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Demand for different qualities of service for Internet access: a review of INDEX findings

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The Internet Demand Experiment (INDEX) is a market experiment to measure demand for Internet access as a function of Quality of Service (QoS), pricing scheme and application. INDEX subjects choose their desired network services from a menu of QoS-price offerings, which currently consists of different bandwidth–price choices, and they pay for their usage of the network services. The approximately 70 subjects currently in the experiment include faculty, staff and students of the University of California, Berkeley.

This paper describes the objectives and experimental design and summarizes the findings to date from the first four experiments conducted under the INDEX project. This paper also characterizes the INDEX subject pool using demographic data collected. Overall, the INDEX findings indicate that usage is responsive to price signals, although the degree of responsiveness varies widely across users. The INDEX findings also show that the INDEX subject pool is heterogeneous in many respects, including individual-specific valuations of time and convenience. In addition, we conclude that users prefer a pricing scheme in which they pay a flat-rate for basic service and have access to higher bandwidths that they can use on demand. We also find that when usage is free of marginal usage charges, users tend to transmit significantly greater volume than when usage is priced at the margin, which lends further support to the implementation of the suggested pricing scheme.

Keywords: Internet access; pricing; Internet access demand; Quality of Service; experimental studies

1. Introduction

The Internet Demand Experiment (INDEX), is a market experiment to measure demand for Internet access as a function of Quality of Service (QoS), pricing scheme and application. INDEX subjects are provided Internet access over ISDN lines. They choose their desired network services from a menu of QoS-price offerings and pay for their usage of the network services. In all the INDEX experiments conducted to date, QoS is operationalized as different bandwidth choices. The menu of QoS choices

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Table 1. *Distributions from which price increments were drawn*

increments (kb s^{-1})	distribution
8–16	$0.1 + 0.6 \times 2.8X^{1/0.3}$
16–32	$0.1 + 0.7 \times 2.8X^{1/0.3}$
32–64	$0.1 + 2.0 \times 2.8X^{1/0.3}$
64–96	$0.1 + 2.0 \times 2.8X^{1/0.3}$
96–128	$0.1 + 2.0 \times 2.8X^{1/0.3}$

and the pricing scheme change every 6–10 weeks, moving the subjects through a sequence of experiments that are designed to measure user response to various quality differentiated, usage-based pricing schemes. Enrollment of members of the University of California campus as subjects in INDEX began in April 1998. The approximately 70 subjects currently in the experiment include faculty, staff and students.

Overall, the INDEX findings indicate that usage is responsive to price signals, although the degree of responsiveness varies widely across users. The INDEX findings also show that the INDEX subject pool is heterogeneous in many respects, including individual-specific valuations of time and convenience. In addition, we conclude that users prefer a pricing scheme in which they pay a flat rate for basic service and have access to higher bandwidths that they can use on demand. Finally, the INDEX findings show that when usage is free of marginal usage charges, users tend to transmit significantly greater volume than when usage is priced at the margin, which lends further support to the implementation of the suggested pricing scheme.

The paper proceeds as follows: § 2 describes the objectives and experimental set-up of INDEX overall, and also the experimental design and objectives of each of the experiments for which data is currently available. Section 3 characterizes the INDEX subjects using demographic and other self-reported data and compares the INDEX subjects with the general US population on a number of measures. Section 4 presents findings on user choices and preferences.

2. Design and objectives of the experiments

(*a*) *Objectives and general experimental set-up of INDEX*

The primary goal of each of the INDEX experiments is to determine the dimensions of QoS that matter to users, assess users' valuation of these dimensions of QoS, and measure the responsiveness of users to different pricing schemes. The INDEX access network provides IP service over dedicated 128 kb s^{-1} ISDN lines to each subject's home. The 128 kb s^{-1} basic rate interface lines coming from the subjects' homes are multiplexed over ISDN primary rate lines at the Pacific Bell central office before they reach the INDEX project network operations centre (NOC). The overall available bandwidth is not reduced in the multiplexing process and the INDEX network is heavily over-provisioned to ensure that the subjects' selected QoS do not deteriorate due to potential bottlenecks in the INDEX access network. At the INDEX NOC, all user traffic is distributed over a set of billing gateways specifically designed to meter usage and to selectively adjust the service quality of individual connections (Rupp *et al*. 1998).

INDEX subjects are provided with a Java application that runs on their computers. This application is the user interface to the INDEX network. The user interface informs the subjects about the set-up of the currently running experiment, including prices currently in effect. The user interface also enables subjects to select different qualities of service, displays the subjects' currently selected choice, and reports the subjects' usage charges for either the session, the day, or the current month. The technology for QoS provisioning, accounting, and billing was completed in January 1998 and INDEX began the market trial portion of the experiment in April 1998.

(*b*) *Variable Symmetric Bandwidth (Per Minute Pricing) Experiment*

The first experiment in which the INDEX subjects participated was the Variable Symmetric Bandwidth (Per Minute Pricing) Experiment (VSBE). The objective of this experiment is to assess the responsiveness of usage to per minute prices and to measure users' valuation for the different bandwidths.

In this experiment, the INDEX subjects were charged per minute prices for connect time to each of five offered bandwidths above 8 kb s^{-1}.† The five bandwidths were: 16 kb s^{-1}, 32 kb s^{-1}, 64 kb s^{-1}, 96 kb s^{-1} and 128 kb s^{-1}. Subjects could select any of the offered bandwidths at any time and it was even possible to change bandwidths during an active session.

This experiment ran for a total of seven weeks. The first week was unpriced to enable subjects to become comfortable using the user interface and to allow subjects to experience the different bandwidths so that they would be able to make informed choices in the subsequent weeks. In weeks 2–6, prices changed every week. In week 7 of the experiment, prices changed every day.

The prices that subjects faced for each of the five priced bandwidths were random draws that were subject specific. Each subject's price schedule was determined by five independent random variables. Each of these random variables was a price increment. The 8 kb s^{-1} service was always priced at 0 cents per minute. The first increment drawn was added to the per minute price of the 8 kb s^{-1} service to form the per minute price of the 16 kb s^{-1} service. The second increment drawn was similarly added to the per minute price of the 16 kb s^{-1} service to form the per minute price of the 32 kb s^{-1} service, and so forth. The distributions from which each of the five price increments was drawn are presented in table 1.

Table 2 lists the analytical and empirical summary statistics for the per minute prices of each of the five priced bandwidths.

(*c*) *Variable Asymmetric Bandwidth (Per Minute Pricing) Experiment*

In the Variable Asymmetric Bandwidth (Per Minute Pricing) Experiment (VABE), subjects were also charged per minute prices for connect time to each of the five priced bandwidths. Unlike the first experiment (the Variable Symmetric Bandwidth (Per Minute Pricing) Experiment), subjects in this experiment were able to select different bandwidths for upstream (out-bound) and downstream (in-bound) traffic. This experiment was motivated by access technologies with different data rates

† 8 kb s^{-1} service is always available and priced at zero in every experiment. This gives INDEX subjects an alternative within INDEX that may keep them from switching to their common outside option—the campus modem pool—which is also free of usage charges.

Table 2. *Analytical and empirical summary statistics for prices of the five priced bandwidths in cents per minute*

bandwidth (kb s^{-1})	analytical			empirical	
	minimum	mean	maximum	mean	maximum
16	0.10	0.49	1.78	0.51	1.80
32	0.20	1.04	3.84	1.06	3.70
64	0.30	2.43	9.54	2.46	8.20
96	0.40	3.82	15.24	3.77	10.70
128	0.50	5.22	20.94	5.14	13.70

for upstream and downstream traffic, such as asynchronous digital subscriber line (ADSL). The experiment seeks to determine whether users value bandwidth for in-bound traffic differently than bandwidth for out-bound traffic.

This experiment ran for a total of seven weeks. The first week was unpriced, allowing subjects to experience choosing bandwidths separately for in-bound and out-bound traffic. In the remaining six weeks, prices changed every week.

Weekly per minute prices for each bandwidth were constructed using the same method as that used in the previous experiment, with one minor adjustment: to ensure that the INDEX subjects would have the same expenditures for the same bandwidth choice in the absence of behavioural changes, the resulting prices, after adding the randomly drawn price increments, were halved, since connect time to upstream and downstream bandwidth were charged separately. Thus subjects who spent 2 min using the 32 kb s^{-1} service in the first experiment would incur the same expenditures under this experiment if they received the same exact draw of the five price increments, selected 32 kb s^{-1} for upstream and 32 kb s^{-1} for downstream traffic, and connected for a total of 2 min.

(*d*) *Byte Volume Pricing Experiment*

In the Byte Volume Pricing Experiment, INDEX subjects were charged by the megabyte rather than the minute. This experiment seeks to explore whether users understand the basis for per megabyte pricing, which differs significantly from the telephone-oriented per minute pricing to which users are accustomed. Another objective of this experiment is to assess the price sensitivity of users to per megabyte pricing and to compare it with the price sensitivity of users under per minute pricing.

In this experiment, the INDEX subjects were given the choice of only two bandwidths: 8 kb s^{-1}, which was free of usage charges, and 128 kb s^{-1}, whose usage was charged according to the number of megabytes transmitted. The experiment ran for a total of seven weeks. Week one was again unpriced to allow subjects to learn about the volume of traffic that they generate. In weeks 2–7, the per megabyte prices changed every week. Prices were randomly drawn for each subject. The price range of 0.1 cents to 20 cents (with granularity of 0.1 cents) was divided into three price segments (low, medium, high). Two prices were drawn from each of the three price segments. Afterwards, the six weekly per megabyte prices for each subject were permuted to ensure that subjects would not be able to predict future prices and hence shift usage inter-temporally.

Table 3. *Per minute prices for each bandwidth with no buyout*

bandwidth (kb s^{-1})	per minute price with no buyout (cents)
16	0.4
32	0.8
64	1.6
96	2.4
128	3.2

Table 4. *Fixed charge and per minute prices for different buyout choices*

α	fixed charge (times weekly buyout charge)	per minute price vector (cents) (16, 32, 64, 96, 128 kb s^{-1})
0.125	0.125	(0, 0.4, 1.2, 2.0, 2.8)
0.25	0.25	(0, 0, 0.8, 1.6, 2.4)
0.5	0.50	(0, 0, 0, 0.8, 1.6)
0.75	0.75	(0, 0, 0, 0, 0.8)
1.0	1	(0, 0, 0, 0, 0)

(*e*) *Flat-Rate Buy Out Option Experiment*

In the Flat-Rate Buy Out Option Experiment (FRBOOE), the INDEX subjects were charged per minute prices for the five priced bandwidths.† These per minute prices, listed in table 3, were fixed for the entire experiment.

Each week, the subjects were given the opportunity to buyout any of the five bandwidths for the week by paying a fixed charge. The fixed charge for buying out all five bandwidths was a randomly drawn weekly buyout price. The fixed charge for buying out any of the first four bandwidths was a fraction of the weekly buyout price.‡ The fractions were 0.125, 0.25, 0.5 and 0.75, respectively. For example, a subject could buyout only 16 kb s^{-1} service by paying a fixed charge of 0.125 multiplied by the week's buyout price, after which the subject faced no per minute charges for using the 16 kb s^{-1} service. The subjects' buyout decisions were binding for the rest of the week and could not be changed until the following week, when the following week's buyout price was revealed to them.

Each subject's weekly buyout price was drawn randomly with replacement from the range \$1 to \$20 (integer values only). The experiment ran for ten weeks for each subject, so each subject had ten draws of weekly buyout prices. Three of the weekly buyout prices were drawn with replacement from the range \$1 to \$6 (all ranges include integer values only), four of the weekly buyout prices were drawn with replacement from the range \$7 to \$14, and the remaining three weekly buyout prices were drawn with replacement from the range \$15 to \$20. The ten drawn weekly buyout prices were then permuted and revealed to the subject a week at a

† Data on this experiment are currently available for only 40 of the approximately 70 subjects.

‡ When a subject buys out a particular bandwidth, he/she is also buying out all bandwidths below that.

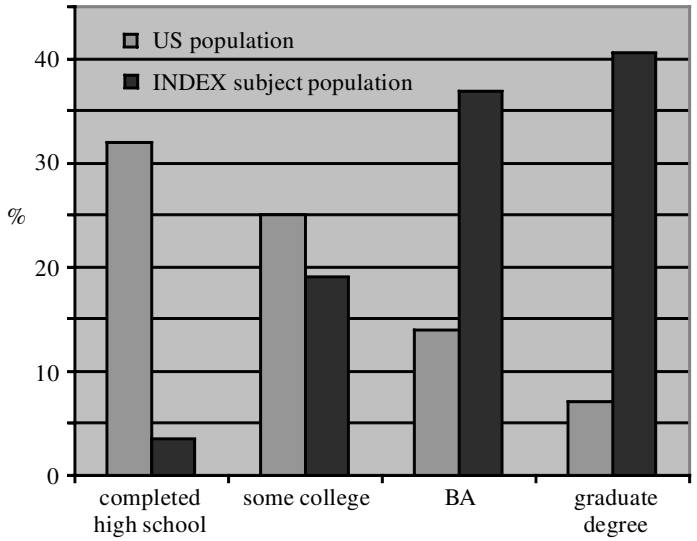

Figure 1. Educational attainment of INDEX subjects and of the US population.

time. Subjects therefore had no information about what buyout prices they would face in subsequent weeks, limiting inter-temporal substitution.

After subjects buyout a particular bandwidth, they can continue to use higher bandwidths on demand during the week. Buying out a particular bandwidth also reduces the per minute prices of the remaining (higher) bandwidths. Table 4 lists the price vector for each of the different buyout choices. α is the fraction by which the weekly buyout price is multiplied for each of the different buyout choices.

3. Characteristics of the INDEX subject population

INDEX subjects range in age from 20 to 72 years, with a mean age of 35 and a median age of 29. Not surprisingly, due to their university affiliation, INDEX subjects have a higher level of education compared with the US population. Figure 1 compares the educational achievement of the INDEX subject population with the educational achievement of the US population.†

While the level of education of the two groups differs significantly, the income distribution of the INDEX subjects does not appear to differ significantly from the income distribution of the US population. Approximately 6.5% of the US population have annual household incomes of less than \$10 000 compared with *ca.* 8.3% of the INDEX subject population (US Census Bureau 1999). Approximately 33.3% of the US population have annual household incomes between \$50 000 and \$99 999, which is comparable with the 28.6% of INDEX subjects with annual household incomes in that range. On the high end, *ca.* 13.3% of the US population have annual household incomes of greater than \$100 000, compared with *ca.* 15.5% of the INDEX subject population. Figures 2 and 3 show the distribution of annual household incomes of the INDEX subject population and the distribution of annual household income of the US population, respectively.

† US Census Bureau, educational attainment table 1, March 1998 (see http://www.census.gov).

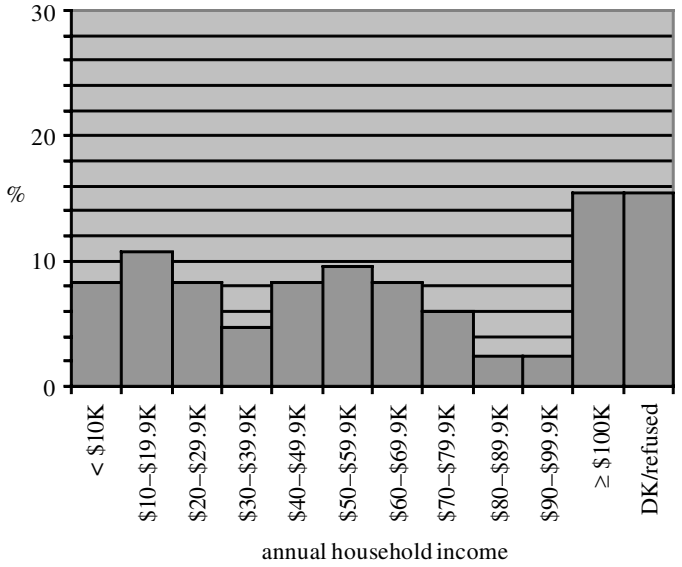

Figure 2. Annual household income of INDEX subject population.

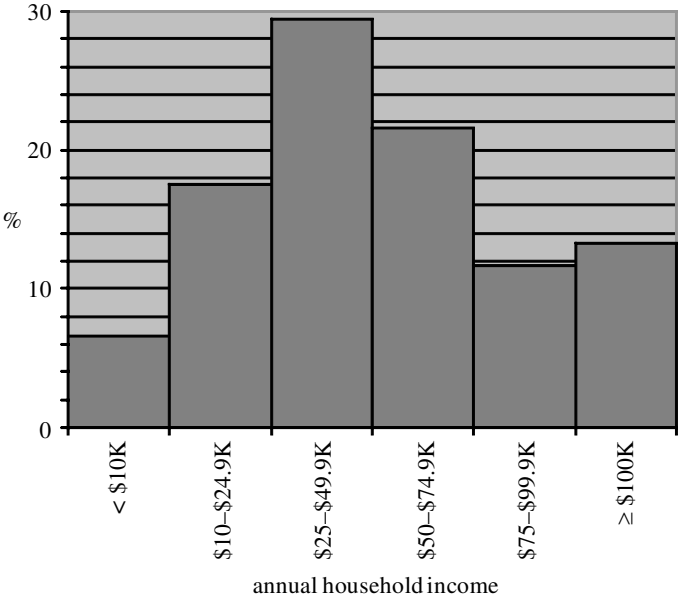

Figure 3. Annual household income of US population.

In addition, most INDEX subjects are experienced computer and Internet users: 90% of INDEX subjects first used the Internet three or more years ago, compared with 9% of the respondents in a population-representative Nielsen survey (Rupp *et al*. 1998).

The primary difference between the INDEX population and the general US population that are likely to influence usage of Internet access includes the university affiliation of the INDEX subjects, which provides the INDEX subjects with a non-

priced option for Internet access: the campus modem pool and Ethernet access if the subjects live in the dorms. In addition, the type of applications used by INDEX subjects during Internet sessions differ from the types of applications used by the general public. For example, 88% of connections to commercial ISPs are HTTP or NNTP connections compared with only *ca.* 45% of the INDEX connections, while FTP connections account for 11% of the INDEX connections compared with 3% of commercial connections (Edell & Varaiya 1999). In addition, few, if any, connections to commercial ISPs are telnet or Xwindows sessions. Different characteristics of access to the Internet may be particularly important for a particular type of application. Hence, the extrapolation of findings from INDEX to the general US population may require additional analyses of the effects of different applications on users' choices of different bandwidths. This additional analysis is beyond the scope of this paper, which aims to provide a summary of the findings available to date. Future work on this question will proceed as data on the types of applications used become available.

4. User preferences and choices: INDEX findings

(*a*) *Users are price responsive*

Not surprisingly, we find that the INDEX subjects are price-responsive. During the free trial weeks, usage is significantly higher than during priced weeks. In addition, utilization rates increase as prices increase. Estimated demand elasticities show that demand is in the elastic range and also show that demand appears to depend significantly on both own prices and the prices of (usually) the next higher bandwidth.

Figure 4, which comes from Altmann *et al.* (1999*a*), shows that during the free trial periods, the INDEX subjects stayed connected longer at higher bandwidths than when they faced marginal usage charges in the Symmetric Bandwidth Per Minute, the Asymmetric Bandwidth Per Minute, and the Byte Volume Experiments.

In addition, we see from figure 5, also from Altmann *et al.* (1999*a*), that the average number of bytes transmitted per user-day also differs significantly, depending on whether usage is or is not priced.

Altmann *et al.* (1999*a*) also examine connection use, which is the percentage of the requested connection capacity that is actually used, across the free weeks.† They find that connection use increases from 2.0% in the free weeks to 7.5% in the VSBE, to 10.4% in the VABE. This suggests that the INDEX subjects were more conscious of the amount of time for which they were connected and made more effort to disconnect or switch to the non-priced 8 kb s^{-1} service when they had completed their task.

Beckert (1999) finds similar price responsiveness in his study. Figure 6, from his study, shows the load–duration curve for a representative INDEX subject for the 128 kb s^{-1} service during the VSBE. The load–duration curves display the fraction of time during which use of 128 kb s^{-1} was at least as high as a particular utilization rate. Utilization rate is represented on the y-axis in the graph. So we see that when the per minute price of 128 kb s^{-1} was 1.7 cents per minute, this representative INDEX subject's utilization rate was at least 20% in one-third of the subject's total time connected to 128 kb s^{-1} at that price. However, when the per minute price of 128 kb s^{-1} increased to 3.9 cents per minute, this subject's utilization rate was

† Connection capacity is defined as the number of bytes that could have been sent by a user fully using all requested bandwidth.

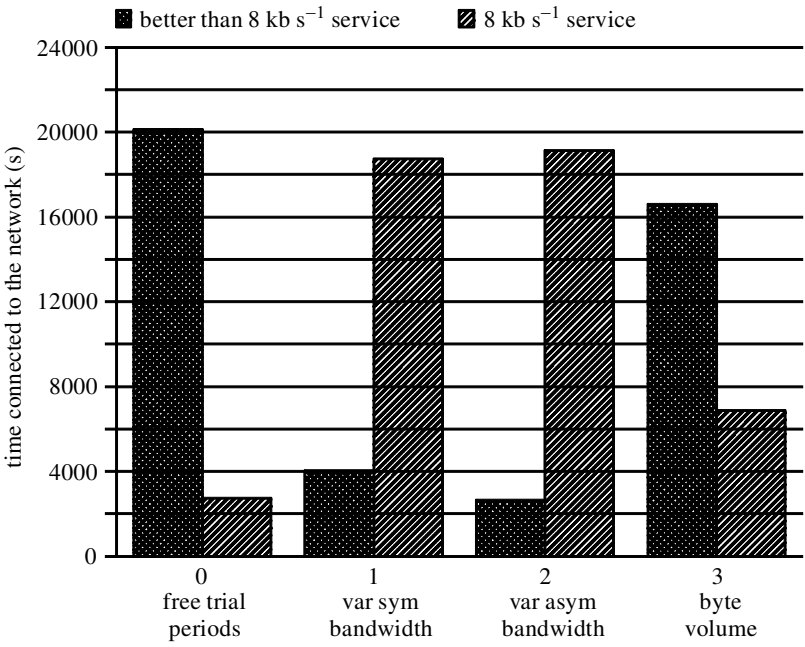

Figure 4. Average daily connect time.

at least 20% in approximately six-tenths of the subject's total time connected to 128 kb s^{-1} at that price, a dramatic increase.

Varian (1999) estimates demand elasticities for each of the five priced bandwidths using data from the VSBE. Table 5 below presents his elasticity estimates with connect time in each bandwidth as the dependent variables (asterisks indicate that the estimate is statistically significant.) He finds that own prices are statistically significant, as are the prices of the next higher bandwidth, indicating that users are sensitive to price changes not only in the bandwidth that they have chosen, but also in the next higher bandwidth.

(*b*) *Users have heterogeneous preferences*

Another finding that is not entirely surprising is that the INDEX subjects have heterogeneous preferences. This heterogeneity of preferences is exhibited by large inter-subject variations in weekly expenditures, weekly transmitted volumes, and the number of different bandwidths selected in experiments in which more than one priced bandwidth was offered.

In the VSBE, the VABE, and the Byte Volume Experiment, the INDEX subjects' weekly expenditures ranged from a low of \$0.20 a week to a high of \$21.23 a week (Altmann *et al.* 1999*b*). In the Flat-Rate Buy Out Option Experiment (FRBOOE), the subjects spent a low of \$0.61 a week to a high of \$12.56 a week, which includes the fixed charge, if they bought out a bandwidth, and the per minute charges. In this experiment, 27.5% of the subjects spent less than \$3 a week while 20% spent more than \$8 per week.

In the FRBOOE, the INDEX subjects transmitted a low of 0.85 Mb per week to a high of 292.9 Mb. 12.5% of the 40 subjects transmitted less than 3 Mb per week while

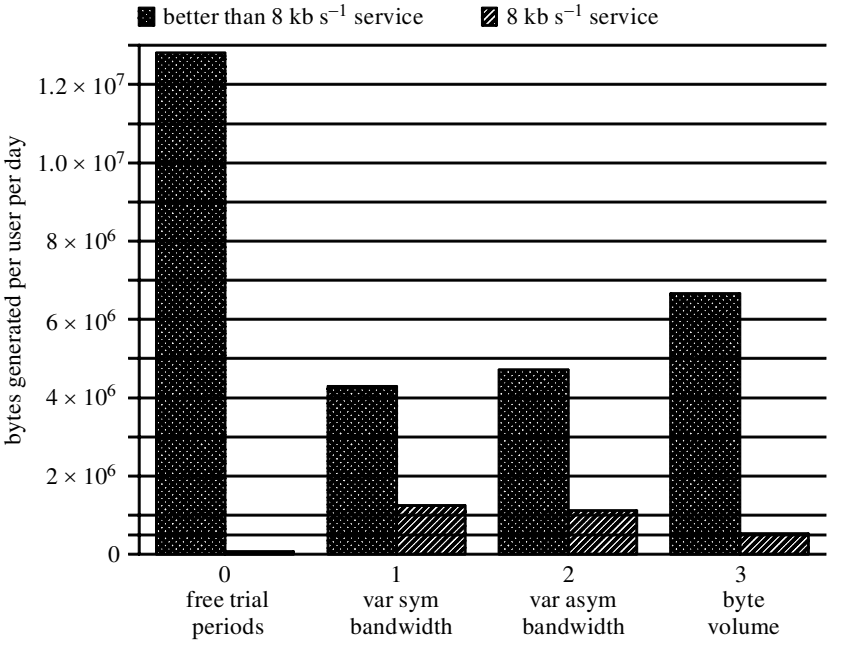

Figure 5. Average number of bytes transmitted.

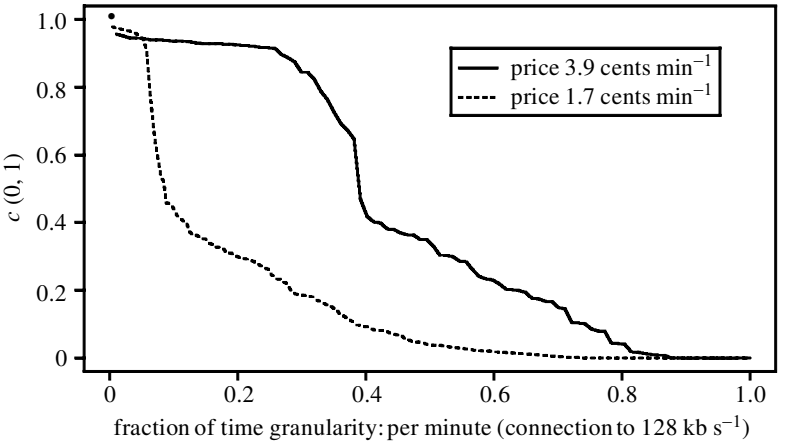

Figure 6. Representative INDEX subject's use of 128 kb s^{-1} at 1.7 and 3.9 cents per minute.

Table 5. *Estimated demand elasticities for each bandwidth in the variable symmetric bandwidth experiment*

$$u128 = -2.0p128 * +0.80p96 + 0.25p64 - 0.02p32 - 0.16p16$$
$$u96 = +1.7p128 * -3.1p96 * +4.3p64 * +0.19p32 + 0.18p16$$
$$u64 = +0.77p128 + 1.8p96 * -2.9p64 * +0.59p32 + 0.21p16$$
$$u32 = +0.81p128 - 1.0p96 + 1.0p64 * -1.4p32 * +0.15p16$$
$$u16 = +0.2p128 - 0.29p96 + 0.4p64 + 1.2p32 * -1.3p16*$$

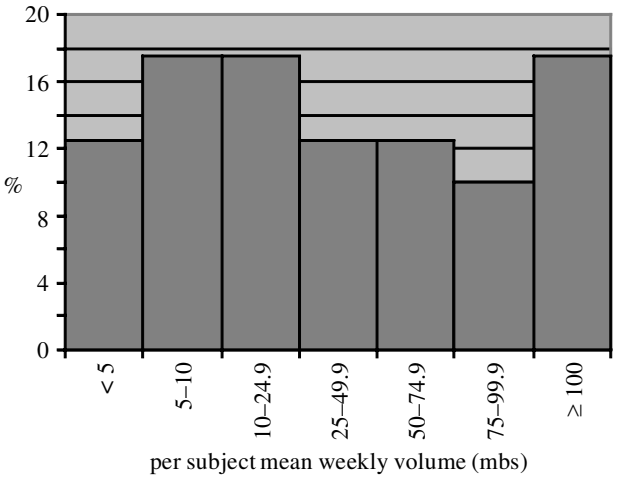

Figure 7. Subject-specific mean weekly volume in FRBOOE.

17.5% of the subjects transmitted greater than 100 Mb per week. Figure 7 shows the distribution of per subject mean weekly transmitted volume in the FRBOOE.

In the FRBOOE, 5% of the subjects bought out the same bandwidth in every week of the experiment while another 5% of the subjects bought out every bandwidth at least once during the course of the experiment.

These differences in the behaviour of the subjects do not appear to be easily explained by differences in demographics. For example, differences in education levels do not appear to significantly affect the usage behaviour of the subjects, their elasticities, nor their buyout decisions. Subjects who considered their Internet usage to be above average did not have significantly different elasticities compared with either subjects who considered their Internet usage to be average or subjects who considered their Internet usage to be below average. Nor did they exhibit significant differences in their buyout behaviour. Differences in household income across subjects had no significant effect on buyout behaviour although subjects in the bottom third of the income distribution appeared to exhibit slightly more elastic demand for usage of the 16 kb s^{-1} service. Thus an increase in the price of the 16 kb s^{-1} service would result in a slightly greater reduction in the demand for connect time to the 16 kb s^{-1} service by subjects in the bottom third of the income distribution, relative to subjects with incomes in the top two-thirds of the income distribution. There were no significant differences in the elasticity of demand for the other four bandwidths with respect to differences in income.

(*c*) *Users prefer a flat-rate pricing scheme for basic service with access to higher bandwidths on demand*

From the data currently available from the FRBOOE, it appears that the INDEX subjects prefer flat-rate pricing to measured rate pricing when the flat-rate charge is comparable with current unlimited use subscription prices charged by most major commercial Internet Service Providers (ISPs).† In that experiment, every subject bought out a bandwidth in at least one week, 85% of the subjects bought out a

† The findings in this subsection are from Chu (1999).

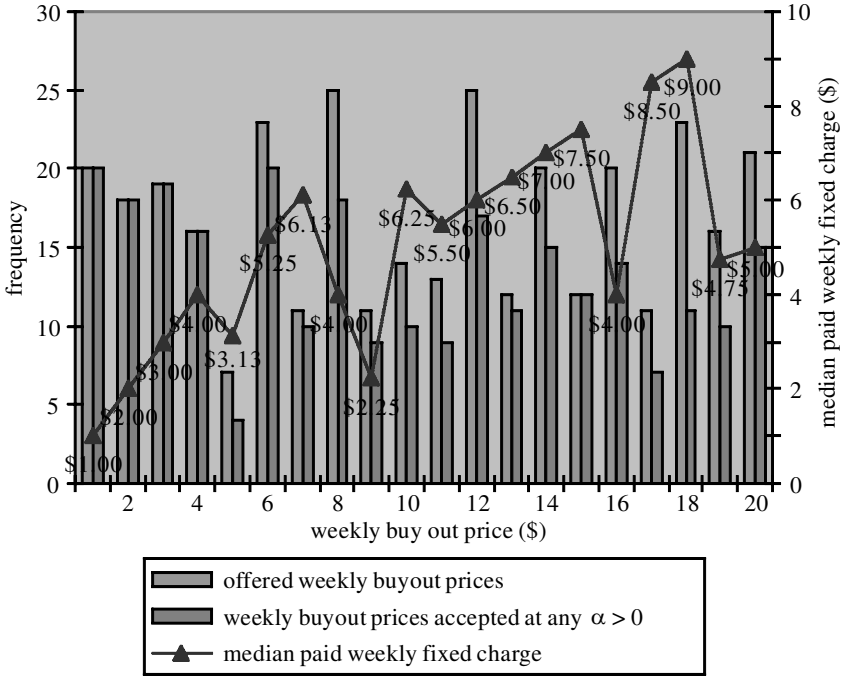

Figure 8. Frequency of drawn/offered and accepted buyout prices and median paid weekly fixed charges for each bandwidth.

bandwidth in 50% or more of their weeks in the experiment, and 52.5% of the subjects bought out a bandwidth in every one of their weeks in the experiment. Not surprisingly, given the alternatives available outside of INDEX, the mean weekly fixed charge paid by the INDEX subjects in the 265 weeks in which a bandwidth was bought out was \$5.25, which is approximately equal to the monthly flat-rate of \$21 charged by major ISPs for Internet access.

The prevalence of subjects choosing to buyout a bandwidth during the FRBOOE was no doubt facilitated by the existence of draws of very low weekly buyout prices and the ability of subjects to tailor the fixed charge by selecting the bandwidth to buyout for the week. In 73 person-weeks, a weekly buyout price of between \$1 and \$4 was drawn. In every week in which these buyout prices were drawn, the subjects chose to buyout some bandwidth, and at least half of them bought out the 128 kb s^{-1} service. Figure 8 shows the drawn and accepted weekly buyout prices. In addition, figure 8 shows, for each weekly buyout price, the median weekly fixed charge paid by the subjects who bought out a bandwidth when they drew that buyout price.

From figure 8, we see that at weekly buyout prices above \$4, the median bought out bandwidth is no longer 128 kb s^{-1} and the ability of the subjects to reduce their fixed charge by buying out a lower bandwidth appears to begin to matter. The median bandwidth chosen when subjects drew weekly buyout prices of \$6 and \$7 falls to between 128 kb s^{-1} and 96 kb s^{-1}. The median bandwidth bought out continues to fall as the weekly buyout price increases. It drops to between 96 kb s^{-1} and 64 kb s^{-1} when the weekly buyout price is \$10, then to 64 kb s^{-1} for most of the buyout prices between \$11 and \$18, and finally drops to 32 kb s^{-1} for weekly buyout prices of \$19

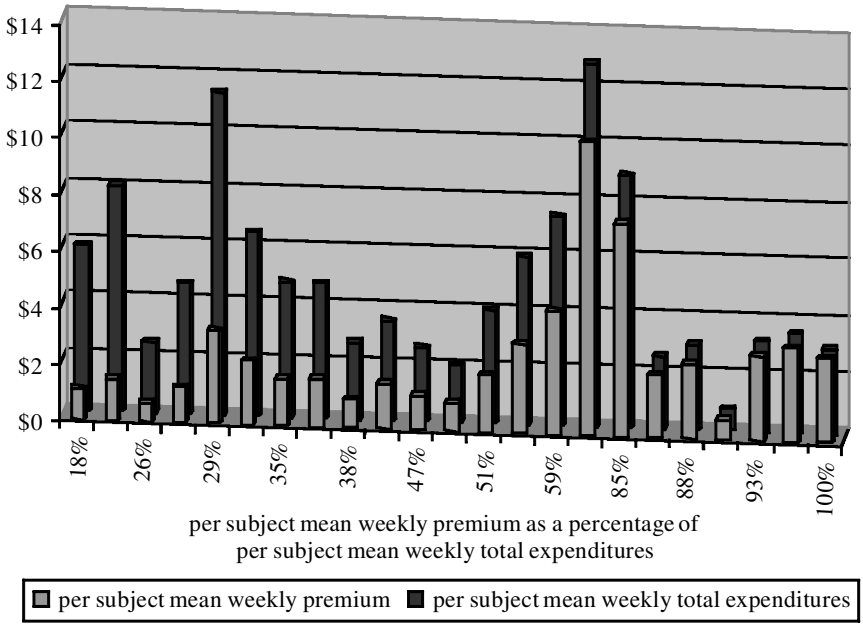

Figure 9. Individual-specific values of mean weekly premiums compared with individual-specific values of mean weekly total expenditures.

and \$20. The fact that the median bandwidth that was bought out falls as the weekly buyout price increases supports the contention that many subjects prefer flat-rate pricing for basic access, since they appear willing to buyout a lower bandwidth when they draw higher buyout prices, rather than not buyout at all if they could not afford to buyout the highest bandwidth.

Other evidence that supports the contention that the INDEX subjects prefer flat-rate pricing for basic access is the fact that many subjects appeared to be paying a premium to buyout a bandwidth for the week, where the premium is defined as the difference between the subject's total expenditures for his/her INDEX usage that week minus what the subject's total expenditures would have been under the cost-minimizing choice. Using a conservative estimate of the cost-minimizing choice,† we find that in 61 of the 265 weeks in which a bandwidth was bought out, the subject's bandwidth buyout decision was not cost minimizing because he/she chose to buyout too high a bandwidth. A total of 23 subjects were responsible for these 61 weeks.

Figure 9 shows, for the 23 subjects, the subject-specific mean premium for the weeks that were bought out and were not cost-minimizing. The highest value of the subject-specific mean weekly premium was \$9.21, which means that particular subject spent an average of \$9.21 more than the cost of his or her cost-minimizing choice in each of his or her non-cost-minimizing bought out weeks. The lowest value of the per subject mean weekly premium was \$0.65, with a median of \$2.02.

† To compute each subject's cost-minimizing choice for a particular week, we took as given the subject's chosen vector of connect time that week at each bandwidth and computed the cost of that vector at every possible buyout choice. This method of computing the minimum charge for a particular choice tends to overstate the number of cost minimizing choices, since a subject is likely to use more connect time when the marginal price is zero than when the price is positive.

Figure 9 also shows, for the 23 subjects, the subject-specific mean weekly expenditures in the weeks that were bought out and were not cost-minimizing. The highest value of the per subject mean weekly expenditures in those weeks was \$12.81, which means that particular subject spent an average of \$12.81 per non-cost-minimizing bought out week for fixed charges and per minute charges for access. The lowest value of the per subject mean weekly expenditures in those weeks was \$0.79.

Finally, figure 9 shows the per subject mean weekly premium as a percentage of the per subject mean weekly total expenditures. Thus we see that the premium as a percentage of the mean total weekly expenditures ranged from a low of 18% to a high of 100%,† with a median of 50%.

This premium can be interpreted as either an optimization error or as a measure of the subject's willingness-to-pay to avoid metering. Seven of the 23 subjects had only one week in the experiment in which their buyout choice was not cost-minimizing because they chose to buyout too high a bandwidth, which might suggest that the premiums for these seven subjects are due to optimization error. Eleven of the 23 subjects bought out too high a bandwidth in at least 50% of the time in which they chose to buyout a bandwidth for the week. The premiums for these 11 subjects can potentially be interpreted as the subject's willingness-to-pay to avoid metering.

Looking more closely at these 11 subjects, we find that they have much lower per subject mean transmitted volumes compared with the 40 INDEX subjects for whom we have data on this experiment. These 11 subjects generally bought out either the 32 kb s^{-1} service or the 64 kb s^{-1} service. However, due to their low usage, the scaling down of the full buyout price was not enough to make their buyout choices cost-effective. The fact that these subjects were willing to pay a premium to obtain the flat-rate option for 32 kb s^{-1} service or 64 kb s^{-1} service supports the contention that the INDEX subjects prefer flat-rate pricing for basic access.

Even though INDEX users appear to prefer flat-rate pricing for basic access, they also demonstrate that they want the ability to use higher, non-bought-out bandwidths on demand. After buying out a bandwidth during the week, 82.5% of INDEX subjects continued to use higher, non-bought-out bandwidths on occasion even though they were charged per minute prices for using the non-bought-out bandwidths. An additional 10% of the subjects bought out the 128 kb s^{-1} service in every week. Hence only 7.5% of the INDEX subjects did not use higher, non-bought-out bandwidths on demand.

(*d*) *Volume transmitted is significantly higher under flat-rate pricing*

There is a systematic difference in usage when comparing the 265 weeks in which a bandwidth was bought out in the FRBOOE with the 72 weeks in which no bandwidth was bought out.‡ The mean volume transmitted in the bought out weeks was 10.71 Mb, compared with a mean volume transmitted of 1.27 Mb in the weeks in which no bandwidth was bought out.¶ The finding that greater volume is transmitted in bought out weeks is not surprising since one would expect heavier users to buyout a bandwidth while light users may find it not cost-effective to do so. In

† The subject with the premium percentage of 100% bought out a bandwidth for the week but did not otherwise have any activity during that week.

‡ The findings in this subsection are from Chu (1999).

¶ The differences in the weekly transmitted volumes is statistically significant at 1%.

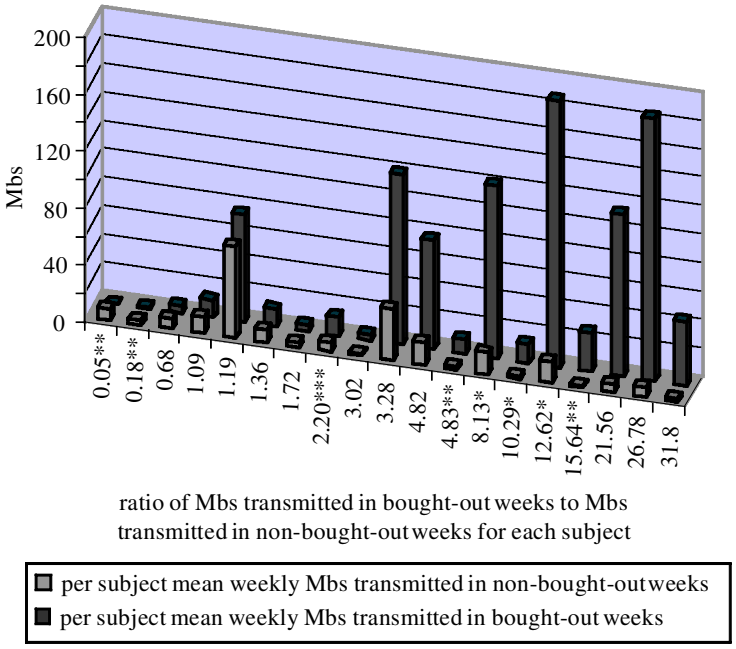

Figure 10. Individual-specific comparison of usage in flat-rate or bought out weeks versus non-flat-rate or non-bought-out weeks.

addition, conditional on having bought out a bandwidth in a week, one would expect the user to increase his or her usage as a result of facing zero marginal prices for the bought out bandwidths.

A finding that is more surprising is that usage differences exist even for the same subject in the weeks in which the subject bought out a bandwidth compared with the weeks in which in which the subject did not buyout a bandwidth. Nineteen of the 40 INDEX subjects for whom data from this experiment are available bought out fewer than 100% of their weeks in this experiment. For each of these 19 subjects, figure 10 shows the ratio of the volume transmitted during their bought out weeks to the volume that they transmitted in their non-bought-out weeks.†

Along with greater volume transmitted, the mean weekly total expenditures (fixed charges plus per minute charges) were also higher for the bought out weeks: \$5.81 for the 265 bought out weeks compared with \$2.77 for the 72 non-bought-out weeks. However, the per megabyte revenues collected by INDEX were lower in the bought out weeks than in the non-bought-out weeks, since the increase in volume transmitted was greater than the increase in revenues. INDEX received revenues of 7.75 cents per megabyte in the 265 bought out weeks, compared with revenues of 30.41 cents per megabyte in the 72 non-bought-out weeks.

These large and significant differences in transmitted volumes by the same subject between weeks in which they selected the flat-rate option and weeks in which they did not, and the significantly lower per megabyte revenues in the bought out weeks further support the implementation of a flat-rate pricing scheme that includes

† The ratios with one asterisk indicate that the difference is statistically significant at 1% while the ratios with two asterisks indicate that the difference is statistically significant at 5%. Three asterisks indicates statistical significance at 10%.

only basic, best-effort service in the flat-rate portion. Users who need higher quality Internet access should be given the option of selecting higher quality service, which is priced at the margin, on demand.

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