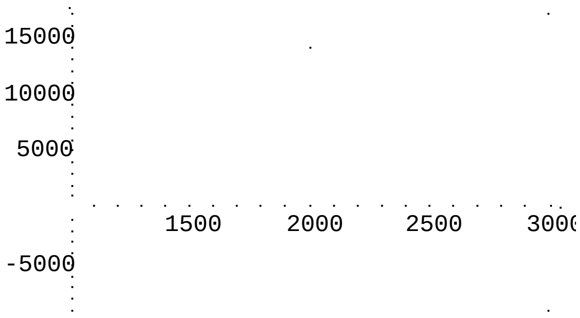
Whenever each ISP faces the number of subscribers over its capacity such as 1000, 2000, 3000, or 4000 subscribers, it has to decide whether to make an investment for new subscribers or not. If we assume that capacities of ISP_1 and ISP_2 are below 1,000 subscribers, optimal q_1 and q_2 are 999 subscribers whatever the other ISP's is, because profit is continuously increasing within this interval as the number of subscribers increases. Therefore, $(q^1{}_1{*}, q^1{}_2{*}) = (999, 999)$ is the local equilibrium point within an interval of $0 \leqq q_1, q_2 < 1,000$. We can assume that if the ISP_1 increases its capacity up to 1,999 subscribers, $q^2{}_1{*}$ is always 1,999 whatever the value of q_2 is, because profit of ISP_1 is still increasing in this interval ($1,000 \leqq q_1 < 2,000$, $0 \leqq q_2 < 1,000$). This time, local equilibrium point moves to $(q^2{}_1{*}, q^1{}_2{*}) = (1999, 999)$. However, from this point the ISP_1 does not want to increase its capacity any more because the profit turns into down abruptly at the quantity of 2,000 subscribers. The following graph illustrates this phenomenon.

[Graph-5: $f_1[q_1, 999]$ when $q_2 = 999$ and $1000 \leqq q_1 < 3000$]



At the current equilibrium point $(q^2{}_1^*, q^1{}_2^*) = (1999,999)$, the profit of ISP$_1$ $(f_1[q_1,q_2])$ is \$34,013 and the profit of ISP$_2$ $(f_2[q_1,q_2])$is \$16,993. However, at this time, the ISP$_2$ does not want to increase its capacity because the profit of ISP$_2$ $(f_2[1999,q_2])$ in the new cost interval $(1000 \leqq q_2 < 2000)$ is lower then the current profit $(f_2[1999, 999]= \$16,993)$. The following graph illustrates this situation. The horizontal line in this graph represents \$16,993. This is the case for first mover's advantage. Once one of ISPs increase its capacity, it is better off than the other when the profit is increasing.

[Graph-6: $f_2[1999,q_2]$ when q_1=1,999, and $1000 \leqq q_2 < 3000$]



However, if ISP$_1$ and ISP$_2$ increase their capacity simultaneously, then the new equilibrium point is $(q^2{}_1^*, q^2{}_2^*) = (1900, 1900)$. From the third to the fifth cost interval $(2,000 \leqq q_1, q_2 < 5,000)$, each ISP does not want to increase their capacity because of decreasing profits. Once the two ISPs choose the equilibrium point in the second cost interval, i.e. (1900, 1900), even though first interval's equilibrium point (999, 999) gives more profit to each ISP, they can't go back to that point, because the capital cost in the Internet industry is irrecoverable sunk cost.

The following payoff matrix table is made by the level of investment, i.e. \$10,000 for capital and transit costs for up to 999 subscribers and \$20,000 cost for 1,000 to 1,999 subscribers. Each cell represents ISP$_1$'s and ISP$_2$'s profits of equilibrium point at the first and second cost intervals. If we try to find the Nash equilibrium among the four cells, there are two equilibriums in the matrix: (ISP$_1$, ISP$_2$) = (\$10,000, \$20,000) and (ISP$_1$, ISP$_2$) = (\$20,000, \$10,000). If ISP$_1$ chooses \$10,000, ISP$_2$'s best response is \$20,000 because (f$_2$[999,999] = \$26,983) < (f$_2$[999,1999] = \$34,013). If ISP$_1$ chooses \$20,000, ISP$_2$'s best response is \$10,000 because (f$_2$[1999,999] = \$16,993) > (f$_2$[1900,1900] = \$16,100). The same logic can be applied to ISP$_2$. If ISP$_2$ chooses \$10,000, ISP$_1$'s best response is \$20,000 because (f$_1$[999,999] = \$26,983) < (f$_1$[1999,999] = \$34,013). If ISP$_2$ chooses \$20,000, ISP$_1$'s best response is \$10,000 because (f$_1$[999,1999] = \$16,9893) > (f$_1$[1900,1900] = \$16,100).

[Table-8: Payoff Matrix of Selected Cost Interval]

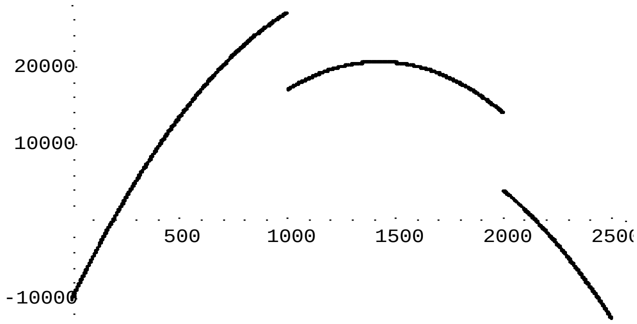
ISP$_2$ **ISP$_1$**	\$10,000 for 0 ~ 999 subscribers	\$20,000 for 1,000 ~ 1,999 subscribers
\$10,000 for 0 ~ 999 subscribers	f$_1$[999,999] = \$26,983 f$_2$[999,999] = \$26,983	**f$_1$[999,1999] = \$16,993** **f$_2$[999,1999] = \$34,013**
\$20,000 for 1,000~1,999 subscribers	**f$_1$[1999,999] = \$34,013** **f$_2$[1999,999] = \$16,993**	f$_1$[1900,1900] = \$16,100 f$_2$[1900,1900] = \$16,100

If two ISPs decide their new investment simultaneously without knowledge of the other's payoff, we can easily assume that equilibrium points of each interval are on the locus of q_1=q_2 because the profit functions are symmetric. The table 9 shows local equilibrium points at each interval. Among them the maximum profit point is (q_1*, q_2*) = (999, 999). The graph 7 shows ISP's profit curve when q_1=q_2.

[Table-9: Equilibrium Point and its profit at each interval]

Interval	Min	Max	q1*	q2*	f1*	F2*
1	0	999	999	999	26,983	26,983
2	1000	1999	1900	1900	16,100	16,100
3	2000	2999	2000	2000	4,000	4,000
4	3000	3999	3000	3000	-49,000	-49,000
5	4000	4999	4000	4000	-142,000	-142,000

[Graph-7: Profit curve when $q_1 = q_2$]



4.6 Collusion between ISP_1 and ISP_2

Because ISP_1 and ISP_2 are in the same market area and their profit structure is symmetric, it would be possible for them to collude, earn monopoly profits and then divide it equally. The monopoly profit function can be expressed by

$$F[Q]=\{Q*(5{,}000-Q)/100 + 8*Q\} - \{(k+1)*10{,}000 + Q\} \qquad (6)$$

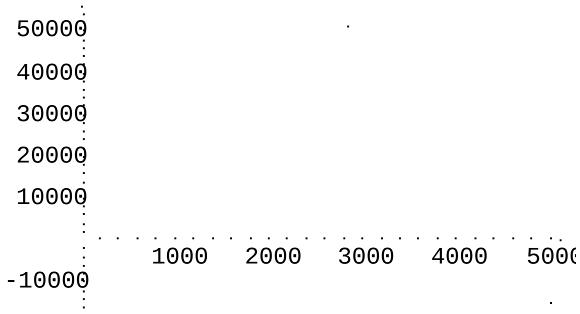
for $k*1{,}000 \leq Q < (k+1)*1{,}000$, k= 0, 1, 2, 3, 4,

Q = market quantity,

F = monopoly profit.

The graph 8 shows the above profit function curve.

[Graph-8: Monopoly Profit Curve]



The following table 10 shows the maximum monopolist’s profit at each interval. In summary, the optimal point of collusion case is where the Internet access market produces 1,999 quantities with a profit of $53,983, which means that each ISP produces 999.5 quantities equally with a profit of $26,991.5 that is the same as equilibrium point in the first cost interval[37].

[Table-10: Max profit in case of collusion like a monopolist]

Interval	Min	Max	K+1	(cc+ct)*(k+1)	Q*	Q*/2	F*	F*/2
1	0	999	1	10000	999	499.5	36,963	18,481.5
2	1000	1999	2	20000	**1999**	**999.5**	**53,983**	**26,991.5**
3	2000	2999	3	30000	2850	1425.0	51,225	25,612.5
4	3000	3999	4	40000	3000	1500.0	41,000	20,500.0
5	4000	4999	5	50000	4000	2000.0	18,000	9,000.0

- **F*: Monopoly profit**
- **Q*: Monopoly Quantity**

4.7 Welfare Analysis

According to Carlton and Perloff (1999, p71-72), one common measure of welfare from a market is the sum of consumer surplus (CS) and producer surplus (PS). This measure of welfare is the value that consumers and producers would be willing to pay and to produce the equilibrium quantity of output at the equilibrium price. CS is defined as the amount above price paid that a consumer would willing spend to consume the units purchased. In our model, CS can be written by “0.5*(50 – P)*Q”, where P = (5000-Q)/100 is the market price and Q is the market quantity, which is equivalent to the shaded triangle in the following graph.

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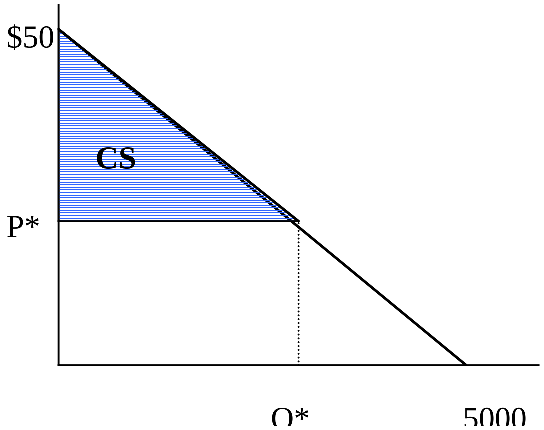
[37] Only the integer value is useful for the sales of Internet connectivity, i.e. 999.5=999.

[Graph-9: Consumer Surplus]



PS is defined as revenues minus variable costs, or equivalently, profits plus the fixed costs. (Varian, 1999, p382) The variable cost is dependent on the level of output while the fixed cost is independent on the level of output. In our model, within each cost interval, transit and capital costs are not dependent on the number of subscribers. Therefore, in the short-run we can assume transit and capital costs are fixed and operation cost is variable. A cell of the following table shows sum of profits of two ISPs (f1+f2), fixed costs of ISP_1 and ISP_2 (FC1, FC2) and the producer's surplus (=f1+f2+FC1+FC2). If we assume that each ISP will make an investment for new capacity only if it is expected to have a positive profit, the 11 shaded cells in the following table are feasible areas for both ISPs.

[Table-11: Producer Surplus of Each Cost Interval]

ISP2 ISP1	< 1,000	< 2,000	< 3,000	< 4,000	< 5,000
< 1,000	**f1+f2=53,966** **FC1=10,000** **FC2=10,000** **PS=73,966**	**f1+f2=51,006** **FC1=10,000** **FC2=20,000** **PS=81,006**	**f1+f2=38,735** **FC1=10,00** **FC2=30,000** **PS=78,735**	**f1+f2=18,023** **FC1=10,000** **FC2=40,000** **PS=68,023**	f1+f2= -18,775 FC1=10,000 FC2=50,000 PS=41,225
< 2,000	**f1+f2=51,006** **FC1=20,000** **FC2=10,000** **PS=81,006**	**f1+f2=32,200** **FC1=20,000** **FC2=20,000** **PS=72,200**	**f1+f2=21,225** **FC1=20,000** **FC2=30,000** **PS=71,225**	f1+f2=-1,275 FC1=20,000 FC2=40,000 PS=58,725	f1+f2= -35,000 FC1=20,000 FC2=50,000 PS=35,000
< 3,000	**f1+f2=38,735** **FC1=30,000** **FC2=10,000** **PS=78,735**	**f1+f2=21,225** **FC1=30,000** **FC2=20,000** **PS=71,225**	**f1+f2=8,000** **FC1=30,000** **FC2=30,000** **PS=68,000**	f1+f2=-35,000 FC1=30,000 FC2=40,000 PS=35,000	f1+f2=-98,000 FC1=30,000 FC2=50,000 PS=-18,000
< 4,000	**f1+f2=18,023** **FC1=40,000**	f1+f2=-1,275 FC1=40,000	f1+f2=-35,000 FC1=40,000	f1+f2= -98,000 FC1=40,000	f1+f2=-181,000 FC1=40,000

	FC2=10,000 **PS=68,023**	FC2=20,000 PS=58,725	FC2=30,000 PS=35,000	FC2=40,000 PS=-18,000	FC2=50,000 PS=-91,000
< 5,000	f1+f2=-18,775 FC1=50,000 FC2=10,000 PS=41,225	f1+f2=-35,000 FC1=50,000 FC2=20,000 PS=35,000	f1+f2=-98,000 FC1=50,000 FC2=30,000 PS=-18,000	f1+f2=-181,000 FC1=50,000 FC2=40,000 PS=-91,000	f1+f2=-284,000 FC1=50,000 FC2=50,000 PS=-184,000

The social welfares (SW) of the 11 shaded cells are calculated by summation of CS and PS. The following table is sorted by the social welfare value (last column).

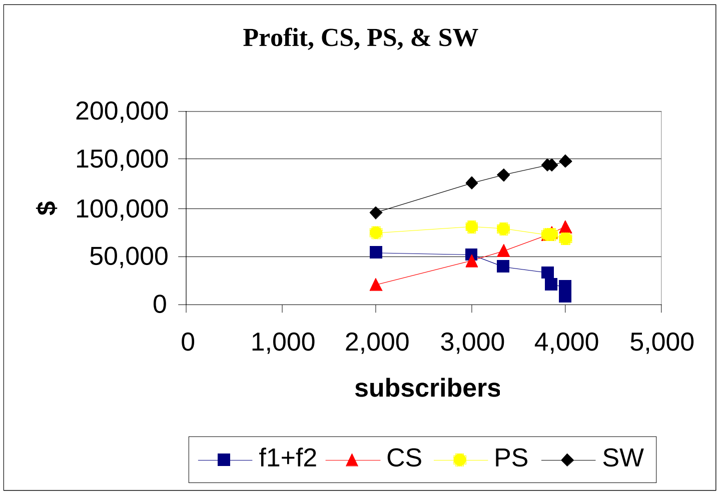
[Table-12: CS, PS, and SW]

q1*	q2*	Q	P	f1+f2	Consumer Surplus	Producer Surplus	Social Welfare
2,000	2,000	4,000	10.00	8,000	80,000	68,000	**148,000**
3,000	999	3,999	10.01	18,023	79,960	68,023	**147,983**
999	3,000	3,999	10.01	18,023	79,960	68,023	**147,983**
2,000	1,850	3,850	11.50	21,225	74,113	71,225	**145,338**
1,850	2,000	3,850	11.50	21,225	74,113	71,225	**145,338**
1,900	1,900	3,800	12.00	32,200	72,200	72,200	**144,400**
2,350	999	3,349	16.51	38,735	56,079	78,735	**134,814**
999	2,350	3,349	16.51	38,735	56,079	78,735	**134,814**
1,999	999	2,998	20.02	51,006	44,940	81,006	**125,946**
999	1,999	2,998	20.02	51,006	44,940	81,006	**125,946**
999	999	1,998	30.02	53,966	19,960	73,966	**93,926**

- f1+f2 = Sum of both ISPs' profits
- Q = q1*+q2* and P = (5000 – Q)/100

The following graph is built by the above table: X-axis is the market quantity (column 3) and Y-axis is the sum of profits, CS, PS, and SW (column 5,6,7, and 8). As the number of subscribers in the market increase, the CS and SW increase and sum of profits decreases. PS also decreases except for the last row. Those imply that rural small ISPs are reluctant to make a new investment after both reach the initial equilibrium, but large output level is good for consumers and society. Stimulating new investment in the rural area is the point that the Internet industry policy maker has to consider.

[Graph-10: Profits, CS, PS, & SW]



5. 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 models that provide results that might be generalizeable to the larger markets in some cases.

In this paper, we show that the unique cost and revenue structure of the Internet access market has a significant influence on the equilibrium results. The optimal production quantities of ISPs are maximized within the first cost interval, which might be a tendency to under-invest in capacity if each ISP was fully aware of future consequences. In reality, the average number paying dial-up users per ISP without the top 10 dial-up ISPs is roughly 800[38]. That means they may not have large enough subscriber base to accumulate money to invest for potential future users. In our analysis, the maximum profit of each ISP in its optimal equilibrium point is the same as the half of monopoly profit. Therefore, there is no incentive for additional investment to expand their business causing “over-subscription”, which seems to be common in the Internet access market.

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[38] {The number of paying dial-up users (=49.6 millions) - Sum of top 10 dial-up ISP users (=44.3 millions)} / Number of ISPs in the downstream market (=7,000) = 800 / ISP

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[Appendix: Finding Nash Equilibrium in each Cost Interval]

(1) Nash equilibrium at the same cost intervals, for example $0 \leqq q_1$, $q_2 < 999$. The followings are the response values (q_2*) of ISP$_2$ when q_1 changes from 0 to 999. Whatever the value of q_1 is, q_2* is always 999.

q_1	q2*	$f_2(q_1, q_2^*)$	$f_1(q_1, q_2^*)$
==	==	========	========
00	**999**	36962.99	-10000.00
01	**999**	36953.00	-9953.00
02	**999**	36943.01	-9906.02
03	**999**	36933.02	-9859.06
04	**999**	36923.03	-9812.12
…	**…**	**…**	**…**
995	**999**	27022.94	26874.70
996	**999**	27012.95	26901.80
997	**999**	27002.96	26928.88
998	**999**	26992.97	26955.94
999	**999**	26982.98	26982.98

The followings are the response values (q_1*) of ISP$_1$ when q_2 changes from 0 to 999. Whatever the value of q_2, q_1* is always 999. As a result, the equilibrium point in this interval is (q^1_1*, q^1_2*) = (999, 999).

q_2	q_1*	$f_1(q_1*, q_2)$	$f_2(q_1*, q_2)$
00	**999**	36962.99	-10000.00
01	**999**	36953.00	-9953.00
02	**999**	36943.01	-9906.02
03	**999**	36933.02	-9859.06
04	**999**	36923.03	-9812.12
…	…	…	…
995	**999**	27022.94	26874.70
996	**999**	27012.95	26901.80
997	**999**	27002.96	26928.88
998	**999**	26992.97	26955.94
999	**999**	26982.98	26982.98

(2) The Nash equilibrium in different cost intervals. The followings demonstrate the procedure of finding equilibrium point with different cost intervals.

For example, (a) in the case of $0 \leqq q_1 < 1{,}000$ and $4{,}000 \leqq q_2 < 5{,}000$, (q^1_1*, q^5_2*) = (850, 4000) is the equilibrium point of two best response values.

q_1	q_2*	$f_2(q_1, q_2*)$	$f_1(q_1, q_2*)$
4000	**850**	**-2775.00**	**-16000.00**
4001	849	-2783.50	-15991.50

q_2	q_1*	$f_1(q_1*, q_2)$	$f_2(q_1*, q_2)$
849	4000	-15960.00	-2775.01
850	**4000**	**-16000.00**	**-2775.00**
851	4000	-16040.00	-2775.01

(2) In the case of $1{,}000 \leqq q_1 < 2{,}000$ and $2{,}000 \leqq q_2 < 3{,}000$, (q^2_1*, q^3_2*) = (1850, 2000) is the equilibrium point of two best response values.

q_1	q_2*	$f_2(q_1, q_2*)$	$f_1(q_1, q_2*)$
1849	2000	7020.00	14224.99
1850	**2000**	**7000.00**	**14225.00**

1851	2000	6980.00	14224.99

q_2	q_1^*	$f_1(q_1^*, q_2)$	$f_2(q_1^*, q_2)$
==	==	========	========
2000	**1850**	**14225.00**	**7000.00**
2001	1849	14206.50	7018.50

(3) In the case of 1,000 $\leq q_1 < 2{,}000$ and 3,000 $\leq q_2 < 4{,}000$, $(q^{2}_{1}{}^{*}, q^{4}_{2}{}^{*})$ = (1350, 2000) is the equilibrium point of two best response values.

q_1	q_2^*	$f_2(q_1, q_2^*)$	$f_1(q_1, q_2^*)$
==	==	========	========
1349	3000	530.00	-1775.01
1350	**3000**	**500.00**	**-1775.00**
1351	3000	470.00	-1775.01

q_2	q_1^*	$f_1(q_1^*, q_2)$	$f_2(q_1^*, q_2)$
==	==	========	========
3000	**1350**	**-1775.00**	**500.00**
3001	1349	-1788.50	513.50