Local Telephone Pricing and Universal Telephone Service

Rolla Edward Park, Bridger M. Mitchell

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RAND
PREFACE

This report describes a computer model that simulates households’ decisions to subscribe to telephone service. It also applies the model to investigate the effects of offering options (such as measured service and lifeline rates) on telephone penetration and consumer surplus by income class.

The report was supported by a grant from the National Science Foundation (Dr. Laurence C. Rosenberg, project officer). It was presented at the Sixteenth Annual Telecommunications Policy Research Conference, Airlie, Virginia, October 1988. A companion report by Leland L. Johnson, entitled Telephone Assistance Programs for Low-Income Households: A Preliminary Assessment (RAND R-3603-NSF/MF, February 1988), surveys several states’ experience with lifeline rates.
SUMMARY

This report describes an economic assessment of several different ways of trying to maintain universal telephone service in the face of increasing local telephone rates. The assessment is based on a simulation model that extends Mitchell's American Economic Review (1978) paper to describe households more completely, to model the choice among optional tariffs, to distinguish between installation and monthly service charges, and in other ways. The simulation model is calibrated using recent empirical estimates of telephone demands and costs.

The simulations compare various tariffs—including flat rates, mandatory measured rates, optional measured rates, and income-targeted lifeline rates—in terms of their effects on telephone penetration, economic welfare, and consumer surplus. At current price levels, neither optional measured rates nor lifeline rates have much effect on telephone penetration, even among low income households. At a doubled price level that may prevail in the future, however, adding a measured rate option to flat rates adds about three percentage points to penetration among low income households; adding lifeline service adds another five or six percentage points. At either present or future price levels, lifeline rates result in substantial consumer surplus transfers from higher- to lower-income households, although adding measured rate and lifeline options has little effect on aggregate economic welfare.
ACKNOWLEDGMENTS

During the course of this project we met periodically with Jan Paul Acton and Leland L. Johnson of The RAND Corporation to discuss progress and problems. We greatly appreciate their patient and insightful counsel. We are also grateful to Jeffrey H. Rohlf of Shooshan & Jackson Inc. and Thomas C. Spavins of the Federal Communications Commission, who reviewed the work in draft form and made many helpful comments and suggestions.
CONTENTS

PREFACE .................................................. iii

SUMMARY ............................................... v

ACKNOWLEDGMENTS ...................................... vii

FIGURES AND TABLES .................................... xi

Section

I. INTRODUCTION ........................................ 1
   Background ........................................... 2
   Issues .................................................. 2
   Overview of the Simulation Approach ................. 2
   Relation to Previous Studies ......................... 5
   Organization of the Report .......................... 7

II. SPECIFYING AND CALIBRATING THE SIMULATION
    MODEL ................................................ 8
    Specification of the Distribution of Household
       Characteristics ................................... 8
    Calibration of Household Characteristics .......... 21
    Specification of Telephone Service Options ...... 25
    Specification of Incremental Costs ................. 26

III. SIMULATION DETAILS AND RESULTS ................ . 28
    Cases Simulated .................................... 28
    Details of the Simulation Method ................... 28
    Simulation Results .................................. 31

IV. DISCUSSION .......................................... 37
    Findings from the Simulations ....................... 37
    Rural Costs ......................................... 38
    Time-of-Day Rates .................................. 38
    Business Users ..................................... 39
    Some Possible Variations ........................... 39

Appendix: FORTRAN 77 PROGRAM ......................... 41

REFERENCES ............................................ 51
FIGURES

1. Structure of the simulation model of telephone demand ........................................ 3
2. Mitchell’s analytic model of telephone demand ..................................................... 5
3. Perl’s econometric model of telephone demand ..................................................... 7
4. Distribution of calls as a function of income ......................................................... 12
5. Distribution of reduction in calls as a function of income ........................................ 14
6. Distribution of reduction in calls as a function of calls ........................................... 14
7. Distribution of time cost as a function of income .................................................... 17
8. Distribution of time cost as a function of calls ....................................................... 17
9. Distribution of option value as a function of income .............................................. 19
10. Distribution of option value as a function of calls ............................................... 19
11. Distribution of tenancy as a function of income .................................................... 20
12. Distribution of tenancy as a function of calls ....................................................... 20

TABLES

1. Distribution of households by income category ..................................................... 10
2. Plausible values of extra time to make out-of-house calls ....................................... 15
3. Target and simulated telephone penetration by income and flat rate prices ............... 22
4. Calibrated parameter values .................................................................................... 24
5. Relative prices for options in California ................................................................ 26
6. Assumed incremental costs used in model ............................................................. 26
7. Effect of adding options on price levels ................................................................... 31
8. Effect of adding options on telephone penetration, by income tercile ....................... 32
9. Effect of adding options on consumer surplus, by income tercile ............................ 34
10. Effect of adding options on contributions to telephone company’s revenue requirement and on economic welfare ................................................................. 35
I. INTRODUCTION

BACKGROUND

Telephone rates in the United States are currently being restructured to decrease the contribution that long distance service has historically made to maintaining low rates for local service to residential customers. Most experts agree that this restructuring will increase aggregate economic welfare—by bringing prices more in line with costs, or by lowering prices on services with more elastic demand while raising prices on services with less elastic demand.

Despite the acknowledged welfare gains to be had from this restructuring, many people are concerned that universal service could be jeopardized if local rates are increased.¹ There is also concern that higher local rates may disproportionately burden low income subscribers who make few long distance calls. As a result, several states have adopted so-called “lifeline” plans that offer local telephone service at lower prices to households that meet some eligibility criterion, usually an income test.

Local telephone service in the United States is priced according to one or more of the following plans: flat rate—a fixed monthly price for unlimited local calling; measured rate—a monthly price plus one or more charges for each local call or minute of calling; lifeline rate—a discounted flat or measured rate available to low income or other specific consumers. The availability and use of these rates vary across the country.

Flat rate service, still by far the most common way of pricing residential telephone service, is the only service offered residential customers in many communities. In an increasing number of locations, however, measured rate service is offered as an option to flat rate. Most residential customers offered this choice choose flat rates. In a few places, notably New York City and Chicago, flat rate service is not available, and all residential customers face mandatory measured rates. In most communities, business customers pay only measured rates.

¹“Universal” service is conventionally considered to have been achieved when almost all households have a telephone. In 1987, 92.5 percent of U. S. households in the Current Population Survey reported having a telephone in their house or apartment (Perl, 1988).
ISSUES

In some states a variety of lifeline plans have been in place for several years. These policies and their apparent outcomes are critically examined in a companion RAND study (Johnson, 1988). In this study we focus on the potential results that could be obtained by the strategic use of lifeline and measured service tariffs, looking for answers to questions like these:

- Do higher local telephone rates threaten universal telephone service?
- Can lifeline service in fact increase telephone penetration, or does it only redistribute income?
- What effect do lifeline rates have on economic welfare?
- Is measured service a satisfactory alternative to lifeline rates?
- If lifeline rates are offered, should they be available only as a measured service rate, or should a flat rate lifeline service be offered?

Our objective in this report is to assess the effectiveness of changes in local rate structures in terms of the long-established "universal service" policy goal. We analyze the quantitative effects of alternative rate plans on three primary variables: the number of telephone subscribers (penetration); the distribution of benefits among consumer groups (consumer surplus distribution); and the economic efficiency of local telephone rates (aggregate economic welfare). Looking at the use of optional measured rates as well as subsidized or "lifeline" rates, we assess what reduction in availability is likely if the average price of local telephone service is increased, and how measured or lifeline rates would help limit the loss of subscribers.²

OVERVIEW OF THE SIMULATION APPROACH

We chose computer simulation as a method for systematically analyzing these rather complicated questions. In the simulation model, households are characterized by six key variables which we model as probability distributions rather than as single values. Although this approach leads to a richer and more realistic model, it also makes the

²We do not attempt to model interactions between the markets for local and long distance telephone service. Long distance services affect the demand for access and also affect the intrastate revenue requirement. Interactions with long-distance services would be a good topic for further research.
problem analytically intractable and necessitates the use of numerical methods.\(^3\)

The general structure of the simulation model is shown in Fig. 1. The six variables that affect or characterize a household's demand for telephone service include income, telephone usage, price responsiveness, time cost, option value, and tenure in residence. When available, empirical information is built into the distribution functions to make them as realistic as possible. Parameters for which empirical information is not available are calibrated based on reasonableness and the fit of model predictions to empirical penetration estimates.

We confront the simulated households with alternative sets of optional rate plans, including the prices charged under each plan.

![Diagram](image)

Fig. 1—Structure of the simulation model of telephone demand

\(^3\)We chose simulation over numerical integration because it was easier to program. Simulation has the disadvantage of introducing sampling error, but that can be limited to any desired small amount by doing enough iterations of the simulation. We found that 100 iterations were sufficient of make the standard errors of the results inconsequentially small.
Following Mitchell (1978) and Alleman (1977), we treat the demand for access to telephone service as derived from the demand for telephone calls. We assume that consumers make rational economic choices, deciding on a telephone rate based on complete information about the alternative rates. We exclude any preference that consumers may have for flat rate as a pricing structure, perhaps because they dislike the risk of bill fluctuations or the idea of a meter ticking while they talk. This idealization of consumer choice permits us to concentrate on the principal longer-term effects of rates.4

For each household in the simulated population we calculate the number of calls it would make under each available rate plan and the consumer surplus it would realize from that plan. We assign each household to the plan that maximizes surplus for that household (which may possibly be not to subscribe at all). We then aggregate over all households to find overall subscriber penetration and overall consumer surplus.

The simulation model also includes realistic information on the incremental costs of local telephone service. Adding telephone company revenue to aggregate consumer surplus and deducting incremental cost yields a measure of relative aggregate economic welfare for each set of alternative rate plans.

Calculated quantities of calls and subscribers, together with prices, determine telephone company revenue. Revenue less incremental costs is a measure of the local service contribution to the company’s revenue requirement. That contribution will typically decline as additional options are introduced at fixed prices, because households will tend to migrate to options that lower their telephone bills. To make the alternative option packages comparable, the simulation adjusts price levels to keep net revenue constant as options are added.

Our approach has several strengths:

- It exploits the economic structure of the demand for telephone service and telephone calls, and derives the value of service to a potential subscriber from the value of calls.
- It makes possible quantitative comparisons of economic efficiency of different rate plans.

4In the short term, Infosino (1979) and others have shown that more households choose flat rates than the rational economic choice model predicts. Also, Johnson (1988) finds that only a fraction of those eligible (some 50 percent in California) sign up for life-line service. Thus, our results should not be taken as short term predictions of consumer reactions to alternative rate plans, but rather as an evaluation of the long term consequences of alternative plans if consumers were eventually to reach equilibrium based on fully rational choices.
- It makes possible analysis of detailed local tariffs as optional rates.
- It incorporates, from a variety of sources, existing empirical estimates of the effects of income and price on telephone calling, and variations in the distribution of telephone penetration and calling across income groups.

**RELATION TO PREVIOUS STUDIES**

**Mitchell's Analytic Model of Telephone Demand**

The simulation model is an outgrowth and elaboration of a simpler analytic model by Mitchell (1978). Mitchell's model has the same structure as our current simulation model, but the components are all simpler: more abstract and less realistic (see Fig. 2).

![Diagram of Mitchell's Analytic Model of Telephone Demand]

---

**Fig. 2**—Mitchell's analytic model of telephone demand
Mitchell’s model differs from our simulation model in several ways:

- Mitchell characterizes households using just two parameters: income and taste for calls, rather than the six parameters used here.
- Mitchell’s specification of the demand for telephone calls constrains the demand curves for different households to be non-crossing; we do not impose that constraint here.
- In Mitchell, the customer can choose only between subscribing and not subscribing; here, customers can choose from among up to four telephone subscription options.
- Mitchell ignores the possibility open to non-subscribers of making local calls from neighbors’ or other out-of-house phones; that possibility is included in our model.
- Mitchell ignores the installation charges associated with starting telephone service; those charges are explicitly included in our model.
- Mitchell’s simpler model can be solved analytically; our more complex model requires numerical simulation.
- We have more empirical evidence now available to assist in calibrating our model.

Perl’s Econometric Model of Telephone Demand

Perl’s econometric study of the determinants of telephone penetration (1984) offers a possible alternative way to answer some of the questions investigated here and is an important input into our simulation model.

An econometric prediction is the most direct and probably the most accurate way to estimate telephone penetration for options and prices similar to those currently offered. If that were the only issue we wanted to address, we would not need to construct a simulation model; we could rely on Perl’s econometric model. But, as indicated in Fig. 3, the econometric model does not have some of the pieces that are needed to analyze changes in consumer surplus and aggregate welfare. Also, we want to analyze the effect of more complex local rate options than those included in Perl’s model.

Although Perl’s econometric model is not a substitute for the simulation model, it is a very important input. In Sec. II we describe how we use Perl’s estimates to calibrate our model.
Fig. 3—Perl's econometric model of telephone demand

ORGANIZATION OF THE REPORT

The specification and calibration of the simulation model are described in detail in Sec. II. In Sec. III we present some detailed results from running the simulation model and in Sec. IV discuss the results and possible extensions of the model. An Appendix gives the computer code.
II. SPECIFYING AND CALIBRATING THE SIMULATION MODEL

We specified a computer simulation model that describes (1) a population of households that choose whether to subscribe to telephone service, (2) the various options that they get to choose among, and (3) the incremental costs of providing telephone service. By running the model, we simulated the choices that rational households would make, and the telephone penetration, consumer surplus, and economic welfare that would result from those choices. This section describes the particular specification that we used to obtain the results described in this report.

The model offers flexibility for exploring other alternatives. The numerical parameters that define the distributions of household characteristics, telephone service prices, and telephone service costs can all be easily varied by changing the input to the model. Even the form of some of the distributions can be varied by changing input. With only slightly more work, the computer code could be modified to alter the assumptions in other ways. We discuss some of these alternatives in Sec. IV.

SPECIFICATION OF THE DISTRIBUTION OF HOUSEHOLD CHARACTERISTICS

In the model, a household is characterized by six numbers (units are shown in parentheses):

- $y = \text{income ($1000/\text{year}$)}$
- $x = \text{number of local calls at zero price per call (calls)}$
- $r = \text{reduction in calls at$0.10\text{ per call (fraction)}$
- $t = \text{time cost of an out-of-house call ($/\text{call}$)}$
- $o = \text{additional value of having a phone in the house for incoming calls, toll calls, and emergencies ($/\text{month}$)}$
- $h = \text{duration of tenancy (months)}$

Using these numbers we could model the household's choice among telephone service options (including the option of not subscribing) as a rational surplus-maximizing decision. The basic idea was to compare the net value to each household of each available option (not subscribing, subscribing to flat rate service, subscribing to measured rate
service, etc.), and assume that the household chooses the option with the highest net value. The net value is the consumer surplus from making local calls, plus the additional value of having a phone in the house for other reasons, less the cost of having a phone. The consumer surplus from making local calls is determined from the demand curve for local calls (which in turn depends on income, number of local calls at a zero price per call, and the reduction in calls at 10 cents per call) and the price of a call (which is zero for flat rates, and is the time cost of out-of-house calls for non-subscribers). The cost of having a phone, which may differ for each option, is the monthly charge plus the installation charge prorated over the duration of tenancy.

The six numbers that describe each simulated household were determined by drawing randomly from statistical distributions:

- **Income**: empirical distribution per *Statistical Abstract* (1987)
- **Number of calls**: calls to the .27 power normally distributed per Pavarini (1979)
- **Elasticity of calls**: logistically distributed around value estimated by Park, Wetzel, and Mitchell (1983)
- **Time cost**: heteroscedastic normal distribution around implied wage rate
- **Option value**: heteroscedastic normal distribution around a value related to income and number of calls
- **Tenancy period**: heteroscedastic normal distribution around a value related to income.

Some of the distributions (income, calls) have been carefully studied empirically; we specified these in detail a priori. Others (time cost, option value) have not been so carefully studied; we specified reasonable functional forms and general ranges of values for these, but left the details for the calibration step described later.

### Income

We specified a lognormal distribution of income, with piecewise adjustments to match the proportions of households in the income categories reported in *Statistical Abstract* (Table 722, 1987). The effect of this two-step specification is that the lognormal distribution determines the distribution of households within income categories, and the empirical distribution determines the distribution between categories.
proportions are shown in Table 1. The following lognormal distribution of income \( y \) roughly approximates the distribution in Table 1:

\[
\ln(y) \sim N(3.165, .85)
\]

A representative sample of \( \ln(y) \) for \( n \) simulated households can be obtained by systematically sampling \( \ln(y) \) from the above distribution with a sampling interval equal to \( 1/(1 + n) \), that is, by finding

\[
\ln(y) = 3.165 + .85z(p), \quad p = \frac{1}{1 + n}, \ldots, \frac{n}{1 + n}
\]

where \( z(\cdot) \) is the inverse normal distribution function.

The resulting distribution of \( y \) does not match that in Table 1 exactly in each category. To get an exact match, we adjusted the sampling interval within each income category. For example, a sampling interval of \( 1/(1 + n) \) results in 12.6 percent of households having an income between $15,000 and $20,000 per year, where we want only 10.9 percent. To get it right, we used a sampling interval of \( (12.6/10.9) \times 1/(1 + n) \) over this range of income. We adjusted the sampling interval in an analogous manner over the other ranges of the tabulated income distribution as well.

**Table 1**

<table>
<thead>
<tr>
<th>Annual Income ($1000)</th>
<th>Percent of Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>7.8</td>
</tr>
<tr>
<td>5–10</td>
<td>12.4</td>
</tr>
<tr>
<td>10–15</td>
<td>11.5</td>
</tr>
<tr>
<td>15–20</td>
<td>10.9</td>
</tr>
<tr>
<td>20–25</td>
<td>10.0</td>
</tr>
<tr>
<td>25–35</td>
<td>17.0</td>
</tr>
<tr>
<td>35–50</td>
<td>15.8</td>
</tr>
<tr>
<td>50 +</td>
<td>14.6</td>
</tr>
</tbody>
</table>

**SOURCE:** *Statistical Abstract of the United States* (1967).
Local Calls at Zero Price per Call

Pavarini (1979) examined the distribution of households by the number of telephone calls they make per month under flat rates \( x \). He found that \( x^{27} \) is normally distributed, and that the standard deviation of \( x \) is .8 times the mean of \( x \) regardless of the value of the mean. Mitchell (1978) chooses a value of 120 as the mean number of calls per month.² Park, Mitchell, Wetzel, and Alleman (1983) found only a weak relationship between income and the number of calls made under flat rates. Infosino (1980) found that the number of flat-rate calls was not monotonically related to income. Brandon (1981) found a slight positive relationship between income and the number of calls made at a positive price per call.

Based on this evidence, we simulated the number of calls that a household would make at a zero price by randomly drawing from the distribution

\[
x^{27} \sim N(3.4, .77)
\]

independent of income.³ We drew \( x^{27} \) from this distribution and calculated the corresponding values of untransformed \( x \) as \( (x^{27})^{.7037} \). One realization of values of \( x \) is plotted against income in Fig. 4. The simulated value of \( x \) establishes one point on a household’s demand curve for telephone calls, that is, the point on the zero-price axis.

Reduction in Calls at a Positive Price per Call

We used price effects estimated by Park, Wetzel, and Mitchell (1983) to guide our specification of the distribution of households by their sensitivity to the price per call. We specified price sensitivity in terms of the fractional reduction in calls when the price per call increases from 0 to 10 cents, a reduction that we denote by \( r \). The Park, Wetzel, and Mitchell estimates suggest that a price of \( p_r = 10 \) cents (in current dollars) would reduce the number of calls by about 17 percent on average.⁴ Also, Park, Mitchell, Wetzel, and Alleman (1983)

²He cites “a study of exchanges in California and conversations with Bell System personnel.”

³We found the mean (3.4) and standard deviation (.77) of the normal distribution of \( x^{27} \) by trial and error such that the mean and standard deviation of \( x \) were 120 and \( 8 \times 120 \), respectively. In all of the simulations, we rejected random draws that were more than 3 standard deviations from the mean, so negative realizations of \( x^{27} \) never occurred.

⁴Park, Wetzel, and Mitchell estimated that a price of \( p_r = 6 \) cents reduced calls from \( x_0 \) to \( x = x_0 e^{-.004p_r} = .83x_0 \) in the GTE Illinois experiment. This is the estimated repression effect of a per call charge on the number of calls (Table V in Park, Wetzel, and Mitchell, 1983). There \( p_r \) was measured in 1978 dollars. Adjusting for inflation gives \( p_r = 10 \) cents in current dollars.
found that the fractional reduction $r$ was smaller for higher income households, and larger for households that made more calls at a zero price. Finally, admissible values of $r$ must lie between 0 and 1.

Based on this evidence, we simulated a household's value of $r$ by randomly drawing from a logistic distribution of $r$ as a function of $y$ and $x$:

$$\ln\left(\frac{r}{1-r}\right) \sim N(\mu(y,x), \sigma_r)$$

$$\mu(y,x) = b_{r0} + b_{ry}(\ln(y) - 3.165) + b_{rx}(x^{.27} - 3.4),$$

where $b_{ry}$ is a negative coefficient, $b_{rx}$ is a positive coefficient, and $b_{r0}$ is a coefficient with a value in the neighborhood of $\ln(.17/(1-.17)) = -1.6$. That is, the logit of $r$ is normally distributed about a mean value
that is a decreasing function of income and an increasing function of the number of calls at a zero price. One realization of values of \( r \) drawn from this distribution is plotted against income in Fig. 5 and against monthly calls in Fig. 6.

The exact values of the coefficients were determined in the calibration step described below.

Given an assumed functional form, the values of \( x \) and \( r \) together completely determine a household's demand curve for local telephone calls. In the simulations reported here, we used a negative exponential demand curve:

\[
\hat{x} = xe^{-\alpha p}.
\]

where \( \hat{x} \) is the number of calls demanded at the price \( p \). The value of \( \alpha \) for a particular household is calculated as

\[
a = \frac{-\ln(1 - r)}{10}.
\]

The consumer surplus that this household gets from making \( \hat{x} \) calls at a price of \( p \) is measured by the area under the demand curve and above \( p \). That amount is

\[
cs = \frac{(\hat{x}/a)[1 + \ln(x/\hat{x})]}{2} - p \hat{x}
\]

\[
= \frac{\hat{x}}{a}.
\]

**Time Cost of Out-of-House Calls**

A household that chooses not to subscribe to telephone service can still ordinarily make and receive some calls on other phones (neighbors' phones, coin phones). We modeled the disutility of leaving the house to make calls as the value \( t \) per call (measured in dollars per call). We refer to \( t \) as the time cost of an out-of-house call, but more broadly it will include other costs in addition to time costs.

To get a rough idea of the values that \( t \) might take, we calculated a household's implicit wage rate by dividing its annual income \( y \) by (235 workdays per year) \times (8 hours per day) \times (1.33 wage earners per average household) \approx 2500 work hours per year. Then with \( y \) measured in $1000 per year, the value of \( t = (y/2.5) \times \) the extra time (in hours) that it takes to make a call from outside the house, a value that is shown for various levels of income and extra time in Table 2. Because \( t \) is time cost per call, there is no compelling reason to think that it would vary with a household's value of the number of calls \( x \).
Fig. 5—Distribution of reduction in calls as a function of income

Fig. 6—Distribution of reduction in calls as a function of calls
From Table 2, if the extra time to make an out-of-house call is 15 minutes, then $t$ equals $y/10$. For households with the same income, there will be random variations around that value reflecting differences in the proximity of an out-of-house phone, departures of actual time value from our calculation of the implicit wage rate, existence of other costs (or benefits) of making out-of-house calls, and so on. We expected that the variation would be greater for larger values of $t$.

Based on these musings, we simulated a household's value of $t$ by randomly drawing from a normal distribution whose mean and standard deviation are increasing functions of $y$ (a "heteroscedastic normal" distribution):

$$t \sim N(\mu(y), \sigma(\mu))$$

$$\mu(y) = b_{t0} + b_{t1}(y/100)$$

$$\sigma(\mu) = \mu^\rho \sigma_t$$

where $b_{t0}$ is the expected value of $t$ for a household with $y = 0$ (and a plausible value of $b_{t0}$ is approximately 0), $b_{t1}$ is the expected additional value of $t$ for a household with $y = 100$ (and plausible values of $b_{t1}$ would be on the order of 10), and $\rho$ is the heteroscedasticity parameter for $t$ (and we expect $\rho$ to be around 1, certainly greater than 0 and less than about 2). The exact values of these parameters were determined in the calibration step. One realization of values of $t$ drawn from this

<table>
<thead>
<tr>
<th>Annual Income ($1000)</th>
<th>5 min</th>
<th>15 min</th>
<th>30 min</th>
<th>60 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.17</td>
<td>0.50</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>10</td>
<td>0.33</td>
<td>1.00</td>
<td>2.00</td>
<td>4.00</td>
</tr>
<tr>
<td>20</td>
<td>0.67</td>
<td>2.00</td>
<td>4.00</td>
<td>8.00</td>
</tr>
<tr>
<td>50</td>
<td>1.67</td>
<td>5.00</td>
<td>10.00</td>
<td>20.00</td>
</tr>
<tr>
<td>100</td>
<td>3.33</td>
<td>10.00</td>
<td>20.00</td>
<td>40.00</td>
</tr>
</tbody>
</table>

---

*We reset realizations of $t < 0$ dollars per call to $t = 0$ dollars per call.*
distribution is plotted against income in Fig. 7 and against monthly
calls in Fig. 8.

In the simulations, we treated \( t \) as the equivalent of a price per call,
\( p_c \). Thus the consumer surplus that a household would obtain from
making \( x = xe^{-at} \) out-of-house calls is given by the \( cs \) equation above
with \( t \) substituted to \( p_c \).

**Additional Value of Having a Phone in the House for Incoming
Calls, Toll Calls, and Emergencies**

The demand curves defined by \( x \) and \( r \) let us evaluate the consumer
surplus that a household obtains from originating local calls, and let us
compare the surplus from placing those calls on a telephone in the
home vs. placing them on an out-of-house phone. Most households
that subscribe to telephone service will get additional benefits: conven-
tient origination of long-distance calls, convenient receipt of incoming
calls, peace of mind from having a phone readily available for
demergencies.

We did not model these additional benefits in the same detail that
we modeled the value of originating local calls, because we could find
no empirical basis for doing so. Instead, we summarized them in a sin-
gle value \( o \) for each household. We expected that \( o \) would tend to be
larger for households with higher income \( y \) and also for households
with higher calling rates \( x \). We also expected larger values of \( o \) to have
higher variance than smaller values.

We simulated \( o \) by random draws from a heteroscedastic normal dis-
tribution of \( o \) around a linear function of \( y \) and \( x \):

\[
\begin{align*}
o & \sim N(\mu(y, x), \sigma(\mu)) \\
\mu(y, x) & = b_{00} + b_{oy}(y/100) + b_{ox}(x/500) \\
\sigma(\mu) & = \mu^\rho \sigma_o
\end{align*}
\]

where \( b_{00} \) is the expected value of \( o \) for a household with \( y = 0 \) and
\( x = 0 \), \( b_{oy} \) is the expected additional value of \( o \) for a household with
\( y = 100 \), \( b_{ox} \) is the expected additional value of \( o \) for a household with
\( x = 500 \), and \( \rho_o \) is the heteroscedasticity parameter for \( o \) (again, we
expected \( \rho_o \) to be around 1, certainly greater than 0 and less than
about 2).\(^6\) We had no strong expectations about values of the other
parameters; they were determined in the calibration step. One

\(^6\)We reset realizations of \( o < 0 \) dollars to \( o = 0 \) dollars.
Fig. 7—Distribution of time cost as a function of income

Fig. 8—Distribution of time cost as a function of calls
realization of values of $o$ drawn from this distribution is plotted against income in Fig. 9 and against monthly calls in Fig. 10.

**Duration of Tenancy**

In the simulations, households compare the value of telephone service to its cost in order to decide whether to subscribe. The costs of service include monthly fees $p_m$ which can be compared directly to monthly benefits. Costs also include one-time installation fees $p_i$ which must be amortized over the time that the potential subscribing household expects to remain in its new location. Consequently we needed to know the duration of tenancy $h$ for each household.\(^7\)

Tenancy periods average somewhere around five years in the United States. We expected they would tend to be shorter for households with lower income $y$ and longer for households with higher $y$. We also expected the same sort of heteroscedasticity in the distribution of $h$ as we specified for $t$ and $o$. Thus we simulated $h$ by random draws from a heteroscedastic normal distribution of $h$ around a linear function of $y$:

$$h \sim N(\mu(y), \sigma(\mu))$$

$$\mu(y) = b_{h0} + b_{hy}(y/100)$$

$$\sigma(\mu) = \mu^\rho \sigma_h$$

where $b_{h0}$ is the expected value of $h$ for a household with $y = 0$ (and plausible values of $b_{h0}$ would be less than 60 months); $b_{hy}$ is the expected additional value of $h$ for a household with $y - 100$ (and plausible values of $b_{h0} + b_{hy}$ would be greater than 60 months); and $\rho_h$ is the heteroscedasticity parameter for $h$ (expected to be around 1, certainly greater than 0 and less than about 2).\(^8\) The exact values were determined in the calibration step. One realization of values of $h$ drawn from this distribution is plotted against income in Fig. 11 and against monthly calls in Fig. 12.

---

\(^7\)In principle, the household's discount rate is also needed to calculate an "effective" tenancy duration. A household with a higher discount rate would have a shorter effective tenancy than would another household with exactly the same actual tenancy. However, we found during the calibration step that the discount rate had very little effect and consequently the parameters of the discount rate distribution were impossible to estimate. Thus we decided to drop the unnecessary complication and model only actual tenancy.

\(^8\)We reset realizations of $h < 1$ month to $h = 1$ month.
Fig. 9—Distribution of option value as a function of income

Fig. 10—Distribution of option value as a function of calls
Fig. 11—Distribution of tenancy as a function of income

Fig. 12—Distribution of tenancy as a function of calls
CALIBRATION OF HOUSEHOLD CHARACTERISTICS

So far we have specified functional forms for the distributions from which we drew the six numbers that characterize a household in our simulations. We have also specified some, but not all, of the numerical parameters of those distributions. In the calibration step described here, we picked numerical values for the rest of the parameters.

Perl Estimates of Flat Rate Telephone Penetration as Targets

The basic idea of the calibration step was to find values for the parameters that would produce reasonable estimates of flat rate telephone penetration by income category at various price levels. Probably the best estimates of penetration are those of Perl (1984).

The target values for penetration, calculated from Perl’s logistic regression equation, are shown in Table 3. We calculated nine different values of telephone penetration by setting the flat rate price variables to three different levels and for each level, finding the predicted penetration for each income tertile. The flat rate prices were set to zero, to about current levels, and to double current levels. For current levels, we used \( p_m = \$11.20 \) flat-rate monthly fee and \( p_t = \$50.00 \) installation fee, which approximate current prices in California (Table 5 below).\(^9\) We then calculated a probability of subscribing for each simulated household, and summed the probabilities over all households in each income tertile to get estimated penetration.\(^10\)

According to the Perl estimates, not all households subscribe to telephone service even when it costs nothing to do so. This is not consistent with a world consisting solely of fully rational households in perfect equilibrium, but it does seem to make sense as a statement about the real world. In reality, some households will be in transition or in turmoil at any given time, and unable to take advantage of telephone service even if it is free.

\(^9\)The other independent variables in the Perl equation were set to the mean of Perl’s sample values, except: income squared was set to the square of the simulated value of income; income \( \times \) age was set to income \( \times \) sample mean age; proportion of households in areas with measured service was set to 0; the non-farm dummy variable was set to 1; the southern region dummy was set to 0.

\(^10\)The Perl equation is quadratic in income, and the estimated probability of subscribing falls off rapidly (to almost zero at very high income levels) past its maximum value, which occurs at a household income of about \$54,000 per year. In calculating target penetration levels, we reset the estimated probability at current prices to .99 for all simulated households with incomes above \$54,000 per year. For zero and doubled prices, we reset it to correspondingly higher and lower values as determined by the price coefficients in Perl’s equation.
Table 3
TARGET AND SIMULATED TELEPHONE PENETRATION BY INCOME AND FLAT RATE PRICES
(In percent)

<table>
<thead>
<tr>
<th>Income Tertile</th>
<th>Flat Rate Prices</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perl Estimates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest</td>
<td>.944</td>
<td>.893</td>
<td>.804</td>
</tr>
<tr>
<td>Middle</td>
<td>.983</td>
<td>.965</td>
<td>.931</td>
</tr>
<tr>
<td>Highest</td>
<td>.993</td>
<td>.986</td>
<td>.972</td>
</tr>
<tr>
<td>Raw Simulation Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest</td>
<td>1.000</td>
<td>.958</td>
<td>.846</td>
</tr>
<tr>
<td>Middle</td>
<td>1.000</td>
<td>.990</td>
<td>.956</td>
</tr>
<tr>
<td>Highest</td>
<td>1.000</td>
<td>.998</td>
<td>.987</td>
</tr>
<tr>
<td>Adjusted Simulation Results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest</td>
<td>.939</td>
<td>.900</td>
<td>.794</td>
</tr>
<tr>
<td>Middle</td>
<td>.976</td>
<td>.966</td>
<td>.938</td>
</tr>
<tr>
<td>Highest</td>
<td>.989</td>
<td>.986</td>
<td>.976</td>
</tr>
</tbody>
</table>

Reconciling Raw Simulation Results with the Perl Estimates

The simulation model, in contrast, assumes that all households are both rational and in equilibrium. Consequently, the raw simulation results in Table 3 show 100 percent telephone penetration when prices are zero. We reconcile the simulation model and the more realistic Perl estimates by saying, plausibly enough, that the simulation model explains the behavior of something less than all households—only those that might conceivably make a rational decision to subscribe to telephone service. A smaller group of never-subscribing households—that is, those who would not subscribe even at a zero price—are outside the model.

Denote the fraction of all households in each income tertile $i$ that are included in the simulation model by $f_i$, $i = 1, 2, 3$, and the fraction of those households that subscribe at each price level $j$ by $s_{ij}$, $j = 1, 2, 3$.\textsuperscript{11} Then the fraction of all households in income tertile $i$ \textsuperscript{11}The $s_{ij}$ are the values shown as “raw simulation results” in Table 3. We have not yet said anything about how we arrived at these numbers; we will cover that in the next subsection. But for present purposes it does not matter where they came from; the same adjustment procedure applies to any raw simulation results.
subscribing at price level \( j \) is \( f_i s_{ij} \). We estimate \( f_i \) separately for each income tertile by minimizing a weighted sum of squared deviations of \( f_i s_{ij} \) from the corresponding Perl target values. We use a weighted sum, rather than an unweighted sum, in recognition of the fact that the Perl estimates are certainly better in the neighborhood of current prices than they are at zero or doubled prices.\(^{12}\) Multiplying the raw simulation results \( s_{ij} \) by the resulting estimates gives the adjusted simulation results shown in Table 3.

**Search for Calibrated Parameter Values**

At first we attempted to calibrate the model in the following objective manner.

1. Choose "reasonable" values of the parameters that were not already specified exactly.
2. Run the simulation model many times with the individual parameter values in each run randomly multiplied by \((1 - k), 1.0, \) or \((1 + k)\), with equal probability, where \( 0.5 < k < 1.0 \).
3. In each run of the model, calculate adjusted simulated penetration by income tertile at current flat-rate prices (specified as $11.20 per month and $50.00 per installation).
4. In each run of the model, calculate as a goodness-of-fit criterion the sum of the absolute deviations of the predicted penetrations from the Table 3 values.
5. Fit a quadratic goodness-of-fit response surface by regressing the criterion value on the parameter values, the squares of the parameter values, and a complete set of interactions of the parameter values.
6. Find the zero-slope point on the fitted response surface and adopt the parameter values at that point as calibrated values.

Unfortunately, this procedure always found saddle points rather than minima. Fortunately, one of our attempts did find a set of parameter values that fit penetration levels at present price levels reasonably well. These served as a starting point for a judgmental search which led to the calibrated parameter values shown in Table 4.

The calibrated parameters produced adjusted simulation results that matched the target values very well; the adjusted simulation results in

\(^{12}\)We used weights of 1 on the penetration at zero and doubled prices, and 2 on the penetration at current prices.
Table 4

CALIBRATED PARAMETER VALUES

<table>
<thead>
<tr>
<th>Parameter Category/ Symbol</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual income</td>
<td></td>
</tr>
<tr>
<td>$\gamma_0$</td>
<td>3.165</td>
</tr>
<tr>
<td>$\sigma_y$</td>
<td>0.85</td>
</tr>
<tr>
<td>Calls per month</td>
<td></td>
</tr>
<tr>
<td>$x_0$</td>
<td>3.4</td>
</tr>
<tr>
<td>$b_{xy}$</td>
<td>0.0</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>0.77</td>
</tr>
<tr>
<td>Percent reduction in calls for $p_r = .1$</td>
<td></td>
</tr>
<tr>
<td>$r_0$</td>
<td>-2.0</td>
</tr>
<tr>
<td>$b_{ry}$</td>
<td>-0.5</td>
</tr>
<tr>
<td>$b_{rx}$</td>
<td>0.36</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>0.35</td>
</tr>
<tr>
<td>Time cost of out-of-house calls</td>
<td></td>
</tr>
<tr>
<td>$o_t$</td>
<td>1.</td>
</tr>
<tr>
<td>$\ell_0$</td>
<td>0.15</td>
</tr>
<tr>
<td>$\ell_{ty}$</td>
<td>4.0</td>
</tr>
<tr>
<td>$\ell_{tx}$</td>
<td>0.0</td>
</tr>
<tr>
<td>$\sigma_t$</td>
<td>0.30</td>
</tr>
<tr>
<td>Option value</td>
<td></td>
</tr>
<tr>
<td>$o_o$</td>
<td>0.72</td>
</tr>
<tr>
<td>$o_0$</td>
<td>17.</td>
</tr>
<tr>
<td>$o_{oy}$</td>
<td>34.</td>
</tr>
<tr>
<td>$o_{ox}$</td>
<td>12.</td>
</tr>
<tr>
<td>$\sigma_o$</td>
<td>1.9</td>
</tr>
<tr>
<td>Tenancy period</td>
<td></td>
</tr>
<tr>
<td>$o_h$</td>
<td>0.72</td>
</tr>
<tr>
<td>$h_0$</td>
<td>36.</td>
</tr>
<tr>
<td>$h_{hy}$</td>
<td>60.</td>
</tr>
<tr>
<td>$h_{hx}$</td>
<td>0.</td>
</tr>
<tr>
<td>$\sigma_h$</td>
<td>1.</td>
</tr>
</tbody>
</table>

Table 3 are in fact the results from the calibrated model. The calibrated parameters also produced reasonable-looking distributions of the six numbers that characterize a household. Graphs illustrating the simulated distributions were given in Figs. 4 through 12 above.
SPECIFICATION OF TELEPHONE SERVICE OPTIONS

In this report, we consider four telephone service offerings:

- Standard flat rate
- Standard measured rate
- Measured rate lifeline service available to low-income households
- Flat rate lifeline service available to low-income households

Standard flat rate is the kind of telephone service most widely available to residential customers today. To start service, a customer pays an installation fee \( p_i \). Then for a flat monthly fee \( p_m \), the customer can make an unlimited number of local calls at no additional charge \( (p_c = 0) \).

Standard measured service is increasingly available, most often as an option to flat rate service, not as a mandatory substitute for it. Under measured rates, customers pay a monthly fee that is lower than the flat rate monthly fee, and in addition pay for each local call they make. (Frequently, there is some allowance of free local usage before the per call charge takes effect. Occasionally, there is a cap on the amount that will be charged for local usage. Often, the per call charge varies with the duration of the call, the distance to the called number, and the time of day. We ignore these complications in the present version of the simulation model.)

Several states now offer so-called lifeline service to households that meet some eligibility criterion, usually defined according to income. More elaborate criteria account for household size or age. Lifeline households pay rates that are lower than the standard rates. Lifeline service may be available either as a lower priced measured rate service, or as a lower priced flat rate service.

All four options are currently available in parts of California. The prices in Table 5 are a stylized version of recent prices in California.\(^{13}\) We used Table 5 to define relative prices for the four options, and for the three component prices \( p_i, p_m, \) and \( p_c \). As discussed in Sec. III, the overall price level varies as necessary to meet assumed revenue requirements.

\(^{13}\)We did not attempt to deal with a number of real-world complications, including among others: (1) free call allowances under the standard and lifeline measured rate plans, (2) variations in installation fee depending on whether work must be done at the customer's premises, (3) deposits that may be required of some but not all customers before service commences, (4) variations in lifeline-eligibility income cutoffs depending on household size.
Table 5

RELATIVE PRICES FOR OPTIONS IN CALIFORNIA
(In dollars)

<table>
<thead>
<tr>
<th>Option</th>
<th>Per Call</th>
<th>Per Month</th>
<th>Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard flat rate</td>
<td>0.00</td>
<td>11.30</td>
<td>50.00</td>
</tr>
<tr>
<td>Standard measured rate</td>
<td>0.07</td>
<td>6.00</td>
<td>50.00</td>
</tr>
<tr>
<td>Measured rate lifeline (household income less than $11,800 per year)</td>
<td>0.07</td>
<td>3.00</td>
<td>25.00</td>
</tr>
<tr>
<td>Flat rate lifeline (household income less than $11,800 per year)</td>
<td>0.00</td>
<td>5.60</td>
<td>25.00</td>
</tr>
</tbody>
</table>

SPECIFICATION OF INCREMENTAL COSTS

The specification and calibration of household characteristics and the specification of telephone service options would suffice if all we wanted to do was to evaluate how telephone penetration and consumer surplus would change when price levels or service options changed. But we also wanted to evaluate effects on total economic welfare, and to do this we had to specify incremental costs as well.

We did not need to specify total costs, only those costs incremental to changes that can occur in the model, such as a change in the number of telephone subscribers or in the number of calls they make. Table 6 summarizes our assumptions about incremental costs.

Table 6

ASSUMED INCREMENTAL COSTS USED IN MODEL
(In dollars)

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual capacity cost per design busy-hour call</td>
<td>30.00</td>
</tr>
<tr>
<td>Annual access cost per line</td>
<td>60.00</td>
</tr>
<tr>
<td>One-time installation cost per line</td>
<td>50.00</td>
</tr>
<tr>
<td>Annual measurement cost per measured-rate line</td>
<td>2.10</td>
</tr>
<tr>
<td>One-time measurement cost per call</td>
<td>0.001</td>
</tr>
</tbody>
</table>
We chose the annual capacity cost per design busy-hour call ($30) from the range that we argued in previous work is most likely to be representative of the digital switching and fiber optic transmission facilities now being installed (Park and Mitchell, 1987). This is the annualized average incremental capacity cost of serving an additional call during the design busy hour. On a monthly basis, the figure is a $30/12 = $2.50 cost saving when the number of calls during the design busy hour decreases by one.

Our specification of household characteristics allowed us to calculate the change in total monthly calls associated with a change in service offerings. How is that change related to the change in calls during the design busy hour? We assumed that calls during all hours of the month changed in the same proportion, and that there were three times as many calls during the design busy hour as there were during the average hour of the month. Then a decrease of one in the number of total monthly calls corresponds to a decrease of \( \frac{3}{30 \times 24} \) or the fraction \( .0042 \) of a call during the design busy hour. The corresponding incremental monthly capacity cost saving is \( 2.50 \times .0042 = .0104 \).

The annual access cost per line ($60) is meant to reflect the annualized average incremental capacity cost of an access line in an existing urban area. Access lines consist of two fairly distinct portions. Feeder facilities consist of cable and structures (typically conduit or poles) from the central office to a neighborhood cross-connect device or junction box. Distribution facilities consist of cable and structures (typically poles or direct-burial trenches) from the junction boxes to the home. Feeder cable is added as needed to serve growing demand for telephone lines. In contrast, distribution cable is initially installed with enough capacity to serve the maximum demand that might ever reasonably be expected, and it is not affected by changes in the number of subscribers. Thus the incremental cost of distribution facilities includes the annualized average incremental cost of feeder facilities, but not distribution facilities. On a monthly basis, that cost is \( $60/12 = $5 \).

We assumed that the installation price \( p_i \) for non-lifeline customers in Table 6 is compensatory, and specified the one-time installation cost per line at $50.

We used measurement costs estimated by Beauvais (1984) and used as base-case values in Park and Mitchell (1987). They are $2.10 per year, or $0.175 per month, per line, and $0.001 per call. These apply to measured lines and calls only.

\[ \text{This is a stylized statement of what was actually observed in the GTE Illinois measured-service experiment; see Park and Mitchell (1987).} \]
III. SIMULATION DETAILS AND RESULTS

CASES SIMULATED

We simulated the effect of offering consumers an increasing menu of options—including measured service and lifeline plans in addition to a standard flat rate—at two different price levels: prices near current levels, and prices near double current levels. In all of the simulations, we held relative prices constant, with the relationships as shown in Table 5.

At each of the two price levels, we made options available in the following sequence:

1. Flat rate only
2. Flat rate and measured service options available to everyone
3. Flat rate and measured service options available to everyone, plus a measured rate lifeline service available to low-income households
4. Flat rate and measured service options available to everyone, plus both measured rate and flat rate lifeline services available to low-income households

The idea was to see what effect adding options had on (1) telephone penetration by income class, (2) the distribution of consumer surplus by income class, and (3) the overall level of economic welfare. We wanted to know what these effects would be both at present price levels and at the higher price levels that might prevail in the future.

DETAILS OF THE SIMULATION METHOD

Current Prices

The simulation for situation 1 (only flat rates available) compared for each household the value of subscribing and the value of not subscribing. The value of not subscribing was the consumer surplus from making out-of-house local calls, calculated as the area under the household’s demand curve above the household’s value of \( t \), the time cost of making an out-of-house call. The value of subscribing was:

the area under the household’s demand curve for local calls all the way out to \( x \), the number of calls that household would make at \( p_c = 0 \).
plus \( o \), the additional value of having a phone in the house for incoming and toll calls;

less \( p_m \), the monthly service charge;

less \( p_i/h \), the installation charge prorated over the number of months of tenancy for that household.

If the value of subscribing exceeded the value of not subscribing, we assumed that that household chose to subscribe.

After simulating the subscription decision for all households in situation 1, we noted the value of a quantity that we call "incremental net revenue." This is the excess of the telephone company's simulated monthly revenue (including in this situation monthly fees \( p_m \) and a prorated share of installation fees \( p_i/h \) for households that choose to subscribe) over the incremental costs of serving its customers (including in this situation the incremental cost of calls made by both subscribers and non-subscribers, and the incremental cost of access for subscribers). As we added options in situations 2, 3, and 4, we adjusted the price level as necessary to keep incremental net revenue constant.\(^1\)

A positive value of incremental net revenue does not mean that local telephone service makes a positive contribution to the telephone company's revenue requirement, because incremental net revenue does not account for fixed costs such as the cost of distribution plant. But a change in incremental net revenue from situation 1 (flat rate only) to situation 2 (flat rate and measured service) would signal a matching change in the level of the revenue contribution from local service (whether the contribution itself were positive or negative). We held incremental net revenue constant across the four simulated situations in order to make the situations comparable.

In situation 2, we started with Table 5 prices and compared three values for each household: (1) the value of not subscribing and (2) the value of subscribing to flat rate service, both calculated as before, and (3) the value of subscribing to measured rate service. The value of subscribing to measured rate service was the area under the household's demand curve for local calls above the price per call \( p_i \); plus \( o \), the additional value of having a phone in the house for incoming and toll calls; less \( p_m \), the monthly service charge for measured rate service (which is less than \( p_m \) for flat rate service); less \( p_i/h \), the prorated installation charge. Again, we assumed that each household made its highest valued choice.

\(^1\)That is, we multiplied all of the prices in Table 5 by the same adjustment factor, keeping relative prices the same but changing the price level.
Incremental net revenue in situation 2 included not only revenue from subscribers, but also call revenue from the calls that non-subscribers placed on measured rate phones. And it was calculated by deducting not only the costs of access, usage, and installation, but also measurement costs for measured rate subscribers and for the calls placed from measured rate phones by non-subscribers.

On the first pass, incremental net revenue in situation 2 fell short of that in situation 1. We raised the price level and recalculated all household decisions at the higher prices. We then kept on adjusting the price level and re-simulating household decisions as necessary until incremental net revenue equaled that in situation 1.

In situation 3 (flat rate, measured service, measured rate lifeline service to low income households), we started with final situation 2 prices and compared four values for households with incomes below the eligibility level for lifeline rates ($11,800 per year in Table 5), including the three values described under situation 2 above and adding (4) the value of subscribing to measured rate lifeline service. Again, it was necessary to search for a price level high enough to keep incremental net revenue constant.

In situation 4 (flat rate, measured service and both measured rate and flat rate lifeline services to low income households), we started with final situation 3 prices and added a fifth choice for eligible households: (5) flat rate lifeline service.

**Doubled Future Prices**

The loops through the four situations described above simulated penetration, surplus, and welfare at price levels that yield something like the current revenue contribution from local service (be it positive or negative). We then repeated the whole process starting from prices equal to twice those in Table 5 to simulate penetration, surplus, and welfare in the future when, by assumption, local service might be required to yield substantially more revenue.

---

2We assumed that non-subscribers’ calls were divided between flat rate and measured rate service in proportion to the number of households in the lowest income tertile that subscribed to each service.

3Households with incomes above the eligibility cutoff had only the same three choices as in situation 2.
SIMULATION RESULTS

Tables 7 through 10 summarize the results. These results are mean
dvalues from 100 simulation runs for 2004 households each. The stan-
dard errors of the reported means are all very small compared to the
means; the largest value of the standard error for any value in each
table is given in a note to the table.

Price Levels

Table 7 shows how much the price level had to rise to keep the reve-
uue contribution from local service constant when options were added.
Adding measured service attracted a few new customers who did not
subscribe when only flat rate service was available. Revenues gen-
erated by these customers exceeded the incremental costs of serving
them, so when they subscribed they increased incremental net revenue.
The increase was more than offset, however, by the revenue loss that
occurred when substantial numbers of low-use flat-rate customers
shifted to measured rates. In order to keep the revenue contribution

Table 7
EFFECT OF ADDING OPTIONS ON
PRICE LEVELS

<table>
<thead>
<tr>
<th>Option</th>
<th>Percent of Present Price Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Present Prices</td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>100</td>
</tr>
<tr>
<td>Add measured</td>
<td>109</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>115</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>124</td>
</tr>
<tr>
<td>At Doubled Prices</td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>200</td>
</tr>
<tr>
<td>Add measured</td>
<td>216</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>226</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>242</td>
</tr>
</tbody>
</table>

NOTE: Options are cumulative.
Standard errors for values, based on 100
simulation runs, are all \( \leq 0.12 \).
from local service constant, it was necessary to raise the price level by 9 percent when a measured service option was added.

Additional price increases were required to offset the revenue losses that occurred when eligible households chose lower cost lifeline services. When all four options (including flat rate lifeline service) were offered, required prices were 24 percent above those shown in Table 5.

A similar pattern held when we started with flat rate service only at 200 percent of current prices (\(p_m = 22.40\) and \(p_l = 100.00\)) and kept the revenue contribution constant at that level as options were added. Then by the time all four options were in place, required prices were 242 percent of those in Table 5.

Penetration by Income Class

Table 8 shows simulated telephone penetration by income class and overall. The penetration values when only flat rate service is offered at present prices match the values shown for the calibration run in Table 3. Adding options increased penetration among low income households, but only slightly.

<table>
<thead>
<tr>
<th>Option</th>
<th>Income Tertile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>At Present Prices</td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>90</td>
</tr>
<tr>
<td>Add measured</td>
<td>91</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>92</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>92</td>
</tr>
<tr>
<td>At Doubled Prices</td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>79</td>
</tr>
<tr>
<td>Add measured</td>
<td>82</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>87</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>88</td>
</tr>
</tbody>
</table>

NOTE: Options are cumulative. Standard errors for values, based on 100 simulation runs, are all \(\leq 0.14\).
When only flat rates were offered and prices were doubled, there was a large drop in penetration—from 90 percent to 79 percent for low income households, and from 95 to 90 percent overall. Adding measured rates raised low income penetration to 82 percent, and adding the lifeline options raised it further to 87 or 88 percent. A measured rate option also increased middle-income penetration from 93 to 95 percent. The price increases necessary to support lifeline service, however, decreased middle-income penetration to 94 percent when both of the lifeline options were added.4

Consumer Surplus by Income Class

The numbers in Table 9 are average changes in consumer surplus. The averages were calculated over all 668 simulated households in each of the three income classes, whether they subscribed or not.

Overall consumer surplus decreased slightly when options were added at current price levels. This is the net of two effects that work in opposite directions. Giving households more options to choose among tended to increase consumer surplus, as they chose the options that were most valuable to them. But the higher prices needed to maintain local service's contribution to the telephone company's revenue requirement tended to reduce consumer surplus. On balance, the effect of the price increases slightly outweighed the effect of additional choice.

When lifeline rates were introduced at present price levels, low income households benefited substantially from choosing this low cost service. The benefit came largely at the expense of higher income customers, who had to pay higher rates to support the lifeline offerings.

At doubled prices, consumer surplus was substantially lower than it was under present flat rate service, for all income classes and regardless of what options were offered. (But remember that this is for the local telephone market only; many customers would benefit from the lower long distance rates that the higher local rates would make possible.)

The lowest block of Table 9 takes doubled prices as a given, and shows the effects of adding options at these higher prices. Adding a measured service option had only small effects on consumer surplus. The effect of adding lifeline options is similar at present and doubled prices: low income households benefit at the expense of higher income households.

4None of the middle- or high-income households was eligible for lifeline service.
Table 9

EFFECT OF ADDING OPTIONS ON CONSUMER SURPLUS,
BY INCOME TERTILE
(In dollars per month per average household)

<table>
<thead>
<tr>
<th>Option</th>
<th>Income Tertile</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Middle</td>
<td>High</td>
</tr>
<tr>
<td>At Present Prices</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Flat only</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Add measured</td>
<td></td>
<td>-0.15</td>
<td>-0.11</td>
<td>-0.07</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td></td>
<td>1.01</td>
<td>-0.79</td>
<td>-0.73</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td></td>
<td>3.13</td>
<td>-1.79</td>
<td>-1.71</td>
</tr>
<tr>
<td>At Doubled Prices (Relative to Present Flat)</td>
<td></td>
<td>-11.49</td>
<td>-12.08</td>
<td>-11.95</td>
</tr>
<tr>
<td>Flat only</td>
<td></td>
<td>-11.49</td>
<td>-12.08</td>
<td>-11.95</td>
</tr>
<tr>
<td>Add measured</td>
<td></td>
<td>-11.58</td>
<td>-12.06</td>
<td>-11.80</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td></td>
<td>-9.29</td>
<td>-13.21</td>
<td>-12.94</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td></td>
<td>-5.26</td>
<td>-14.93</td>
<td>-14.65</td>
</tr>
<tr>
<td>At Doubled Prices (Relative to Doubled Flat)</td>
<td></td>
<td>-11.61</td>
<td>-11.84</td>
<td>-11.81</td>
</tr>
</tbody>
</table>

aChange is relative to flat rate monthly charge.
NOTE: Options are cumulative. Standard errors for values, based on 100 simulation runs, are all ≤ 0.02.

Contribution to the Telephone Company's Revenue Requirement

Table 10 shows the average change in contribution to the telephone company's revenue requirement. The average is over all 2004 simulated households, whether they subscribed or not. We measured changes relative to the contribution when only flat rates were offered at present prices, so for present prices, flat rate only, the contribution is $0.00. As we added options, we adjusted the price level to keep the contribution constant, so the next three cells are also $0.00.

Doubling prices and offering flat rate service only increased the average contribution by $11.16. This is the net effect of an increase of $11.20 in the monthly bill of households who continued to subscribe at the higher prices, some increase in the prorated installation revenue from continuing subscribers, and the loss of revenue from households
Table 10

EFFECT OF ADDING OPTIONS ON CONTRIBUTIONS TO TELEPHONE COMPANY'S REVENUE REQUIREMENT AND ON ECONOMIC WELFARE
(In dollars per month per average household)

<table>
<thead>
<tr>
<th>Option</th>
<th>Contribution$^a$</th>
<th>Economic Welfare$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Present Prices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Add measured</td>
<td>0.00</td>
<td>-0.11</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>0.00</td>
<td>-0.17</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>0.00</td>
<td>-0.09</td>
</tr>
<tr>
<td>At Doubled Prices (Relative to Present Flat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>11.16</td>
<td>-0.68</td>
</tr>
<tr>
<td>Add measured</td>
<td>11.16</td>
<td>-0.66</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>11.16</td>
<td>-0.66</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>11.16</td>
<td>-0.45</td>
</tr>
<tr>
<td>At Doubled Prices (Relative to Doubled Flat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat only</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Add measured</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>Add measured lifeline</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>Add flat lifeline</td>
<td>0.00</td>
<td>0.23</td>
</tr>
</tbody>
</table>

$^a$Change is relative to flat rate monthly charge.

NOTE: Options are cumulative. Standard errors for values, based on 100 simulation runs, are all ≤ 0.01.

that dropped their subscriptions at the higher prices. We adjusted prices to keep this contribution constant as options were added, so the next three cells are also $11.16.

The lowest block in Table 10 shows the change in contribution relative to the contribution at doubled prices with flat rate service as the only option. Thus all the changes are $0.00.

Economic Welfare

Table 10 also shows average changes in economic welfare. Again, the averages are over all 2004 simulated households.

The change in economic welfare is just the sum of the change in consumer surplus and the change in contribution to the telephone company's revenue requirement (the "overall" column of Table 9 and the "contribution" column of Table 10). The changes in average welfare that resulted from adding options at either present or future prices were quite small.
The welfare effect of doubling prices was modest: a $0.68 welfare loss on average when flat rate service was the only option. This average loss was entirely due to the 11 percent of households that dropped their subscriptions when prices doubled. These are by definition the households who got the least surplus from subscribing. (In fact, they did not lose all their surplus when they stopped subscribing, because they continued to make some telephone calls on out-of-house telephones.) For households who continued to subscribe, there was no welfare effect of the price increase; it simply transferred surplus from customers to the telephone company.
IV. DISCUSSION

FINDINGS FROM THE SIMULATIONS

We obtained the following findings from the simulation model.

Telephone Penetration

- At the current price level, adding measured and lifeline service causes a small but noticeable increase in telephone penetration among consumers in the lowest third of the income distribution. Overall penetration is initially high, and is only slightly affected by adding options.
- When prices are doubled, the effects are more dramatic. Compared with current rate levels, doubled prices significantly reduce penetration in lower income groups. From this lower base, measured service by itself adds about three percentage points to penetration in the lowest income tertile, and lifeline adds 5 percentage points more.

Price Level

- As customers choose lower cost options, prices must rise to keep the contribution to the telephone company's total revenue requirement constant. When a measured rate option is added, required prices are increased by nearly 10 percent; with standard measured, measured rate, and flat rate lifeline service, prices go up nearly 25 percent.

Distribution of Surplus

- At present prices, the addition of rate options consistently causes small consumer surplus losses due to the required rise in price. (At constant prices, consumer surplus would necessarily increase as choice increased.)
- Including the lifeline options results in a substantial transfer of surplus from higher income telephone subscribers to lifeline subscribers.
At doubled rates that could arise in the future, the large overall average loss in consumer surplus is due primarily to higher bills. The surplus transfers to lifeline subscribers are even larger than at present prices.

**Economic Welfare**

- Adding options has only a minor effect on overall economic welfare. That effect is sometimes negative and sometimes positive, depending on the relationship of prices and costs in the particular situation.

**RURAL COSTS**

The incremental costs used in our simulations were meant to reflect current costs in a typical urban area. The cost of access for a household in a rural area could be substantially higher. We did run simulations for rural areas, maintaining the same prices but using an annual incremental cost per access line of $200 instead of $60, and an annual incremental capacity cost per design busy-hour call of $20 instead of $30. Although we do not include the details here, the summary statements above apply to the rural simulations as well as to the urban ones.

**TIME-OF-DAY RATES**

Time-of-day rates that charge less (or nothing at all) for off-peak calls might improve on the efficiency of the rates simulated here, which assume that the same price per call \( p_c \) applies around the clock. Time varying rates could avoid the price rationing of calls at times when a reduction in the number of calls does not yield any capacity cost saving.

A variety of time-of-day rate plans might be considered for both measured service and lifeline rates. Starting from the relative prices in Table 5, peak rates could be raised above the relative $0.07 per call, with lower prices in off-peak hours. Alternatively, only a peak price could be charged, at a level sufficient to yield the same contribution generated by the measured rates considered.

Time-of-day rates, if carefully designed, should be more efficient than uniform measured rates (although not necessarily more efficient than a flat rate; see Park and Mitchell, 1987). Whether they would
result in higher penetration is unclear. If marginal households make predominantly off-peak calls, time-of-day rates should be somewhat helpful.

**BUSINESS USERS**

Telephone penetration among business users is effectively 100 percent, and universal service is not directly an issue. In most communities business customers do not have the option of subscribing under flat rates. By increasing overall rates, optional and lifeline rates for residential users will cause increased business rates. Because business price response is quite low, these higher rates have small efficiency effects and primarily transfer additional revenues to lifeline customers.

**SOME POSSIBLE VARIATIONS**

The simulation model is a reasonably versatile tool that could be modified to examine a variety of other local telephone market conditions and scenarios. We used it to evaluate rate alternatives that are similar to those now available in California. Working within the currently specified model, one might consider other price structures such as free installation for lifeline qualified consumers. More ambitiously, one might compare options that are optimally designed to maximize welfare.

The comparative evaluation of different rate plans depends, to some extent, on the sequence in which the rate options are introduced and the mix of options available. The model could be used to explore the effects of, for example, a flat rate combined with just a measured lifeline rate.

As additional data on customer responses to local rates become available, the demand parameters or functions could be revised. Similarly, improved data on incremental costs of telephone service could be substituted to gain a more accurate measure of the efficiency tradeoffs of alternative rate plans.
Appendix

FORTRAN 77 PROGRAM

* character*8 file10, file11, file12, file13, file14, file15, file16
* character*40 c3trl
* character*24 fd3ate
* integer op, hl
* real cs, rv, ic, rrv, ilc, rvadd, icadd, revcon
* parameter (nh=2004)
* dimension rmm(5*nh)
* dimension y(0:nh), x(nh), b(nh), r(nh), o(nh), h(nh)
* dimension opt(nh), xpc(nh), cap(nh), tsp(nh), bil(nh), cst(nh)
* dimension op(3,4,2,4), h1(3), cs(3,4,2), rv(4,2), iic(4,2), pm(4,2)
* dimension cs1(6, nh, 4, 2)

* household characteristics:
* nh number of simulated households.
* y annual household income, in dollars.
* x calls per month at pc=0.
* r percent reduction in calls for pc=.10.
* t translates into demand parameter (b).
* o time cost of an out-of-house call.
* h monthly option value for having a phone in the house
* for incoming and toll calls, in dollars.
* b tenancy in months.

* system characteristics:
* pc price per call, in dollars.
* pm price per month, in dollars.
* pi price per installation, in dollars.
* cc incremental monthly cost per call of design capacity
* dac ratio of design capacity to average hour
* cm incremental monthly cost per subscriber line
* ci incremental cost of installation
* cme1 incremental measurement cost per line
* cme2 incremental measurement cost per call

* detailed household results:
* opt option chosen.
* xpc calls per month at prevailing prices
* cap "call" surplus = consumer surplus after pc but before o,
* pm, or pi, in dollars.
* tsp "total" surplus = consumer surplus including o, after pc, pm,
* and pi, in dollars.
* bil monthly bill
* cst incremental cost of calls and access, dollars per month.

* summary results:
* ji=3 income classes
* jo=4 option packages
* jp=2 price levels
* je=4 service choices
* op subscriber counts
hh  household counts
 cs  consumer surplus
 rv  company revenue
 ic  company incremental cost

50  format ('/f8.2,a24')
51  format ('f8.2,a24')
52  format (a8)
53  format (a40)

60  format ('\t',a24,\n')
61  format (10e13.6)
62  format (32(4))
63  format (6e16.6)
64  format (14,f12.4)

80  format ('what is the name of the control file?')
81  format ('simul: WARNING:\n',
  'overriding income distribution from statistical abstract')
82  format ('simul: WARNING: set nh to an integer multiple of 3')

if (mod(ch,2).ne.0) then
  write (6,82)
  stop
endif

open (8,status='scratch')
write (6,80)
read (5,52) file10
open (10,file=file10)
read (10,52) file11,file12,file13,file14,file15,file16
if (file11.ne.0) open (11, file=file11)
if (file12.ne.0) open (12, file=file12)
if (file13.ne.0) open (13, file=file13)
if (file14.ne.0) open (14, file=file14)
if (file15.ne.0) open (15, file=file15)
if (file16.ne.0) open (16, file=file16)
read (10,51) aiter
iter=iter+1
iter=0

*------>
read (10,50) pm1
read (10,51) pl1
*------>
read (10,50) pc2
read (10,51) pm2
read (10,51) pl2
*------>
read (10,50) slig3
read (10,51) pc3
read (10,51) pm3
read (10,51) pl3
*------>
read (10,50) slig4
read (10,51) pm4
read (10,51) pl4
*------>
read (10,50) cc
read (10,51) darat
read (10,51) cm
read (10,51) ci
read (10,51) cmea1
read (10,51) cmea2
ccmlt=cc*darat/(2A.*30.)
pmult=0.
call change(pmult,pni,pil,pc2,ps2,pi2,
& elig3,pc3,pn3,pi3,elig4,ps4,pi4)

******
read (10,50) yy0
read (10,51) yystd
******
read (10,50) xx0
read (10,51) xy
read (10,51) xxstd
******
read (10,50) rr0
read (10,51) ry
read (10,51) rx
read (10,51) rrstd
******
read (10,50) tpow
read (10,51) thsc
read (10,51) tt0
read (10,51) ty
read (10,51) tx
read (10,51) ttstd
******
read (10,50) opow
read (10,51) obsc
read (10,51) oo0
read (10,51) oy
read (10,51) ox
read (10,51) oostd
******
read (10,50) hpow
read (10,51) hhsc
read (10,51) hh0
read (10,51) hy
read (10,51) hx
read (10,51) hhstd

* lognormal distribution of income, perhaps fudged to match
if (yy0 .ge. 3.165 .or. yy0 .lt. .85) then
  write (6,81)
  fudge=0.
else
  fudge=1.
endif
prob=0.
dprob=1./((1+nh)
do 101 i=1,nh
prob=prob+dprob
if (prob.ge.1.) go to 500
  yy=yy0+yystd*anorin(prob)
y(i)=exp(yy)
if (fudge.eq.0.) go to 101
if (i.eq.1) then
  dprob=(3.3777)/(1+nh)
else if (y(i).ge.5. .and. y(i-1).lt.5.) then
  dprob=(12.2/12.4)/(1+nh)
else if (y(i).ge.10. .and. y(i-1).lt.10.) then
  dprob=(14.0/11.5)/(1+nh)
else if (y(i).ge.15. .and. y(i-1).lt.15.) then
  dprob=(16.6/10.9)/(1+nh)
else if (y(i).ge.20. .and. y(i-1).lt.20.) then
  dprob=(10.4/10.0)/(1+nh)
else if (y(i).ge.25. .and. y(i-1).lt.25.) then
  dprob=(15.2/17.0)/(1+nh)
else if (y(i) ge 35. and y(i-1) lt 35.) then
dprob=(13.4/15.8)/(1+nh)
else if (y(i) ge 50. and y(i-1) lt 50.) then
dprob=(18.9/14.8)/(1+nh)
endif

101 continue

* repeat for niter trials;
*

500 continue
iter=iter+1

* simulate household characteristics
*
call rnorm(3*nh, rann)
do 210 i=1, nh
if (abs(rann(i)).ge.3.) rann(i)=0.
210 continue

do 202 i=1, nh
yy=log(y(i))

* normal distribution of x**.27 per carl pavarini;
xxhat=xx*xxy**(yy-yy0)
xx=xxhat*xst***rann(i)
if (xx .lt. 0.) xx=0
x(i)=xx**3.7037
xhat=xxhat**3.7037

* logistic distribution of r;
rrhat=r0+xx**(xx-xx0)+ty**(yy-yy0)
rr=rrhat*rst***rann(i)/nh
rr=exp(rr)/(1.+exp(rr))
b(i)=log(1.-rr)/1

* rhatx integrates out y;
rhatx=r0*xx**(xx-xx0)+ty**(yy-yy0)
rxhat=exp(rhatx)/(1.+exp(rhatx))

* rhaty integrates out x;
rhaty=r0*xx**(xxhat-xx0)+ty**(yy-yy0)
ryhat=exp(rhaty)/(1.+exp(rhaty))

if (t(pow.lt.0.) then
* linear function t(y,x);
that=t0+t*y*(y(i))/100.+tx*x(i)/500.
if (that.lt.0.) that=0.
t(i)=that+that**3*that**2*thann(i+2*nh)
if (t(i).lt.0.) t(i)=0.
thatx=t0+tx*x(i)/500.+ty**exp(yy0)/100.
thaty=t0+tx*xx0**3.7037/500.+ty**yy(i)/100.
else
* generalized power distribution of t;
thatx=t0+tx*(xx-xx0)+ty**(yy-yy0)
thaty=t0+tx*(xxhat-xx0)+ty**(yy-yy0)
if (t(pow.eq.0.) then t(i)=exp(tt)
thatx=exp(thatx)
thaty=exp(thaty)
else if (tt.lt.0.) then t(i)=0.
thatx=thatx**tpow
thaty=thaty**tpow
else
t(i) = t^t * pow
that = that * t^t * pow
thaty = thaty * t^t * pow
endif
endif

if (opow .lt. 0.) then

* linear function o(y,x);
  ohat = oo + oxy * y(i)/100. + ox * x(i)/500.
if (ohat .lt. 0.) ohat = 0.
  o(i) = ohat + ostd * ranedi(14^3) nh
if (oi .lt. 0.) oi = 0.
opath = oo + ox * y(i)/100. + oxy * y(i)/100.
opath = oo + ox * x(i)/500. + oxy * y(i)/100.
else
* generalized power distribution of o;
  oopath = oo + ox * (xx - xx0) + oxy * (yy - yy0)
  oo = oopath + ostd * ranedi(14^3 nh)
  oopath = oo + ox * (xx - xx0) + oxy * (yy - yy0)
oopath = oo + ox * (xhat - xx0) + oxy * (yy - yy0)
if (opow .eq. 0.) then
  o(i) = exp(oop)
  ohat = exp(oopath)
  opath = exp(oopath)
else if (co .lt. 0.) then
  o(i) = 0.
opath = oopath
opath = oopath
else
  o(i) = oopath
  ohat = oopath
  opath = oopath
endif
endif
endif

if (bpow .lt. 0.) then

* linear function b(y,e);
  bhat = bh + by * y(i)/100. + bx * x(i)/500.
if (bhat .lt. 0.) bhat = 0.
  b(i) = bhat + bstd * ranedi(14^3 nh)
if (bi .lt. 0.) bi = 1.
bhat = bh + bx * x(i)/500. + by * y(i)/100.
bpath = bh + bx * x(i)/500. + by * y(i)/100.
bpath = bh + bx * x(i)/500. + by * y(i)/100.
else
* generalized power distribution of b;
  bpath = bh + bx * (xx - xx0) + by * (yy - yy0)
bh = bopath + bstd * ranedi(14^3 nh)
bopath = bh + bx * (xx - xx0) + by * (yy - yy0)
bpath = bh + bx * (xhat - xx0) + by * (yy - yy0)
if (bpow .eq. 0.) then
  bi = exp(bh)
  bhat = exp(bopath)
bpath = exp(bopath)
else if (bb .lt. 0. or. bbbw .lt. bpow .lt. 1.) then
  bi = 1.
bhat = bopath
bpath = bopath
else
  bi = bopath
bhat = bopath
bpath = bopath
endif
endif
if (iter.eq.1) then
  if (file1.ne.' ') then
    write (14,53) y(i),x(i),b(i),t(i),o(i),h(i)
  endif
  write (15,53) y(i),xhat,x(i),xhatx,chasy,r,
  & xhatx,chasy,t(i),ohatx,ohasy,o(i),hhatx,hhaty,h(i)
endif
continue
*
* calculate household responses;
*
continue
  if (iter.eq.1.and.file12.ne.' ') then
    write (12,60) fdate()
    rewind (10)
  endif
continue
read (10,53,end=304) cntrl
write (12,53) cntrl
go to 305
endif
continue
  do 306 j=1,3
  do 306 j=1,4
  do 306 j=1,2
  do 306 j=1,4
    hl(jj)=0
    op(jj,jo,jp,js)=0
    cs(jj,jo,jp)=0.
    rv(jo,jp)=0.
    ic(jo,jp)=0.
  306 continue
  do 399 j=1,2
    p9mult=fnat(jp)
    call change(p9mult,pw1,pw2,pw3,pw2,pw2,
    & elig3,pc3,pw3,pi1,pi2,pi3,pi4)
  301 continue
  liter=iter+1
  rrv=0.
  iic=0.
  ohc=0.
  subl=0.
  subl2=0.
  subl3=0.
  do 380 i=1,nh
    jm=1+int((i-1)/(nh/3))
    if (jp.eq.1.and.jo.eq.1) hl(jj)=hl(jj)+1
  380 continue
* exponential demand curves;
* value of not subscribing;
  xpc0=x(i)*exp(-b(i)*t(i))
  xpcp=nmax(xpc0,.001)
  csp=xpc0*(log(x(i)/xpc0)+1.)/b(i)*t(i)*xpc0
  csp0=nmax(csp0,0.)
  tsp=xsp0
* flat rate option only;
  xpcf=x(i)
  cspf=xpcf/b(i)
tspl=spsl(i)+pm1*pl1/h(i)
if (tspl.ge.tsp0) then
  xpc(i)=xpc1
  csp(i)=csp1
tsp(i)=tsp1
  bll(i)=pm1*pl1/h(i)
cst(i)=cm1*mpc1+cm+ci/h(i)
opt(i)=1.
else
  xpc(i)=xpc0
  csp(i)=csp0
tsp(i)=tsp0
  bll(i)=0.
cst(i)=0.
opt(i)=0.
endif
if (jo.eq.1) go to 370

* add measured rate option;
xpc2=xpc(i)*exp(-b(i)*pc2)
xpc2=max(xpc2,0.001)
csp2=xpc2*(log(x(i)/xpc2)+1.)/b(i)-pc2*xpc2
tsp2=csp2+o(i)-pm2*pi2/h(i)
if (tsp2.ge.tsp(i)) then
  xpc(i)=xpc2
csp(i)=csp2
tsp(i)=tsp2
  bll(i)=pm2*xpc2*pc2+pi2/h(i)
cst(i)=cm1*mpc2*cm+ci/h(i)+cmea1+cmea2*xpc2
  opt(i)=2.
endif
if (jo.eq.2) go to 370

* add lifeline measured option;
xpc3=xpc(i)*exp(-b(i)*pc3)
xpc3=max(xpc3,0.001)
csp3=xpc3*(log(x(i)/xpc3)+1.)/b(i)-pc3*xpc3
tsp3=csp3+o(i)-pm3*pi3/h(i)
if (tsp3.ge.tsp(i).and.y(i).le.elig3) then
  xpc(i)=xpc3
  csp(i)=csp3
tsp(i)=tsp3
  bll(i)=pm3*xpc3+pi3/h(i)
cst(i)=cm1*mpc3*cm+ci/h(i)+cmea1+cmea2*xpc3
  opt(i)=3.
endif
if (jo.eq.3) go to 370

* add lifeline flat rate option;
xpc4=xpc(i)
csp4=xpc4/b(i)
tsp4=csp4*o(i)-pm4*pi4/h(i)
if (tsp4.ge.tsp(i).and.y(i).le.elig4) then
  xpc(i)=xpc4
csp(i)=csp4
tsp(i)=tsp4
  bll(i)=pm4*pi4/h(i)
cst(i)=cm1*mpc4*cm+ci/h(i)
opt(i)=4.
endif
370 continue
rreerrv=bll(i)
ije=ije+cst(i)
if (opt(i).eq.0.) ohc=ohc+xpc(i)
if (ji.eq.1) then
if (opt(i).gt.0.) subl=subl+1.
if (opt(i).eq.2.) subl2=subl2+1.
if (opt(i).eq.3.) subl3=subl3+1.
endif

380 continue

* revenues and costs of out-of-house calls;
fs2=subl2/subl
fs3=subl3/subl
rvadd=fs2*pc2*ohc+fs3*pc3*ohc
icadd=cm2*ohc+(fs2+fs3)*cm2*ohc
rrv=rrv+rvadd
ic=ic+icadd
rv(jo,jp)=rvadd
ic(jo,jp)=icadd

if (jo.eq.j) revocab=rrv-ic
        revedf=(revocab-(rrv-ic))/nh
if (iter.eq.1) write (6,66) jo,rewdif
else if (abs(rewdif).lt.0.0005.or.iter.gt.25) then
        do 381 i=1,nh
        if (file13.ne.'') and.iter.eq.1
            write (6,66) xpc(i),csp(i),tsp(i),opt(i),bil(i),cst(i)
            j1=1+int((i-1.)/(nh/3))
            js=1+int(opt(i))
            op(j1,j1,jp,jp)=op(j1,jp,js)+1
            cs(j1,jp)=cs(j1,jp)+tsp(i)
            rv(jp,jp)=rv(jp,jp)+bil(i)
            ic(jp,jp)=ic(jp,jp)+cst(i)
        381 continue
        pm(jo,jp)=pmult
        go to 399
else if (mod(iter,5).eq.0) adjfac=.5*adjfac
        rrvadd=revocab-(rrv-ic)
        pmult=pmult*(rrv+adjfac+rvadd)/rrv
        call change(pmult,pml,ppl,pc2,pn2,pn2,pl2,pl2,pl1,pl1,pl,pl,alig3,pl3,pml,pml,pml,alig4,pm4,pn4)
        go to 301
endif

399 continue

write (16,62) hj
write (16,62) (((op(j1,j1,j1,jp),j1=1,3),js=1,jp),jo=1,4)
write (16,62) (((op(j1,j1,j1,j1),j1=1,3),js=1,jp),jo=1,4)
write (16,62) (((cs(j1,j1,j1),j1=1,3),jo=1,4)
write (16,62) (((cs(j1,j1,j1),j1=1,3),jo=1,4)
write (16,62) hj
write (16,62) hj
write (16,62) hj

if (iter.lt.niter) go to 500

900 continue

if (file13.ne.'') then
        rewind (8)
        read (8,63) csi
        write (13,65) (((cs(i,j1,j1,jp),j1=1,6),jo=1,4),jp=1,2),i=1,nh
endif

990 stop
end
**subroutine change(pm1,pm2,pi1,pi2,pm3,pi3,pm4,pi4,pm5,pi5,pm6,pi6)

dimension phold(12)

if (pmult.eq.0.) then
    phold(1)=pm1
    phold(2)=pi1
    phold(3)=pm2
    phold(4)=pi2
    phold(5)=pm3
    phold(6)=pi3
    phold(7)=pm4
    phold(8)=pi4
    phold(9)=pm5
    phold(10)=pi5
    phold(11)=pm6
    phold(12)=pi6
else
    pm1=pmult*phold(1)
    pi1=pmult*phold(2)
    pm2=pmult*phold(3)
    pi2=pmult*phold(4)
    pm3=pmult*phold(5)
    pi3=pmult*phold(6)
    pm4=pmult*phold(7)
    pi4=pmult*phold(8)
    pm5=pmult*phold(9)
    pi5=pmult*phold(10)
    pm6=pmult*phold(11)
    pi6=pmult*phold(12)
endif

return
end**
INPUT PARAMETERS

input simulated household data (file11)
output results (file12)
output results for stata (file13)
output simulated household data (file14)
output household data for stata (file15)
s.airie output summary data for response surface (file16)

100. number of iterations

11.20 pm1
50. p11

0.07 pc2
6.00 pm2
50. p12

12.1 elig3
.07 pc3
5.00 pm3
25. p13

12.1 elig4
5.60 pm4
25. p14

2.50 cc
darst
3.0 cm
5.00 ci
cmea1
.20 cmea2
.001

ANNUAL INCOME ($1000):
3.165 y00 (3.165)
.85 yystd (.85)

CALLS PER MONTH:
3.4 xsu (3.4)
-.0 xy (-.0)
.77 xstd (.77)

PERCENT REDUCTION IN CALLS FOR PC=.1:
-2.0 rr0 (-1.58)
-5.5 ry (-5.5)
0.0 rx (0.0)
35. rstd (.50)

TIME COST OF OUT-OF-HOUSE CALLS:
-1.1 tspw
1. thsc
.15 tto (0.0)
4. ty (9.26)
0.0 tx
tstd

OPTION VALUE, $ PER MONTH:
-1. opow
.720 ochsc
17. ooo
34. oxy
12. ox
1.9 oostd

TENANCY PERIOD, MONTHS:
-1. bpow
.720 hhsc
36. hhb
60. by
0. bx
1. hhstd
REFERENCES


