INDEX Project Proposal (Draft)

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Abstract

This (draft) document proposes the INDEX Project. There are a few holes in this version. (A later version, submitted to the National Science Foundation, is much more complete; unfortunately, the NSF version isn't available online.) Despite the holes, this version provides an interesting historical perspective of INDEX.

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INDEX: The Internet Demand Experiment*

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Abstract

Successful growth of Internet and other sophisticated network services requires providers to offer combinations of service quality and price that meet the needs of a diverse user population. But to do this providers need to understand the structure of user demand. Market data cannot provide this information, because service providers today offer a very narrow range of quality-price combinations. Providers would also find it difficult to offer variable quality and price using their current systems.

This is a proposal for an experiment to measure the demand over a wide range of service quality and price structures. INDEX—the Internet Demand Experiment—has four objectives:

1. Estimation of user demand for Internet access as a function of quality of service (QoS), price structure, and application;
2. Demonstration of an end-to-end system that provides network access to a diverse group of users at attractive quality-price combinations;
3. Development of a prototype system that can be scaled to serve the demand for remote network access from Berkeley students, faculty and staff on a user-financed basis; and
4. Exploration of the use of the prototype system for "distance learning."

The two year-long experiment will recruit a representative group of 160 users from the Berkeley campus. The experiment will cost $170 per month per user—well below commercial charges for comparable service.

The estimated price and quality elasticities of demand can be used by providers to offer services that meet the needs of a much larger user group than is willing to purchase Internet access under current charges. The data will reveal changes in user demand over time, the correlation between user application and service demand, and the formation of discrete market segments. The experimental data can test hypotheses concerning the market for quality-differentiated ATM services.

The University can use the INDEX prototype system to improve network access on a user-financed basis. This will be a "market test" for network services with variable quality and price.

The experiment will also reveal the network costs of university distance-learning projects now underway. This will help determine the financial viability of these projects.

If facilities are available, INDEX will be enlarged to test CATV access and to include non-university participants.

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1 Summary

Future growth of Internet and other sophisticated network services made possible by ATM networks will depend upon how these services are marketed. Two related marketing decisions are involved: the division of services into market segments, and the pricing structure of each segment. Even a cursory observation of network user behavior shows a wide diversity in user needs, familiarity, and demand or willingness to pay. On the supply side, network technology can also now support a wide range in the quality of network service.

Successful marketing of network services therefore requires providers to offer combinations of service quality and price that match user needs. But to do this providers need to understand the structure of user demand. Such information is lacking at present: current market data would be very costly to collect, and were it to be available it would not provide this information because network services offered today span a very narrow range of quality-price combinations.

A market experiment that can reveal this information at a modest cost is difficult to conduct: it requires a geographically concentrated pool of diverse users, a network that offers a range of service qualities and flexible pricing structures, a system that monitors user behavior, and complex econometric analysis. The experiment must be conducted over a sufficiently long period so that users can learn how to use those services and adapt their behavior accordingly.

This is a proposal for an experiment to measure the demand for network services. INDEX—the Internet Demand Experiment—has four objectives:

1. Measurement of user demand for Internet access as a function of quality of service (QoS), pricing structure, and application;
2. Demonstration of an end-to-end system that provides access to a diverse group of users at attractive price-quality combinations;
3. Development of a prototype system that can be scaled to serve the demand for remote network access from all Berkeley students, faculty and staff on a user-financed basis; and
4. Exploration of the use of the prototype system for "distance learning."

Demand structure

The two year-long experiment will recruit a representative group of 160 users from the Berkeley campus community. (The experiment will be enlarged to test CATV access and to include non-University participants if it is practicable to do so.) Users will select network services from a menu of QoS-price offerings. The menu will be changed eight times over two years in order to measure demand for a wide range of combinations of QoS, price and user characteristics.

INDEX data will be analyzed to estimate price and quality elasticities. The elasticities will provide a basis for the design of commercial Internet service offerings. The data will reveal information about how demand varies with user experience, the correlation between user application and service demand, and whether users form discrete market segments. The data will be able to test hypotheses about the structure of the market for variable-quality ATM services.

Stated preference surveys will be conducted alongside the experiment. Comparison of this data with the "revealed" preferences of INDEX will permit calibration of stated preference surveys for use as a tool to investigate the market for network services.

System demonstration

The experiment will demonstrate a single system that offers: variable service quality-price combinations that meet the needs of a diverse user population; an automated billing system that also gives the user control over service selection; and a remotely operated network monitoring and management system. The per user cost of the demonstration system will be well below commercial charges for comparable services.

If facilities can be acquired, the experiment will be expanded to demonstrate CATV access and to include non-University participants. This is dependent upon cooperative arrangements with a CATV-access and other ISP providers.

University benefits

Limited campus resources now constrain remote Internet access through a highly congested pool of 28.8, 14.4 Kbps and lower-speed modems. INDEX can serve as a prototype for expanding access on a user-financed basis. The prototype will integrate with the existing campus network management and billing systems. If successful, the prototype can be scaled to serve virtually the entire campus of 40,000 students, faculty and staff. Users would pay for this alternative if they prefer it to the free but congested means of network access. The entire campus community will benefit as a result. User demand for services of the prototype system also provides a "market test."

Distance learning

Several distance-learning projects are now underway in the University. To be established as regular campus programs, these experiments must be self-financed. INDEX will reveal the network cost component of these programs. This is not a crucial objective of INDEX, but it will demonstrate the use of the prototype system for purposes other than Internet access.

INDEX status

As of May 1996, the status of INDEX is as follows. The access network has been designed. Software systems for monitoring user behavior, the network-user interface, and billing have been developed. The eight sub-experiments have been designed; certain design parameters may be modified as data is collected and analyzed using software developed in Berkeley's Econometrics Laboratory. Outstanding econometricians have offered assistance in data analysis and interpretation. A trial experiment involving an eight-unit apartment building is underway to test the INDEX software.

The experimental system must be integrated with the campus network which is managed by the University's Information Systems & Technology (IS&T) department. The responsible authorities of IS&T have approved the design, agreed to cooperate with the experiment, and helped in preparing this proposal. The University's Accounts Receivable department will handle user accounts. The experiment involves people, and so the Academic Senate's Human Subjects Committee must approve the protocol describing user participation. The Committee has been contacted, and will act on the INDEX protocol at their next meeting in August, 1996.

The two-year experiment will cost $670,000, based on equipment list prices and published tariffs. This amounts to a fully loaded cost of $170 per user per month, on average. The cost comprises two elements: leasing of ISDN, DS-1 and DS-3 lines, and acquiring equipment. The experiment will be implemented in two stages, of roughly equal cost. The second stage, to start five months after the first, will be launched only if the first stage proceeds satisfactorily. This staging halves the financial risk.

INDEX is a project of the Center for Multimedia Networking, whose co-Directors are Professors Martin Vetterli and Jean Walrand. Financial support for INDEX will come from industry and state and federal agencies. Initial support is expected from Pacific Telesis and CISCO. Professor Pravin Varaiya is the Principal Investigator of INDEX. Richard Edell, PhD student in Electrical Engineering and Computer Sciences, designed the network and most of the software. Harish Chand, PhD student in Economics, together with Richard Edell, designed the experiments. Edell is a networking expert, Chand is an expert in experimental economics.

Hal Varian, Dean of the School of Information Management and Systems and Professor of Economics and the Haas Graduate School of Business, and Dan McFadden, Chair of the Department of Economics, will advise the INDEX researchers on data analysis and experimental design.

Proposal details

Section 2 discusses three barriers in the current model of Internet Service Provision (ISP) that limit Internet use and exclude a significant fraction of potential users. INDEX will estimate the magnitude of those limits and suggest changes in the current ISP model to overcome those limits. Preliminary but suggestive data for

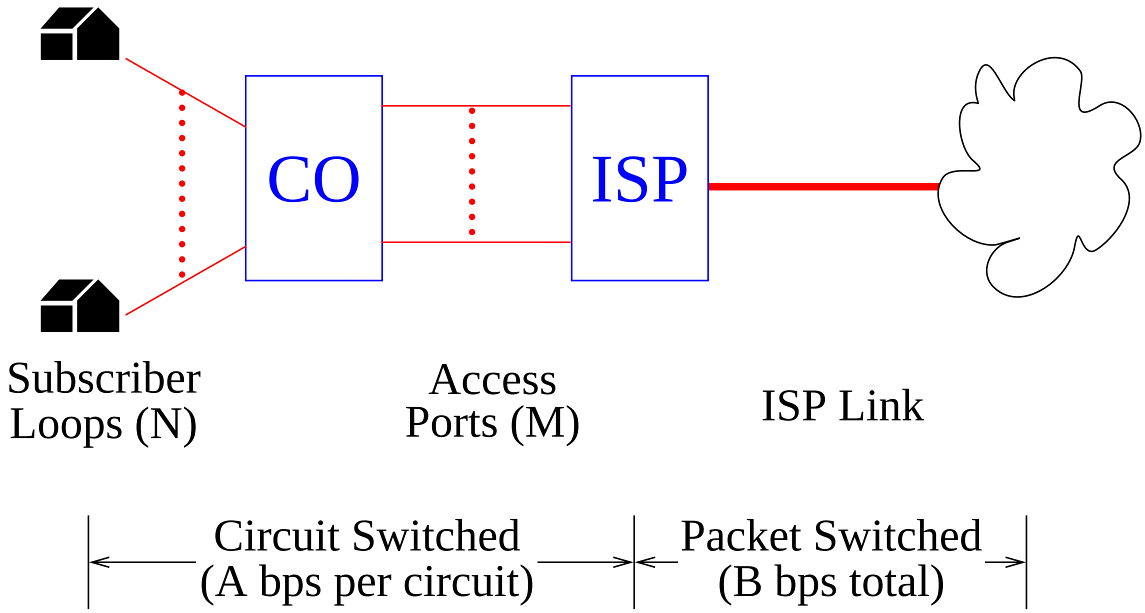

Figure 1: Traditional ISP Resource Model.

the Berkeley network are presented.

Section 3 presents the economic case for INDEX. It draws upon the relevant economics literature to support the proposed experimental design.

Section 4 summarizes the goals, nature and timing of a series of eight sub-experiments that will produce data about user responses to service quality and prices.

Section 5 describes the technology employed by INDEX. This includes: the INDEX access network, TCP/IP usage accounting and network QoS emulation.

Section 6 gives a cost estimate for INDEX. It also discusses how the access network might be economically sized if it were built by the Information Systems & Technology department to serve the campus community.

Section 7 discusses possible future INDEX projects, including CATV access and non-university participation.

Appendix A describes the experiments in detail.

Appendix B describes the network engineering for the INDEX access network in detail.

2 Three Barriers

Figure 1 depicts the current Internet Service Provision (ISP) model. Subscribers access the ISP node with a circuit-switched connection, usually over telephone lines through a 28.8 Kbps or lower speed modem. Access may be blocked because of the limited size of the modem pool. The ISP node has a high-speed, packet-switched link to the Internet backbone network (the "cloud" in the figure). The model erects three barriers that restrict market *depth* and market *width*. Market depth is measured by the range of service quality offered and the variety of applications that can be run over the network. Market width is measured by the fraction of potential users that are paying subscribers.

One barrier is created by the inability of the current version of IP (IPv4) to provide service quality guarantees, making some applications impractical to run over the Internet. This barrier will be removed if IP is suitably upgraded (e.g., IPv6 can provide guarantees) or if ATM networks are widely deployed. INDEX does not address this barrier.[1]

The second barrier is raised by the fixed, low-speed, dedicated link through which subscribers access the ISP node. Higher speed access is available, but it is too expensive.[2] More importantly, this inflexible, low-speed access constrains user choice: for example, a subscriber does not have the option to pay more for higher-speed access for the duration of an interactive application.

The third barrier arises from the common form of ISP charges: a fixed access charge plus a fee proportional to usage, measured by volume or connect time. (Some ‘free’ connect time may be bundled into the fixed access charge. Charge for ‘content’, such as access to databases, is ignored in this discussion.) The fixed charge excludes the occasional or novice user, shrinking market width.

The first and second barriers limit market depth as service quality, needed for some applications, cannot be guaranteed. The second and third barriers combine to limit both depth and width. Depth is restricted because subscribers cannot run applications that temporarily require higher speed access for which they are willing to pay. Width is limited because only those potential users whose needs are met by the prevailing structure of charges will actually become subscribers. Users with a structure of demand that is not well-served by the fixed access speed or the form of charges, will not become subscribers.

How people become subscribers is not known. They are likely at first to be occasional users. After some experience, they may become habitual users. The current form of ISP charges may exclude the occasional user who is a potential subscriber. Evidence of the transformation from familiarity into habitual use comes from the CommerceNet/Nielsen survey (CommerceNet/Nielsen, 1995). The survey shows that Internet users are more likely to have higher incomes and Internet access at work. Another analysis of the CN/Nielsen data finds four distinct market segments—which the analysts name ‘Hard Core’, ‘Regular’, ‘Lapsed regular’, and ‘Infrequent’—dependent on type of Internet access, computer ownership and length of computer use (Hoffman, Kalsbeek and Novak, 1996).

The CN/Nielsen data comes from a telephone-based survey of 4,200 respondents. Its purpose was to determine the characteristics (age, income, education) of those with Internet access, those who browsed the Web, and those who have used the Web to shop. INDEX will obtain much more detailed data. It will track the pattern of use (amount of time spent and data transferred, applications run) of the user group over time. Unlike the CN/Nielsen survey, however, INDEX will not be projectable to the US and Canada.

In summary, the second and third barriers serve to exclude many applications and potential users, restricting market depth and width. Preliminary data from the Berkeley campus suggest the existence of this restriction, but it is not possible to estimate its magnitude. INDEX will gauge this magnitude by estimating quality and price elasticities, i.e., the change in patterns of applications and network usage as a function of changes in access quality and prices.

2.1 Preliminary Berkeley Data

Remote access to the Berkeley network fits the ISP model of Figure 1. The campus acts as the Internet Service Provider. It is connected to the Internet backbone via a 45 Mbps, DS-3 link. Remote users access the network through a pool of modems. The pool consists of 128 28.8 Kbps modems limited to faculty use, 32 19.2 Kbps modems limited to a 15-minute connection time (Warhol in Figure 2), 256 14.4 Kbps, 112 2.4 Kbps and 60 1.2 Kbps modems for a campus community of 40,000. The modem pool is accessed via phone lines to the Berkeley Central Office, from which the campus Centrex service is provisioned. Most modem

[1] However, a companion experiment involving a high-performance network emulator seeks to measure user subjective response to video applications over a network with variably quality guarantees.

[2] For example 56 Kbps Frame Relay access costs XXX, 128 Kbps ISDN access costs YYYY, and 1.5 Mbps DS-1 access costs ZZZZ, according to Pacific Bell Internet. These costs do not include additional charges for circuit termination equipment or the additional customer premises equipment. See (Pacific Internet, 1996).

connections use Home IP (PPP or SLIP).

Figure 2 shows the typical daily pattern of modem use. The faculty pool is the least congested. All high-speed (14.4, 19.2) modems are used continually from 8.00 am until past 2.00 am. Evidently, the large demand is curtailed by blocking and resulting time delay, by reducing access speed which limits the range of applications[3], and by flat-rate pricing of dedicated 28.8 Kbps modems. Users whose demand is not met by this modem pool either suppress their demand or travel to campus for LAN access. The total number of TCP connections shows a daily cycle with a peak (in January, 1995) of 1,200 and a trough of 550. More interestingly, there is a large variation in per-host usage even within the ten most active sub-domains. Data from the Electrical Engineering and Computer Science Department sub-domain shows that 20 percent of users account for 93 percent of total bytes exchanged between the campus and the rest of the world (Edell, McKeown and Varaiya, 1995).

The following tentative conclusions may be drawn from the Berkeley data:

- The heavily congested use of the modem pool indicates a willingness to pay for better access;
- The daily pattern of peaks may be relieved by time-of-use pricing;
- The wide diversity in patterns of use across sub-domains and by user suggests that the market for network access should be segmented.

3 Economic Rationale

To maximize the economic worth of current network resources and to optimally deploy future resources, pricing decisions should be based on empirical information about consumer valuation of quality-differentiated services and response to alternative tariff structures. This information can help to: (a) allocate resources on the basis of user valuation rather than rationing through waiting times or chance; (b) provide correct signals for future network expansion; and (c) identify different market segments and target them for cost recovery or profit maximization. The public utility pricing literature can lend theoretical direction to the empirical research.

Internet service provision shares many features with public utilities. For example, telephone, electricity, and Internet provision all face declining marginal costs, usage with pronounced temporal patterns, and congestion. Despite these shared features, the pricing structures for utilities and Internet access are very different. While telephony and electricity have been innovative in adopting time-of-day pricing, priority pricing, multi-part tariffs and self-selecting schedules, such pricing innovation has been absent from Internet pricing. Internet access is typically priced through a flat rate access charge and uniform usage fees. Such pricing practice reduces the economic worth of Internet service provision.

The public utility pricing literature of relevance to Internet is more fully discussed in Train (1991), Brown and Sibley (1986), and Wilson (1993). That discussion explores two themes: (a) pricing resources so that they are allocated on the basis of user value rather than an arbitrary rationing scheme such as waiting time; and (b) efficient pricing of resources to recover costs. The first theme leads to methods to maximize the economic value of network resources, the second seeks to differentiate the resources on the basis of quantity and quality so as to appropriate this economic value.

The discussion below addresses congestion, usage-based and time-of-use and priority pricing, multi-part tariffs, and market segmentation.

Proposals for Internet congestion pricing are of little use to Internet service providers as they address congestion in the Internet "cloud" or propose congestion prices that are theoretically desirable but impractical.[4]

[3] Data not presented here shows that most data transfer occurs using FTP, which does not require high speed.

[4] Shenker, Clark, Estrin, and Herzog (1996) discuss some of these issues. Congestion pricing focused on local pricing

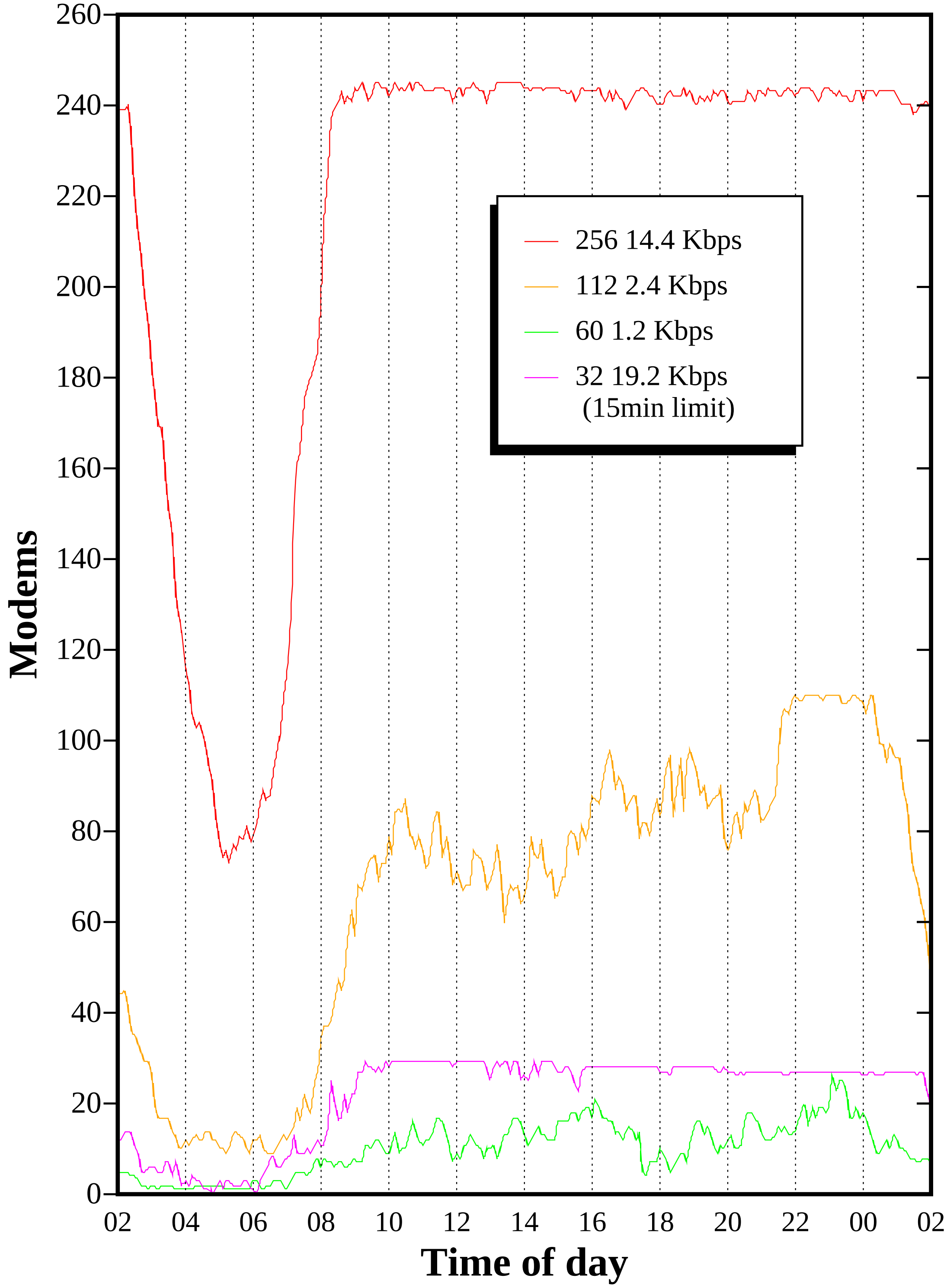

Figure 2: Campus modem utilization, April 18, 1996.

Typically, there is only a very weak link between Internet prices and individual user traffic. As a consequence, users who occasionally need high bandwidth are either forced to lease over-provisioned dedicated lines, risk the vagaries of the performance of shared resources, or forego the desired application altogether. Congestion-sensitive prices can increase the overall value of the network by making available resources when needed for high value applications.

Usage-based pricing such as per-byte charges of traffic needs study, because a small fraction of users typically generate a large fraction of the traffic. Pronounced temporal variation in Internet usage suggests adoption of time-of-use pricing. Priority service such as used in electricity provision can also increase welfare.

These variations in tariff structure all lead to more efficient allocation of available network resources provided the price structure is properly selected on the basis of demand information.

Prices differentiated on the basis of quantity or quality can segment the market and maximize profits. The provision of Internet services involves large fixed costs and low marginal costs, so marginal cost pricing alone does not permit cost recovery. Estimates of price elasticities of access demand and usage demand are needed to determine where best to raise price over marginal cost in order to recover costs.

When demand for Internet access varies among the population, as the CN/Nielsen and Berkeley data indicate, a menu of service offerings can be improved through either a multi-part tariff or a set of self-selecting tariffs. In general, for any tariff with N distinct price blocks, there is a Paerto-superior tariff with N+1 blocks. Such tariff designs could appeal to heavy users who desire a low marginal cost and are willing to pay a high fixed fee, *without* deterring the occasional user, thus expanding the subscriber base.

Empirical research can determine whether individuals have strong preferences regarding tariff structures, whether they make rational choices when given more than one alternative tariff, and the amount of variation in usage and valuation. Self-selecting tariffs may also be used to segment the market in terms of willingness to pay. Thus, it is possible to improve on the typical service offerings by block rate prices or self selecting tariffs, using estimated demand elasticities.

When pricing a product line, cross-price elasticities are needed to analyze the interrelationships of different market segments. For example, appropriate pricing of different service quality levels needs to account for the "cannibalization" by one service of the demand for other services. This implies the need to understand how individuals make tradeoffs between price, quantity, and quality for different applications and times of day.

In summary, empirical research about the structure of Internet demand would be extremely valuable in developing service offerings that cater to a diverse population. This information could be used in the market analysis for new services and the optimal pricing of existing services. Such information would focus on users' perceptions of service quality, their valuation of service quality as measured by the different price elasticities of demand, and how these elasticities vary with user demographics and service quality.

4 Experimental Design

4.1 Goals

A series of eight experiments will be conducted to investigate the effects of alternative price and service combinations on consumer behavior, welfare, and satisfaction. These experiments will seek to examine the issues raised in the previous section and identify they key behavioral parameters needed for pricing decisions. The questions which are addressed may be grouped into: (1) ascertaining user value for price-based resource allocations; (2) behavioral response to alternative pricing structures for cost recovery and profit maximization.

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policies would be more useful. An important question is whether local policies can approximate theoretically superior but less practical schemes such as the smart market mechanism of Mackie-Mason and Varian (1994).

4.1.1 User Valuation of Network Resources

Users' Perceptions of Quality

In order to accommodate diverse users, quality- and price-differentiated services must be offered in a cost-effective manner. A user-network interface must be designed through which users can request service-price combinations that match their applications and need.

The question is to determine how users view quality? Along which dimensions do users notice performance differences and what tradeoffs are they willing to make? To offer variable-quality service, Internet service providers must know which service characteristics are important. Expanding capacity along unperceived dimensions would divert funds from more productive areas.

The first set of experiments will examine these issues. The value which users place on different resource levels for each of the network points contained in Figure 1 will be measured in the first three experiments: (1) the speed of connection to the internet cloud; (2) value of reliability in connection establishment; (3) value of priority service.[5]

This information will aid future network provisioning decisions. For example, it is possible that contention for shared modems is more important than contention for shared bandwidth.

This information will also help inform the what incentives the price structure should provide. For example, congestion based prices requires users and administrators to know the loss of user perceived value from congestion. The degree to which congestion needs to be discouraged or the markup charged to priority service depends on the degradation of user value due to user contention. If the perceived network degradation from congestion is substantial, then congestion related pricing (such as time-of-day, traffic-based, or priority-based charges) can rationalize the allocation of network resources and increase the value of the network. These are issues which warrant systematic study.

4.1.2 Response to Alternative Price Structures

Information on user valuation of resources will also identify the degree and nature of the user heterogeneity. Differentiating types and levels of service through pricing is advantageous whenever their is variation in price elasticity of demand and price exceeds marginal cost. A standard proposition in economics is that, in order to recover network fixed cost, the percentage markup over marginal cost should be in inverse proportion to the price elasticity of demand (see,e.g., Wilson 1993). Since users are heterogeneous in their usage, elasticity information is needed to determine how services should be priced.

The next set of experiments (4-9) will examine user behavior under alternative pricing structures. As mentioned in the previous section, a large body of economic literature pertaining to public utility pricing suggests that the proper choice of tariffs a diverse group of users can be charged according to the value which they place on service. Users who place a high value can be charged an accordingly high price, while those with a lower valuation would be charged a lower price. These experiments will examine how users respond to different menus of tariff choices, such as time-of-day pricing, two-part pricing, and per-byte pricing. If substantial variation exists among users, and if users are sufficiently sophisticated in their decisions, then self-selecting tariffs differentiated on the basis of quantity and quality may segment the market on the basis of willingness to pay.

[5] A related question which will be examined what information would best facilitate these decisions? Time-of-day electricity pricing experiments show that information provision may play an influential role in revealing consumers' desired behavior (Sexton et al, 1989). Just as not all dimensions of quality are equally important, much information will be viewed as extraneous. It is important to determine the information that individuals can best use. For example, would some users rather face prices in terms of price per packet rather than price per minute? How often should the information be updated? If individuals do not change their setting often, then an interface which allows them to set and continue default settings may be of greater value.

Table 1: Summary of Experiments

Exp #	Description	Duration	Academic Calendar
0	Practice Period	2 Weeks	Fall Semester
1	Value of Connection Speed	12 Weeks	Fall Semester
2	Value of Access Reliability	4 Weeks	Spring Semester
3	Value of Priority Service	6 Weeks	Spring Semester
4	Demand under Traffic-Based Charges	12 Weeks	Fall Semester
5	Tariff Selection	10 Weeks	Fall Semester
6	Time of Use and Peak Shifting	8 Weeks	Spring Semester
7	Demand under Flat Rate Pricing	12 Weeks	Summer
8	Two Part Tariff Design	10 Weeks	Spring Semester

4.2 Procedures

Berkeley students, faculty and staff will be recruited to participate in the experiment. Subjects will receive a subsidized dedicated ISDN connection in exchange for agreeing to connect through the Billing Gateway and pay usage-based prices. A series of experiments involving different methods and levels of prices will be conducted in order to investigate the questions outlined above.

4.2.1 Subject pool

The University of California at Berkeley provides a ready group of experimental subjects. The campus modem pool is highly congested. The potential to receive a high-speed dedicated connection to the campus network should make participation attractive. No similar service currently exists.

The availability of this subject pool should reduce the costs of setting up the experiment and ensuring continued participation. As a condition of participation, subjects must agree to allow their use of the network to be monitored. This will include not only their usage from the ISDN connection provided through the experiment, but their use via the campus modem pool as well.

Since the experiment will last roughly two years, students expecting to complete their degree before the end of the experiment will not be recruited. Otherwise, both undergraduate and graduate students will be recruited with the goal of obtaining a suitable variation in field of study, expected computer usage, travel distance to campus, and demographic characteristics.

As described more fully in the following section, a stated preference survey experiment will be conducted prior to and after the main experiment. Completion of this survey will be a condition of application for participation in the experiment. In addition to eliciting attitudes and preferences between hypothetical service choices, the survey will gather the necessary demographic information to select a suitable distribution of subjects. The revealed demand from INDEX will serve to calibrate the stated preference experiment.

4.2.2 Sequence of experiments

Once the network and billing system are in place, a series of eight experiments will be conducted to examine the perception and valuation of service quality. A trial or "practice" period of 2-4 weeks will allow the subjects to gain familiarity with the billing interface and experimental procedures. During the practice period, users will be given pricing information but they will not be charged. Table 1 summarizes the experiment.

Experiments 1-3 explore how the resources shown in Figure 1 affect users' valuation of Internet access. In particular, Experiment 1 varies access link bandwidth (A); Experiment 2 varies access port contention (N and M); and Experiment 3 introduces interference over the packet switched link.

Experiments 5-8 explore how users react to different pricing schemes. In most of these experiments, users will compare an alternative pricing schemes with a flat rate scheme. Experiment 4 introduces the users to per-byte pricing; experiment 5 offers users a self-selecting tariff where they may choose per-minute, per-byte, or a combination of the two pricing methods. Experiment 6 will gauge how much traffic can be shifted away the peak by time of use pricing. Experiment 7 will determine the usage and value under a flat-rate pricing system. Lastly, experiment 8 examines user self-selection into different two-part tariffs.

Each of these experiments is described in detail in Appendix A.

Table 1 shows the tentative schedule for the series of experiments. Rotation groups will be used to account for timing effects related to the academic calendar as well as to investigate a wider range of treatment levels. Experiment One, Elasticity of Demand, will be repeated during the summer when some of the subjects are likely to be out of town.

4.2.3 Analysis

Randomized assignment of treatment groups allows many more questions to be answered than possible in non-experimental settings. Without controlled experiments, one typically is forced to turn to non-experimental market data. If such data exists at all, it is usually plagued by problems of self-selection. Rather than observing exogenous variation in the variables of interest such as price, one typically observes price and service offerings in to which individuals self-selected on the basis on expected outcome (Hausman, 1985). Therefore, econometric analysis is greatly complicated by the need to undo the effects of self-selection before the relationships of interest can be isolated. While econometric methods may be used to account for self-selection bias, they are often sensitive to embedded parametric assumptions, or have stringent data requirements for non-parametric approaches.

The basic model to be estimated involves the relationship between price of the different service offerings and the quantity of service use,

$$Q_{ijt} = f_j(P_{it}, Z_i) + \epsilon_{ijt},$$

where i indexes individuals, j indexes the types of usage, and t denotes the time period. The types of usage include the different service offerings (e.g., connection speed) as well as use of the network outside the subsidized connection (such as on-campus use).[6] P_{it} represents the set of prices faced by individual i in period t, allowing for cross-price effects. The vector Z includes individual-specific demographic and possibly attitudinal variables. The unobserved factors influencing usage are captured by the error term, ϵ_{ijt}, which may be specified to allow an appropriate covariance structure for temporal effects, service specific effects, and individual specific effects. Through the specification of a functional form for f consistent with economic theory and the distribution of the error term, the price elasticity of usage may be measured and used to determine optimal price schedules and bundles for the different services.

4.2.4 Stated preference experiment

Economists traditionally prefer to infer preferences from data based on actual choices rather than attempting to measure preferences directly. The former approach is often referred to as revealed preference analysis, while the latter is often termed stated preference analysis. While revealed preference methods provide more reliable incentives to accurately represent ones preferences, stated preference methods have several benefits.

[6] Different applications used (e.g., HTTP, FTP, email) may be treated either as separate services or as additional covariates.

Repeated measurements are possible under various situations whereas market data typically only present data on the observed choice. This not only permits more efficient estimation of preference parameters, but also avoids problems of self-selection bias. The relevant choice attributes can be uncorrelated by design in stated preference experiments whereas they are typically correlated in market data. Lastly, data can be produced relatively cheaply when market data may be either insufficient or nonexistent. Whereas market data cannot directly predict response to new alternatives, preferences can be elicited for these new choices.

For these reasons, a stated preference experiment will be conducted alongside the main experiments. This data should nicely complement the observed behavior. In the context of the pricing experiment, the stated preference data will have several additional benefits. Preferences are likely to change (or become more distinct) over the course of the experiment. A stated preference experiment conducted before and after the experiment will provide a good basis for measuring preference change. This data will also permit the calibration of stated preference results to revealed preference data. This information would permit future stated preference experiments regarding new product offerings and market analysis to be performed and calibrated to actual market behavior (Atherton and Train, 1995). With this calibration, market forecasting may be performed through inexpensive stated preference methods without great risk of measurement bias.

The stated preference experiment will collect data on user's preferences for different service offerings. These offerings will vary over the dimensions examined in the usage experiments—service quality (connection speed, access reliability), and tariff components (fixed fee, connection time, traffic charges, time-of-use discounts). It will also examine other dimensions not part of the usage experiments such as customer support and content provision. Attitudinal information will also be elicited for background information as well as possible incorporation into econometric models (Train, McFadden and Goett, 1987).

The stated preference experiment data will be analyzed using a random parameters logit model using statistical software developed in the economics department at UC Berkeley. This model is extremely useful for market analysis of new product offerings and market segmentation analysis by measuring the distribution of willingness to pay for different product attributes (Revelt and Train, 1996).

5 INDEX Technology

The INDEX Access Network is designed to provide dedicated access (with predictable and controllable QoS) between the subject sites and the INDEX Project central site. At the central site, individual subject usage is metered by a locally developed Internet billing system. In addition, the QoS is degraded according to the quality level selected by the subjects. The following sub-sections describe each of these components of INDEX Project technology.

5.1 INDEX Access Network

The INDEX Access Network, shown in Figure 3, utilizes several Pacific Bell services. Most of the subjects will access the network with ISDN services. (e.g. subjects living within the Berkeley, Albany and Oakland central office areas will receive ISDN service.) These ISDN services will provide access speeds of 128Kbps. Some subjects will be served by 56Kbps DDS circuits[7]. (e.g. subjects living within the San Francisco central office areas will receive 56Kbps DDS service.) A small number of subjects will access the network with 56Kbps Frame Relay services[8].

The INDEX Access Network is described in greater detail in Appendix B.

[7] We will use DDS circuits in areas where the Pacific Bell central office serving areas are small (e.g. San Francisco).

[8] Frame Relay will be used when an *established* ISDN or DDS subject moves to an area where we are unable to economically provide ISDN or DDS service.

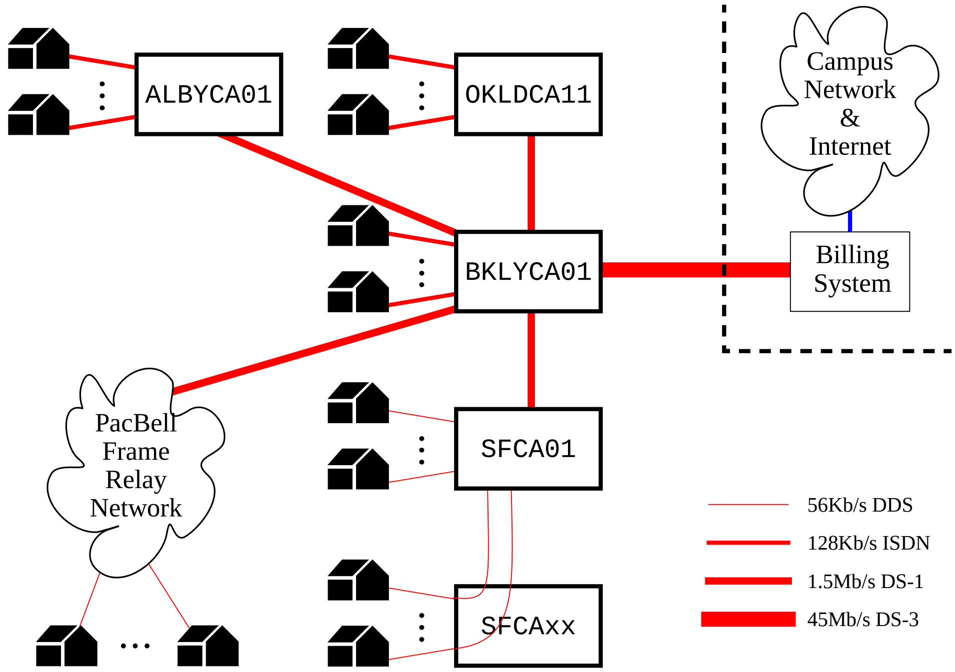

Figure 3: INDEX Access Network.

5.2 TCP/IP Usage Accounting

The INDEX Project will use a locally designed Internet billing system. This billing system functions as a connection aware Internet router. Connection establishment is postponed while the user is contacted, verifying in a secure way that they are prepared to pay. By presenting the user with cost and price information, the system can be used for cost recovery and to encourage efficient use of network resources. The system requires no changes to existing protocols or applications.

The *operation* of the billing system is described fully in (Edell, McKeown, Varaiya, 1995). The INDEX Project implementation of the billing system differs substantially from the implementation described in the paper. For the INDEX Project, we will substitute a Netscape/WWW interface for the purchasing agent software. By using a Netscape/WWW interface, we can describe the goals of the individual sub-experiments to the subjects. Additionally, the "Billing Gateway" (BGW) functionality is implemented differently than was described in the paper. For INDEX, the BGW is implemented in the SunOS kernel. This implementation permits the Network QoS Emulation capability that is described in the next sub-section.

5.3 Network QoS Emulation

Conducting an experiment such as INDEX requires controlling the QoS delivered to the subjects. Today's Internet is generally incapable of controlling QoS. To facilitate INDEX, we have implemented an enhanced BGW. This enhanced BGW can selectively degrade the performance of individual TCP connections[9]. This degradation may take the form of limiting bandwidth, delaying datagram delivery or discarding datagrams. The level of degradation may be quickly altered in response to subject choices or experimentally controlled random processes.

Admittedly, INDEX cannot provide a "better" QoS than the baseline undegraded QoS. However, much of

[9] Classes of connections may also be degraded. For example, all connections on behalf of a given subject.

our subject pool is accustomed to a congested 14.4Kbps modem pool for accessing the campus network. In addition, many of the services that our subjects would like to access are in fact campus services for which there would be little other sources of degradation. Therefore, we believe that INDEX is reasonably capable of controlling the QoS delivered to the subjects.

6 Funding Requirements

All the dollar figures in here need to be reworked...

INDEX project costs are dominated by access network costs. Access network costs depend on experiment length and the number and location of experimental subjects. Our current plans call for a two year experiment with approximately 160 subjects[10]. The experiment will be staged in two phases to facilitate deployment of the access network and to reduce financial risk. The total (two-year) cost for the INDEX access network is approximately $680,000. These costs broken down by phase and type in Table 2. These costs are explained in much greater detail in Appendix B.

Table 2: INDEX access network cost summary.

	Services[a]	Equipment[b]	Total
Phase 1	$56,250	$166,425	$222,675
Phase 2	$248,807	$147,000	$395,807
Phase 2 Run-out	$62,859	–	$62,859
Total	$367,916	$313,425	$681,341

[a]Pacific Bell service installations and recurring charges.
[b]Mostly CISCO equipment.

6.1 IS&T Network Access Costs

The INDEX access network is engineered to provide *dedicated access* between the subject homes and the central site. This is not the usual Internet access arrangement and would represent over-engineering for nearly any Internet access provider including U.C. Berkeley's IS&T department. This section discusses how IS&T might provision an ISDN access network, the costs of such a network, and the cost recovery possibilities.

One possible relationship between IS&T and a "customer" is as follows:[11]

- The customer provides their own ISDN equipment.
- IS&T installs a *Centrex* ISDN BRI in the customer's home (replacing the customer's existing analog phone service).
- IS&T provides the central resources.

[10]Seventy to be served by the Berkeley central office; 70 by the nearby Albany and Oakland central offices; and 20 by the more distant San Francisco or Walnut Creek central offices.

[11]An alternative arrangement makes sense for low intensity users. The less intense users will be better off using Pacific Bells Home-ISDN BRI services. This service costs $16/month less than Centrex ISDN BRI service but imposes a $0.01/minute cost for daytime usage (per B-channel, 8am-6pm, Monday-Friday). Therefore, a user who connects to the campus for fewer than 80 B-channel minutes/business day will be better off with Home-ISDN. These less frequent users can utilize the same central campus resources as the Centrex ISDN BRI users.

- The customer pays IS&T for the BRI, off-Centrex phone calls, and a usage sensitive charge for the accessing IS&T's central resources.

Under this arrangement, the cost to the customer is composed of fixed and variable components. The fixed cost component would be approximately $500 for the equipment and BRI installation, and $40/month for BRI service. Naturally, the variable cost component would depend on individual customer usage and the pricing schedule. The cost, to IS&T for the central resources would be approximately $42/month per B-channel. This includes service installation and equipment costs amortized over three years. Design of a pricing schedule which recovers IS&T's costs is one of the goals of the INDEX project.

6.2 ISP Access Cost Comparison

The service quality delivered by the INDEX Project access network is equal to the quality of several commercial ISP offerings (i.e. flat-rate 128 Kbps access). These commercial ISP offerings cost the end-user about $375/month while the INDEX Project access network costs $150/month. Frame Relay (56 Kbps) service costs about $400/month. These cost figures assume an 36 month ammortization for equipment.

the following economics don't seem very compelling for an IS&T offering. I'll have to do some thinking about this. I think that perhaps 1/hr day peak usage may not support an IS&T network.

The service quality delivered by the IS&T network is simlar to many commercial ISP offerings (i.e. usage sensitive 64 or 128 Kbps access). The commercial ISP offering would cost the end-user about $90/month while the IS&T service would cost about $70/month. These cost figures assume an 36 month ammortization for equipment and 1 hour of daytime usage per-day.

7 Future Experiments

The experiments described in this proposal are the beginning of we hope to be many Internet demand experiments. This section of this document is intended to describe the outlook for future INDEX experiments. None of these future experiments are included in the budget over-viewed in Section 6 or in the budget detailed in Appendix B.

7.1 General Population Subjects

The INDEX Project results can be better calibrated to the general population if our subject pool were expanded to include general population persons. While including these subjects increases the administrative burden for the project (subject recruitment, billing & payment processing, resolution of University policy issues, etc.), we believe that the additional burden can be managed once the U.C. affiliates experiment is underway.

We believe that general population subjects can be adequately served with 56 Kbps DDS service because their existing Internet access options do not include the "free" 14.4 Kbps access available to U.C. affiliates. This DDS service does not require the geographical density that our ISDN services require. In addition, we expect general population subjects to participate in the experiments year-round. Therefore, we anticipate being complete the INDEX experiments in about half the calendar time that it takes for U.C. affiliates.

All together, these factors lead us to believe that we could add 200 general population subjects for approximately $300,000 over two years. This extension would structured as two groups of 100 subjects. The first group would be studied in the first year and then the experimental resources would be relocated to serve the second group.

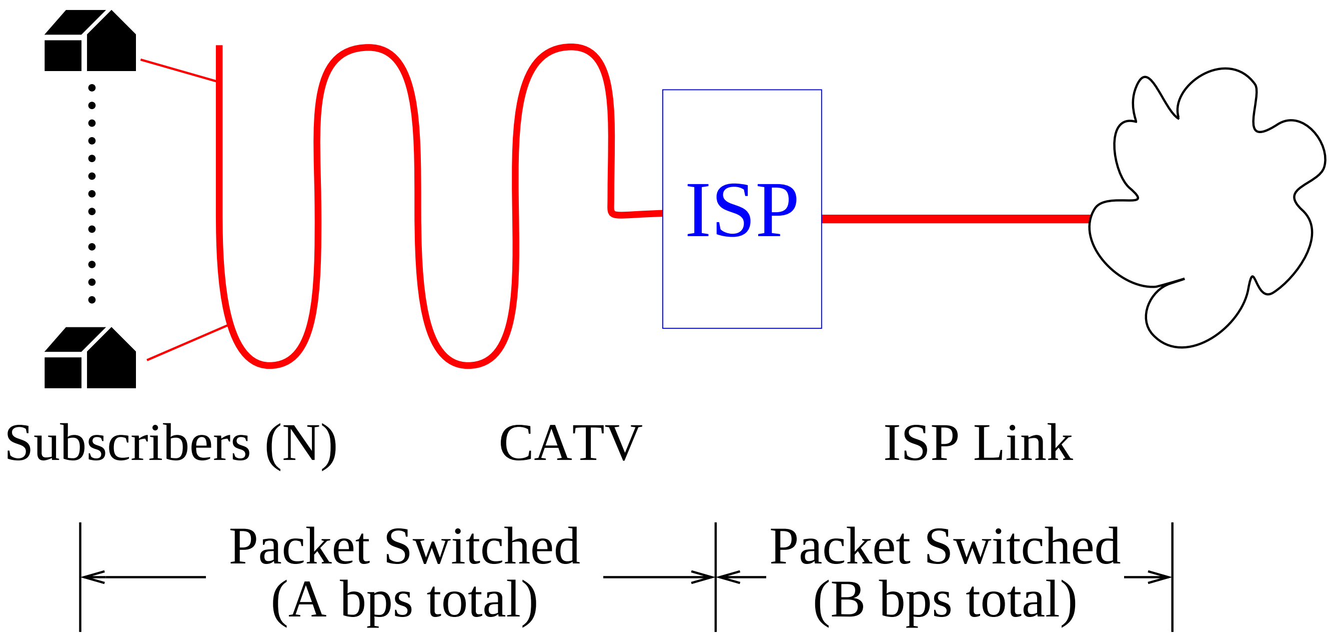

Figure 4: Cable Television ISP Resource Model.

7.2 CATV Access Network Resource Allocation

Internet access provisioned over cable television (CATV) facilities presents several challenges. While most of the technical challenges of CATV Internet access are being addressed, the issues of resource allocation and pricing appear to be overlooked. This INDEX Project extension works from the resource model depicted in Figure 7.2.

Conducting this kind of experiment will require relatively high-bandwidth access in the subjects' homes. We are therefore, talking to CATV Internet access providers and equipment vendors. Alternatively, T-1 or ADSL technology could be used but we expect the cost to be prohibitive.

In addition to addressing CATV pricing and resource allocation issues, this experiment will be able to explore how individuals value the more bandwidth intensive applications.

7.3 Information Providers

All of the previously discussed INDEX Project experiments have focused on individuals as information consumers. Another class of experiments explores how individuals value Internet quality as information providers. Obviously, in the context of information providers, many of the "individuals" will be, in fact, businesses. (Conducting such an experiment presents many administrative problems; this discussion does not attempt to address these problems.)

This class of experiments might involve creating web publishing systems which include usage metering/billing mechanisms for recovering costs from information publishers. To understand how Internet quality affects how value in this context, we would offer publishers quality choices and create some mechanism for emulating service qualities.

References

[1] Atherton, T. and Kenneth Train. 1995. "Rebates, Loans, and Customers' Choice of Appliance Efficiency Level: Combining Stated- and Revealed-Preference Data." *Energy Journal*, Vol. 16, No. 1, pp. 55-69.

[2] Bohn, Roger, Hans-Werner Braun, and Stephen Wolff. 1994. "Mitigating the coming Internet crunch: multiple service levels via Precedence."

[3] Cocchi, Ron, Scott Shenker, Deborah Estrin, Lixia Zhang. "Pricing in Computer Networks: Motivation, Formulation, and Example."

[4] CommerceNet/Nielsen. 1995. " The CommerceNet/Nielsen Internet Demographic Survey, Executive Summary," CommerceNet Consortium/Nielsen Media Research.

[5] Edell, Richard, Nick McKeown and Pravin Varaiya. 1995. "Billing Users and Pricing for TCP." IEEE J. Selected Areas in Communications. Vol. 13, No. 7.

[6] Gupta, Alok, Dale Stahl and Andrew Whinston. 1994. "Managing the Internet as an Economic System." Technical report, University of Texas at Austin, TX, July 1994.

[7] Hausman, Jerry. 1985. "The Econometric of Nonlinear Budget Sets." Econometrics. Vol. 53, No. 6.

[8] Hoffman, Donna, William Kalsbeek and Thomas Novak. 1996. "Internet Use in the United States: 1995 Baseline Estimates and Preliminary Market Segments." Project 2000 Working Paper. Vanderbilt University.

[9] Kelly, Frank P. "Charging and Accounting for Bursty Connections."

[10] Low, Steven and Pravin Varaiya. "A New Approach to Service Provision in ATM Networks." *IEEE Globecom*, pp. 1633-37, 1991.

[11] Mackie-Mason, Jeffrey, Liam Murphy and John Murphy. 1995. "The Role of Responsive Pricing in the Internet."

[12] Mackie-Mason, Jeffrey and Hal Varian. 1994. "Pricing the Internet."

[13] McFadden, Daniel. 1986. "The Choice Theory Approach to Market Research." Marketing Science. Vol. 5, No. 4.

[14] Pacific Internet. 1996. Reference about tariffs.

[15] Revelt, David and Kenneth Train. 1996. "Incentives for Appliance Efficiency: Random-Parameters Logit Models of Households' Choices." mimeo.

[16] Sexton, Richard, Terri Sexton, Joyce Wann, and Catherine Kling. 1989. "The Conservation and Welfare Effects of Information in a Time-of-Day Pricing Experiment." Land Economics, Vol. 65, No. 3.

[17] Shenker, Scott. "Service Models and Pricing Policies for an Integrated Services Internet."

[18] Srinagesh, Padmanabhan. 1995?. "Internet Cost Structures and Interconnection Agreements."

[19] Train, Kenneth. 1986. Qualitative Choice Analysis. Cambridge: MIT Press.

[20] Train, Kenneth. 1986. Optimal Regulation. Cambridge: MIT Press.

[21] Train, Kenneth, Daniel McFadden, and Andrew Goett. 1987. "Consumer Attitudes and Voluntary Rate Schedules for Public Utilities." Review of Economics and Statistics.

[22] Wilson, Robert. 1993. Nonlinear Pricing. Oxford: Oxford University Press.

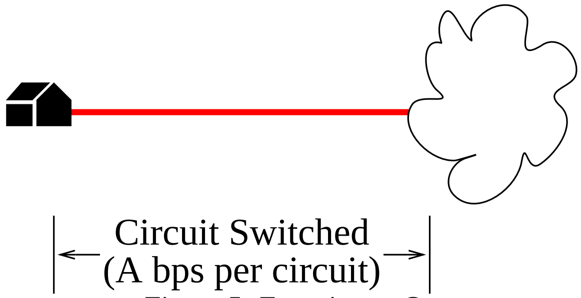

Figure 5: Experiment One.

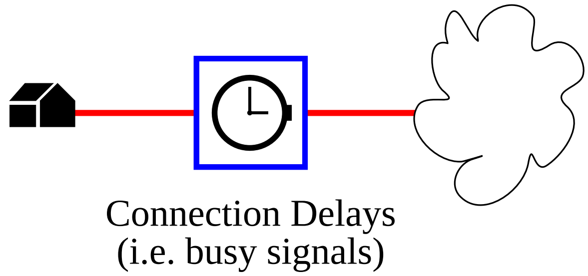

Figure 6: Experiment Two.

A Sub-Experiments

The experiments can be partitioned into two groups. The first group, representing the first three experiments, examines how users value the network resources in Figure 1. The second set of experiments, experiments 5 through 8, examine how users react to different pricing structures.

A.1 Experiment 1. Value of Connection Speed to Internet Cloud

This experiment will examine how users value the speed of their connection to the internet cloud. Users will have a guaranteed connection from their home to the network. They will face neither contention from other users nor fixed access fees to the network. This experiment isolates the last link in Figure 1. Figure 2 depicts this experiment.

Subjects will have a choice between 3 (increase?) connection speeds (which ones?), and be charged a per minute rate corresponding to the connection speed. Higher speeds will incur a higher fee but the level and ratios will change over the course of the experiment. The fee structure will change Monday morning at 4 am and will remain in effect for the duration of the week.

Since this experiment provides critical baseline information, it will be run for a twelve week period to insure that adequate data is collected to measure the responsive of usage to service price. Over the 12 week perid, each subject will thus face 12 different prices. Rotation groups will be utilized within this experiment in order to expand the set of prices which may tested and to control for possible calender effects. The variation in prices between rotation groups will not be so large as to entice any arbitrage between subjects.

This experiment will permit the accurate measurement of the price elasticity of demand for connection speed to the internet.[12] Whereas nonexperimental studies are forced to rely on cross-sectional variation in price and demand to infer the price elasticity, price will be varied during the experiment to measure the demand response for each individual.

With this information, the following questions may be addressed. Do individuals value connection speed sufficiently to pay higher prices for high speed connections? How does the elasticity of demand depend on application and demographics? Does demand exhibit habit formation?

Fairly detailed will be collected on the characteristics of the subjects' usage. Each time the subject uses the ISDN connection, data will be collected on the time and length of the session, the speed of connection, the price in effect, and the amount of data transferred and applications used during the session. The actual content of usage will not be examined.

[12] The price elasticity of demand measures the percent change in demand due to a percent change in price, or simply $\frac{\frac{\delta q}{q}}{\frac{\delta p}{p}}$.

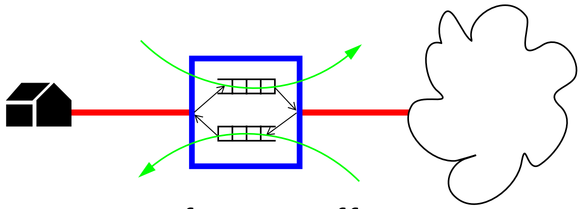

Figure 7: Experiment Three.

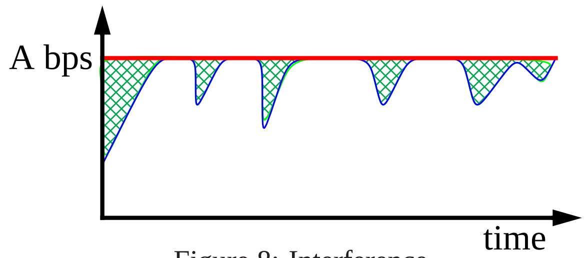

Figure 8: Interference.

A.2 Experiment 2. Value of Access Reliability

This experiment will address the following questions. Do individuals value network access sufficiently to pay higher prices for less contention to the network? Do individuals relinquish lines more often when the can reconnect?

Congestion in dialup access to the network is a significant problem in many networks. At the UCB, the problem is quite severe. Figure 2 shows the utilization of the campus modem pool. The modem pool is fully utilized beginning from 9 am until 2 am. The expected wait for a free line can be significant. As a result, once connected, users are typically reluctant to relinquish their connection even during idle periods for fear of inability to reconnect in a prompt manner.

This experiment will examine the value which users attach to network access and the value of waiting time. Subjects will be presented with a choice of three different modem pools, each facing a different predetermined level of congestion and expected waiting time. This congestion will be simulated since the ISDN connections are dedicated connections. Subjects will be charged higher prices for connecting through modem pools with lower degrees of contention for free circuits. The experiment will be conducted for four weeks, with the price schedule for the different modem pools changing daily.

The price schedule will vary over two dimensions, connection speed and modem congestion. Users will face a different per minute charge based on connection speed. The per minute price schedule will not change during the duration of this experiment. Users will also be charged a fixed fee based on the level of congestion in the modem pool through which they connect. The fixed fee will change daily so that the value of waiting time may be measured.

These data will also help investigate whether the availability of cheap low speed connections can help segment the market.

A.3 Experiment 3. Value of Priority Service

This experiment will address the following questions. Do individuals value the reliability of effective bandwidth sufficiently to pay higher prices for less contention to the internet cloud? Does priority pricing raise the overall value of the network by ensuring available resources for highly valued applications?

Another potential source of contention from other users is for shared bandwidth such as in trunk lines or internet cable access. This experiment will measure the value which users place on service reliability and effective bandwidth by measuring their willingess to pay for different service priorities. While the pricing of traffic on the backbone is not an immediate concern of this research, the findings from this experiment should yield some insights into the cost of congestion along the backbone and the possible role for multiple priority service.

The level of effective bandwidth which the subject obtains will be a function of the chosen priority class and the level of congestion in the network. The interfering traffic will be simulated as shown in Figure 7.

A.4 Experiment 1a. Price Elasticity of Connection Speed, Revisited

This experiment will be rerun for two weeks with two goals in mind. First, repeating the experiment can help investigate whether price elasticities have changed over time. More importantly, rerunning the experiment will help subjects to readjust to making choices based on connection speed and price. It is important to return to this baseline so that salient comparisons to charges based on the traffic generated may be made.

A.5 Experiment 4. Demand under Traffic-Based Charges

How price sensitive is the amount of user generated traffic? What are the optimal usage charges for bandwidth on demand? How much learning about traffic generation occurs? Does the price elasticity change over time?

To the extent that service degradation occurs due to network traffic, prices should reflect the level of traffic which the user generates. Charges based solely on connection time result in a negative externality and increased congestion.

While many researchers have suggested that users should be charged on the basis of their traffic, little is known about whether users will adequately understand the basis for such prices, whether usage will be sensitive to such prices, and whether users could benefit from usage based prices due to a reduction in network congestion. These questions may be addressed by examining the behavior of users when facing charges per byte of traffic.

In this experiment, subjects will face per byte charges which change once per week during the eight week duration of the experiment. Prices will be calibrated so that total charges would be approximately the same as under per minute charges in the absence of behavioral effects. Of primary interest is whether usage decreases in comparison to the first experiment, and whether usage decreases more when per byte charges are higher.

A.6 Experiment 5. Tariff Self-Selection

Would individuals voluntarily choose tariffs based on bytes rather than minutes? Are these choices of self-selecting tariffs rational? Is usage sufficiently predictable?

In this experiment, subjects will be presented with a choice of 3 different connection speeds and three different tariff structures. The tariff structures will be different combinations of per minute charges and per byte charges. Users will be offered the choice of being charged exclusively on the basis of either minutes or bytes, as well as the choice of having half of the charges being determined by each. (Include details on calibration, most likely based on past usage.)

Users will be asked to select which tariff structure they wish to be billed under for the course of the week. The prices contained in the tariff structure will remain in effect for two weeks at a time. Therefore, subjects will have a chance to learn from past behavior.

A.7 Experiment 6. Time-of-Use Charges and Peak Shifting

Do individuals value connection speed sufficiently to pay higher prices for high speed connections?

Network use displays regular temporal patterns. For example, the modem utilization plots in Figure 3(?) show that the patterns of use throughout the day, as well as the consequences for congestion. In order to avoid building extra capacity to meet peak usage, price incentives may be provided in an effort to shift some demand from peak to non-peak periods. This approach has been tried extensively in the public utility pricing.

This experiment will investigate the use of price incentives to shape demand. Since there is likely to be a significant amount of variation in tastes and time constraints, significant welfare gains might be possible. For example, if a sizable segment of the user population could be induced to shift usage to nonpeak hours, the value of the resouces to those unable to shift their usage may increase substantially.

A.8 Experiment 7. Demand under Flat Rate Pricing

This experiment would vary the level of the flat fee charged to users for unlimited usage in order to examine the total value which users place on access at different connection speeds. The relationship of this value to various observable characteristics would also be examined. By obtaining this measure of user heterogeneity in the total value of usage, the design of optimal tariffs will be helped greatly.

This experiment will be similar to the first experiment which examined behavior under alternative per-minute charges, with the difference being that a flat-price will be varied instead. The flat price will differ by connection speed (with higher speeds being charged at higher flat rates). The set of prices will be changed on a weekly basis. Unlike the first experiment where each connection speed could be reselecced as desired, only the speed(s) for which the flat fee has been paid will be allowed. Thus, if an individual discovers in midweek that a higher speed is needed, the individual would have to pay the new higher fixed fee.

This experiment will allow the following questions to be addressed. How price sensitive are users to fixed fees? What are the optimal multi-part tariffs?

A.9 Experiment 8. Two Part Tariff Design

This experiment will combine some of the different features of the previous experiments. Individuals will face a menu of tariff choices which varies each week. The tariffs will vary according to the level of the fixed weekly fee and the usage sensitive fee. Whereas experiment five examined the selection of tariffs which varied according to the basis for usage sensitive fees (per-minute charges versus per-byte charges), this experiment will vary only the relative contributions of the fixed and variable charges. This will allow examination of how users respond to declining block tariffs. This will also provide some insight into whether individuals have preferences over tariff structures themselves due to such effects as risk aversion or mental accounting costs (Train, 1993?).

Combined with data from the other experiments, this will allow the design of price structures which track consumer demand curves more closely than do either fixed fees or uniform prices. This information will also the relationship of these price schedules to different individual characteristics and market segments.

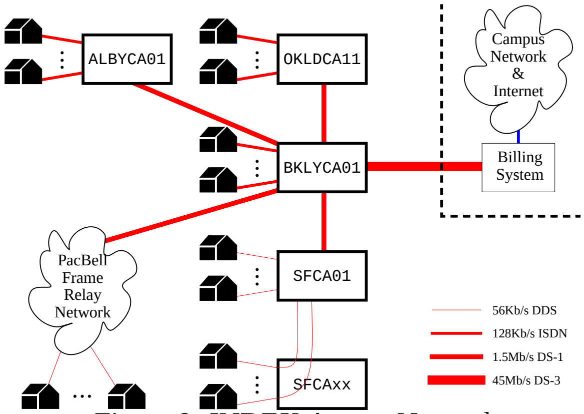

Figure 9: INDEX Access Network.

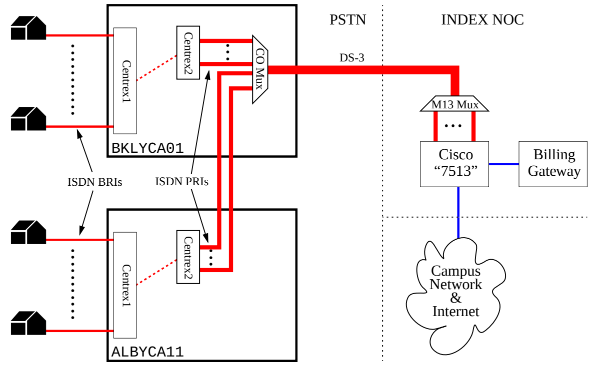

Figure 10: INDEX ISDN Access Provisioning.

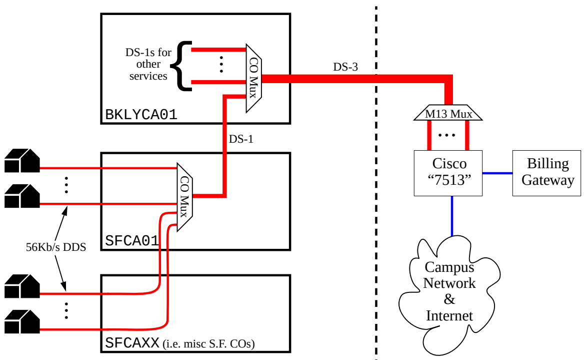

Figure 11: INDEX 56 Kbps DDS Provisioning.

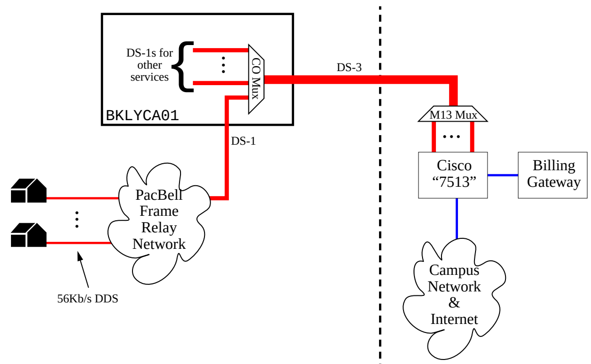

Figure 12: INDEX Frame Relay Access Provisioning.

B Network Engineering