PRICING POLICIES IN SELECTED EUROPEAN TELEPHONE SYSTEMS

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International Institute of Management
and
The Rand Corporation

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Abstract

In the five European telephone systems surveyed (Norway, Sweden, Switzerland, the United Kingdom, and West Germany) there are four categories of charges for telephone service: an installation fee, a monthly subscription fee, local usage charges, and rates for trunk calls. Frequently, the charges for subscriptions and local usage do not fully cover the costs of these services, in which case the deficit is recovered in trunk call rates. Rates for local calls are based on a charge for each call made, and increasingly for the duration of the call. The rate structure for trunk calls is based on call duration and distance, and generally includes reduced charges in off-peak hours.

Consumer response to time-of-day rates is assessed by comparing the trunk traffic patterns before and after rate structure changes that took place in five countries, including the United States. The data indicate that price incentives can significantly alter traffic patterns. Indeed, in some cases sharply reduced off-peak rates have stimulated calling to such a degree that capacity is exhausted and overload conditions occur.

Development of an applied model of peak-load pricing for telephone calls must incorporate the non-uniform interhour cross-elasticity effects observed in consumer responses to rate structure changes. The most important features of own-price elasticities, trends in usage, as well as externality effects can also be included in designing a realistic model to be used for assessing telephone rate structure policy.

Pricing Policies in Selected European Telephone Systems*

Bridger M. Mitchell

This paper presents a brief survey of the principal policies for the pricing of telephone services in five European telephone systems: Norway, Sweden, Switzerland, the United Kingdom and West Germany. After highlighting the important points at which European practices depart from those in use in the United States, I draw together evidence of consumer response to time-of-day rate structures for trunk calls and then consider the principal factors that should characterize an applied economic model of peak-load pricing for telephone services.

PRICING POLICIES

In nearly every European country, telephone service has long been supplied by a public enterprise operating as a monopoly legally protected against competition. In the majority of countries, postal as well as telegraph and telephone services are supplied by a single administration (PTT). In the others, the telephone administration is operationally and financially separate from the postal system.

Generally, the national public enterprise must, in financial terms, operate independently and cover its total costs. These costs may, in addition, include the requirement that a specified surplus be paid into the national treasury; in most cases such transfers are in lieu of the value-added tax that applies to

*I am happy to acknowledge the assistance of J. Schwalbach, the comments of J. Müller and P. Kleindorfer, and the cooperation of numerous officials of the several telephone administrations. The preparation of this paper has been supported by fellowships from the German Marshall Fund and the Alexander-von-Humboldt Foundation and by National Science Foundation grant No. APR77-16286 to The Rand Corporation.

virtually all other goods and services. However, within the public enterprise there is considerable room for cross-subsidies between services.

In many PTT-type enterprises revenues from the newer telecommunications services have been used to support postal deficits.* Within the telecommunications enterprise, whether it is self-standing or one component of a PTT, one typically finds an enduring pattern of cross subsidies. Telegraph service has been priced well below cost and telex service generally in excess of cost. Telephone services as a whole have at least covered their total costs (Table 1).

Nearly all European telephone networks use a periodic pulse method of metering and charging for telephone usage. At the beginning of each call an initial pulse is recorded by a meter on the subscriber's line and located in the central office. Then, as long as the call is in progress, subsequent pulses are transmitted at regular intervals. The time interval between pulses generally depends on the distance called, and frequently on the time of day as well.

Pulses are accumulated over the billing period (one month or one-quarter) and the customer receives an invoice for the total number of telephone "units" (i.e. pulses) multiplied by the current price per unit. Thus, there is no itemized billing of trunk calls (or of multiple-message units). The subscriber may, however, rent an optional meter for keeping track of his calling units, and such meters are commonly used with business phones.

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* Such comparisons involve well-known difficulties of allocating common costs. In all cases the data are those reported by the public enterprises.

General Price Structure

The charges for telephone service in Europe may be divided into four categories. In most countries, the same rates apply to both business and residential customers:

1. Installation fee - a one-time charge for installing a new main station, the required wiring inside the dwelling, and the drop line from the local network.
2. Subscription fee - paid monthly, quarterly or annually - for connection to the telephone network.
3. Local usage charges - originally based on the number of calls made, but increasingly on the length of call and time of day as well.
4. Trunk usage charges - based on the distance, duration and (generally) time of day of trunk calls.

In addition, there are, of course, separate charges for vertical services such as extension telephones and private exchange equipment (PBXs).

All European telephone administrations follow a general pattern of (relatively) uniform nationwide pricing. Thus, connection fees are generally the same in both urban and rural areas, and per-minute rates for trunk calls are equal for equivalent distances regardless of traffic density. However, the monthly subscription charges are frequently graduated with the size of the local community, reflecting the costs of supplying larger calling areas.

Within this overall structure, the relationship of prices to costs is not uniform. Furthermore, several telephone administrations are currently in the process of making major changes in their telephone tariffs.

In several countries the connection and subscription charges are significantly less than the average cost of adding a new subscriber to the network, and probably also below incremental cost. Furthermore, charges for local calls do not fully recover costs. These deficits are recovered by surpluses earned from trunk call traffic.

TABLE 1

Degree of Cost Coverage by Service, in Percent

Service	Switzerland 1976	Sweden 1973/74	United Kingdom 1976	West Germany 1974
Telephone Services				113
Rentals	85-90	47		NA
business	- -	- -	85	- -
residence	- -	- -	87	- -
Calls			128	
local	ca. 60	58		NA
trunk	> 100	245		NA
Private Lines	206	NA	108	NA
Telegram	67	- -	43	52
Telex	119	NA	84	120
Total Telecommunications	108	- -	104	112

Sources: Switzerland: PTT - Geschäftsbericht 1976
Sweden: Televerket-Författningssamling Serie A:29
United Kingdom: Post Office Reports and Accounts, 1976-77
West Germany: Deutsche Bundespost, Geschäftsbericht, 1975

NA = not available.

For example, recent Swedish investigations find the following relationships between revenues and costs:

Service	Average Revenue	Average Cost
subscription (monthly)	SKr. 11.67	SKr. 25.00
local call	0.15	0.26
trunk call	2.64	1.08

Figure 1 provides further insight into the relationship of trunk call revenues and costs in Sweden for an average trunk call as a function of distance. The revenue curve combines the calls of business and residential subscribers weighted by their respective call durations. The cost curve is based on the overall mean duration of 310 seconds and calculated from detailed studies of equipment usage priced at replacement cost for current technology, using distances between reference stations. Although costs do increase with the distance called, they climb much more slowly than the present schedule of rates for the various distance bands.

Detailed Structure of Telephone Rates

The principal charges for a connection to the network, for local calls and for domestic trunk calls are shown in Tables 2, 3 and 4. There are significant one-time charges for the installation of a main station in every country, and no distinction is made between business and residential subscribers. In some systems, temporary "sales" (reduced installation fees) have been used to promote new connections in times of slack demand.

Subscription charges vary between about $4 and $16 per month in urban calling areas (Table 2)*. Only the British Post Office discriminates between classes of customers, charging residential users 50p less per month. The generally uniform treatment of all subscribers thus differs from the wide rate differentials for residential and business subscribers in the United States. Furthermore, customers have but a single rate open to them, whereas U.S. telephone companies frequently market a variety of service packages.

*International comparisons of rate levels are problematic and prices at U.S. dollar exchange rates provide only a rough indication of the relative charges for different services.

Figure 1. Average Trunk Call Revenues and Costs in Sweden

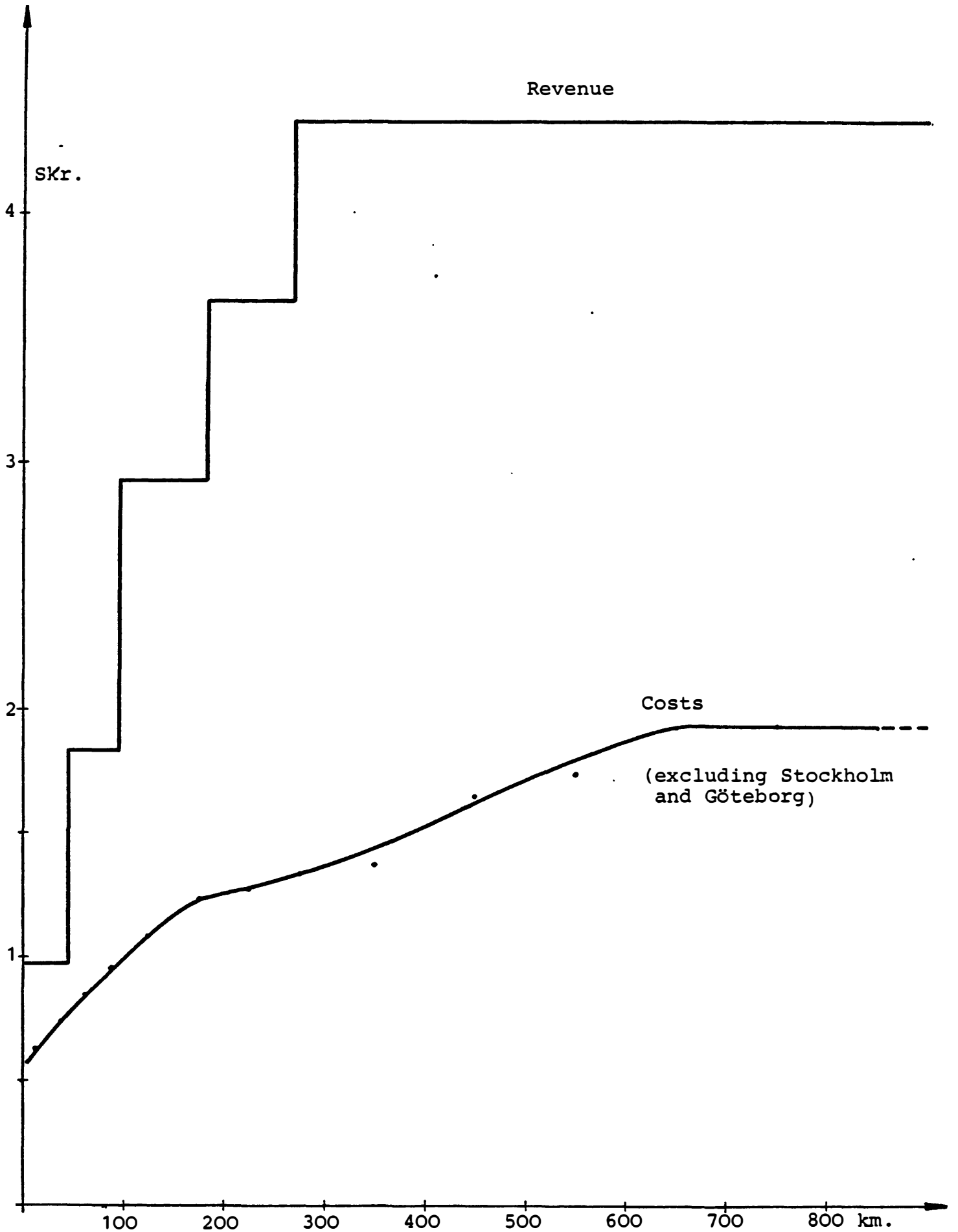


TABLE 2

Telephone Installation and Subscription Prices, 1978

Country	Installation Charge		Subscription Charge (monthly)	
Norway	N Kr 1000[1]	$188.00	N Kr 22-48	$4.14 - 9.02
Sweden	S Kr 300	$ 65.40	S Kr 32-40	$6.98-8.72
Switzerland	S Fr 100-150[2]	$ 54-81	S Fr 13-19	$6.98-10.20
United Kingdom				
business	£ 45	$ 84.15	£ 3.25	$ 6.08
residential	£ 45	$ 84.15	£ 2.75	$ 5.14
West Germany	DM 200	$ 99.40	DM 20-32	$9.94-15.90

1) Plus a loan payment of N Kr 2000 which earns interest at 6.5% per year, returnable at the termination of subscription.

2) Typical installation charges for private contractors.

Notes: Monthly subscription charges shown for the largest local calling areas. Prices in U.S. dollars at rates of exchange prevailing April 10,1978.

The structure of local call rates (Table 3) is based on the periodic pulse system. Here one sees one of the strongest contrasts with the practice of U.S. telephone companies, which in most areas use a flat rate system for local calls. In 1978 three countries are charging for local calls according to duration. Moreover, West Germany will switch to an 8-minute pulse interval in July 1979, and the Swedish telephone administration has adopted a 6-minute interval that will take effect in 1982. Off-peak rates will also be more widely used in the future. Both the West German and Swedish systems will have a 12-minute interval during off-peak hours.

Rates for domestic trunk (i.e. long-distance) calls are based on a series of distance bands and on the time of day (Table 4).* Time-differentiated rates are either 2-level (peak, off-peak) or 3-level (peak, shoulder, off-peak) and distinguish different periods on weekdays, Saturdays and Sundays. Holidays are also charged at Sunday rates.

The price relationships between different distance bands and time periods are, to some extent, constrained by the specific pulse-generating technology that is in use. The pulse interval for a particular route is not infinitely variable; rather, it is mechanically determined by dividing a fundamental time period (e.g., 180 seconds) by an integer. Partly for this reason, the relative price structure has tended to remain fixed in many systems, with adjustments in the overall level of rates accomplished by changing the value of one unit (the pulse interval). Changes in the periods for time-of-day rates have been less frequent. Switzerland, however, is an exception -- the unit price has been kept fixed at 10 Rp, and when revenue increases were necessary the pulse intervals have been shortened.

CONSUMER RESPONSE TO TIME-OF-DAY RATES

In order to employ peak-load pricing effectively in a telephone network it is desirable to have reliable measurements of the parameters of consumer demand functions. However, the amount of data available for assessing demand elasticities is limited

*The Swedish telephone administration will introduce off-peak rates in 1982.

TABLE 3

Tariff Structures for Local Calls, 1978

Country	Price per Unit	Normal Rates		Off-Peak Rates	
		Pulse Interval	Hours	Pulse Interval	Hours
Norway	67 øre (12.5¢)	3 min	08-17 Mon-Fri.	none	other hours
Sweden	17 öre (3.7¢)	none	-	-	-
Switzerland	10 Rp. (5.4¢)	4.8 min	all hours	-	-
United Kingdom	3 p (5.6¢)	2 min	09-13 Mon-Fri.	3 min 12 min	08-09,13-18 Mon-Fri. 18-08,Mon-Fri 00-24,Sat-Sun
West Germany	23 Pf. (11.4¢)	none	-	-	-

Notes: Prices in U.S. currency of rates of exchange prevailing April 10, 1978.

TABLE 4

Tariff Structures for Domestic Trunk Calls, 1978

Country	Price Per Unit	Distance Zone	Pulse Intervals (Seconds) Peak Hours	Shoulder Hours	Off-Peak Hours
			08-20 Mon-Fri.		20-08 Mon-Fri. 00-24 Sat.& Sun.
Norway	67 øre	<50 km	36	-	48
	(12.5¢)	<50 km	20		26.7
			all hours		
Sweden	17 öre	<45 km	45		
	(3.7¢)	45-90 km	24	-	-
		90-180 km	15		
		180-270 km	12		
		>270 km	10		
Switzerland	10 Rp		08-17, 19-21 Mon-Fri.	-	17-19,21-08 Mon-Fri. 00-24 Sat-Sun.
	(5.4¢)	10-20 km	36		36
		20-50 km	22.5		36
		50-100 km	16.3		25.7
		>100 km	12.8		20
United Kingdom			09-13 Mon-Fri.	08-09,13-18 Mon-Fri.	18-08 Mon-Fri. 00-24 Sat-Sun.
	3p	<56 km	30	45	180
	(5.6¢)	>56 km	10	15	60
			06-18 Mon-Fri. 06-14 Sat.	18-22 Mon-Fri. 14-22 Sat.	22-06 Mon-Sat. 00-24 Sun.
West Germany	23 Pf	<25 km	45	67.5	67.5
	(11.4¢)	25-50 km	30	45	67.5
		50-100 km	15	22.5	67.5
		>100 km	12	18	67.5

Note: Prices in U.S. currency at rates of exchange prevailing April 10, 1978

primarily to observations on the few occasions that tariff structures have been changed. For the most part, telephone administrations have not had the flexibility of experimenting with a variety of rate structures, or of introducing a new rate on a trial basis for selected areas.* Furthermore, although there has been some econometric modeling of aggregate traffic demands by telephone administrations in West Germany, the United Kingdom and the United States, detailed traffic data has thus far not been available to outside researchers.

In this section, we bring together evidence of changes in traffic patterns that have been observed in the wake of rate structure changes in several countries. These data are highly aggregated and cover only selected aspects of the traffic patterns of economic interest. While they are probably too sketchy to permit any firm conclusions to be drawn, they do suggest a number of interesting hypotheses.

Norway

On January 1, 1976 the Norwegian Telecommunications Administration introduced its first off-peak trunk rates on an experimental basis in the county of Nordland. Rates were reduced by 40 percent from 8 p.m. to 8 a.m., Monday to Saturday and at all hours on Sunday. This test of peak-load pricing in the trunk network formed the basis of the nationwide peak/off-peak rates introduced in January 1978 (see Table 4).

A limited amount of data is available for the first months that the new rates were in effect. Measurements over this period permit a comparison of the traffic generated in Nordland after the rate change with traffic one year earlier. The changes shown in Table 5 were measured as a percent of the peak-hour traffic in each month. These data show small reductions in traffic in the last hours before the discount rate goes into effect at 8 p.m. and a pronounced increase in calling during the first off-peak hour. The January 1976 traffic to Nordland, which remained subject to the standard rate at all hours, decreased over 1975 at both 7 p.m. and 8 p.m.**

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*Norway is an exception.

**More recent data were not reported.

TABLE 5

Traffic as Percent of Peak Hour Traffic, Nordland, Norway

Weekday Hours	January 1975	January 1976	January change	March 1975	March 1976	March change
17-19*	61.2	58.4	-2.8	63.2	62.8	-0.4
19-20	52.0	51.1	-0.9	59.0	57.3	-1.7
20-21	55.0	65.0	+10.0	53.3	66.8	+13.5

* Per-hour average of data spanning the 2-hour period.

Source: Bø, Ganstad and Kosberg

Switzerland

During the 1920-1974 period, the Swiss PTT enjoyed an essentially constant level of telephone rates.* Then, beginning in 1973 rapidly mounting costs led to pressure for increased revenue, and effective December 2, 1974 new rates were established for trunk and suburban calls. The old and new rates for the various distance zones are shown in Table 6. When the distribution of the duration of calls is taken into account, these rate changes amount to about a 40 percent price increase for suburban calls and somewhat lesser amounts for trunk calls.

The December 1974 tariff revision also provided the PTT with the opportunity to adjust the structure of its peak and off-peak rates. By 1973 weekday trunk traffic was peaking in the early evening, shortly after the off-peak discount went into effect at 6 p.m. To discourage further growth in early evening traffic and to attempt to shift calls to hours when greater unused capacity existed, the PTT introduced peak rates during the 7 p.m. to 9 p.m. evening period and simultaneously established off-peak rates for the preceding two hours, from 5 p.m. to 7 p.m.

In the following diagrams, the relative rates for the longest calling distance band at each hour are shown in the lower portion of a figure. Above them appear the graphs of trunk traffic before and after the change in rate structure.

The effect of the change in the Swiss rate structure, seen in the upper portion of Figure 2a, was extremely favorable.** The evening peak was reduced to just below the level of the mid-morning peak, and traffic in the new late-afternoon discount period grew appreciably. There were essentially no changes in the weekday traffic load curve at other hours.

The tariff revision also eliminated the use of peak prices on Saturdays, which had until December 1974 been in effect from 8 a.m. to 6 p.m. At that time peak traffic on Saturday was only about 65 percent of the weekday peak, and it also occurred in the early evening.

* Trunk call rates were effectively reduced by 20 percent when the network was converted from manual to automatic operation in 1963.

** Traffic measurements are for the Friborg, Olten, Sion and Thun areas.

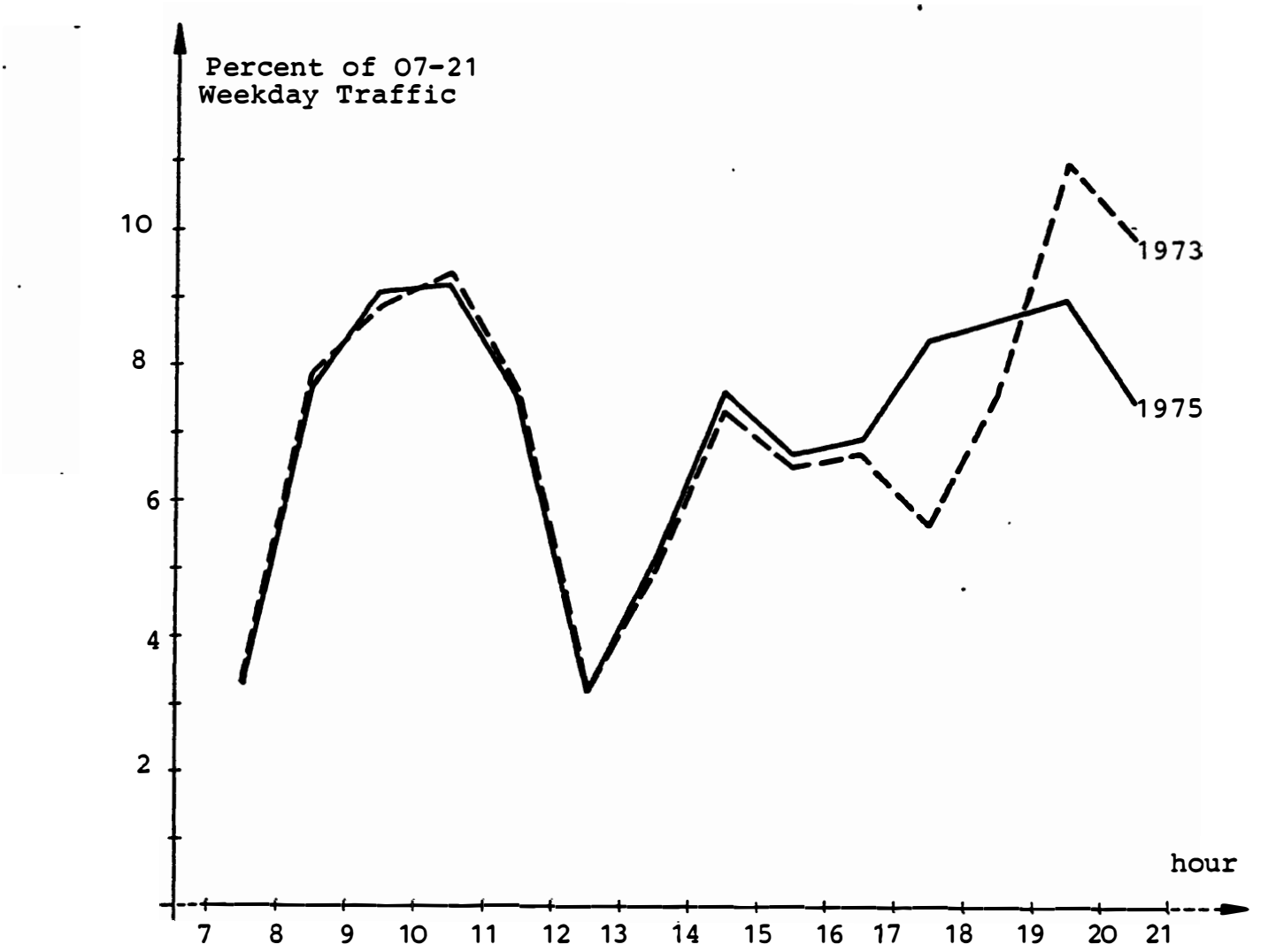
TABLE 6

Trunk Call Pulse Intervals (seconds), Switzerland

1 pulse = 10 Rp (5.4 ¢)

Zone	January 1973 - November 1974		December 1974 -	
	08-18 Mon-Sat	18-08 Mon-Sat 00-24 Sun	08-17,19-21 Mon-Fri	17-19,21-08 Mon-Fri 00-24 Sat-Sun
10-20 km	60	60	36	36
20-50 km	36	60	22.5	36
50-100 km	25.7	45	16.3	25.7
>100 km	18	30	12.8	20

Figure 2a. Weekday Trunk Traffic in Switzerland



Rate Structure

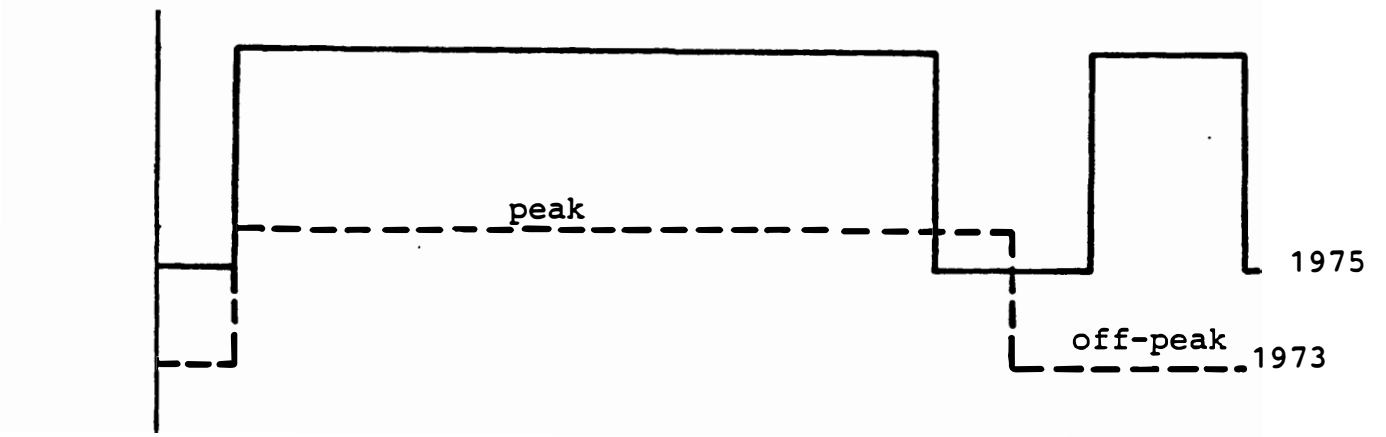
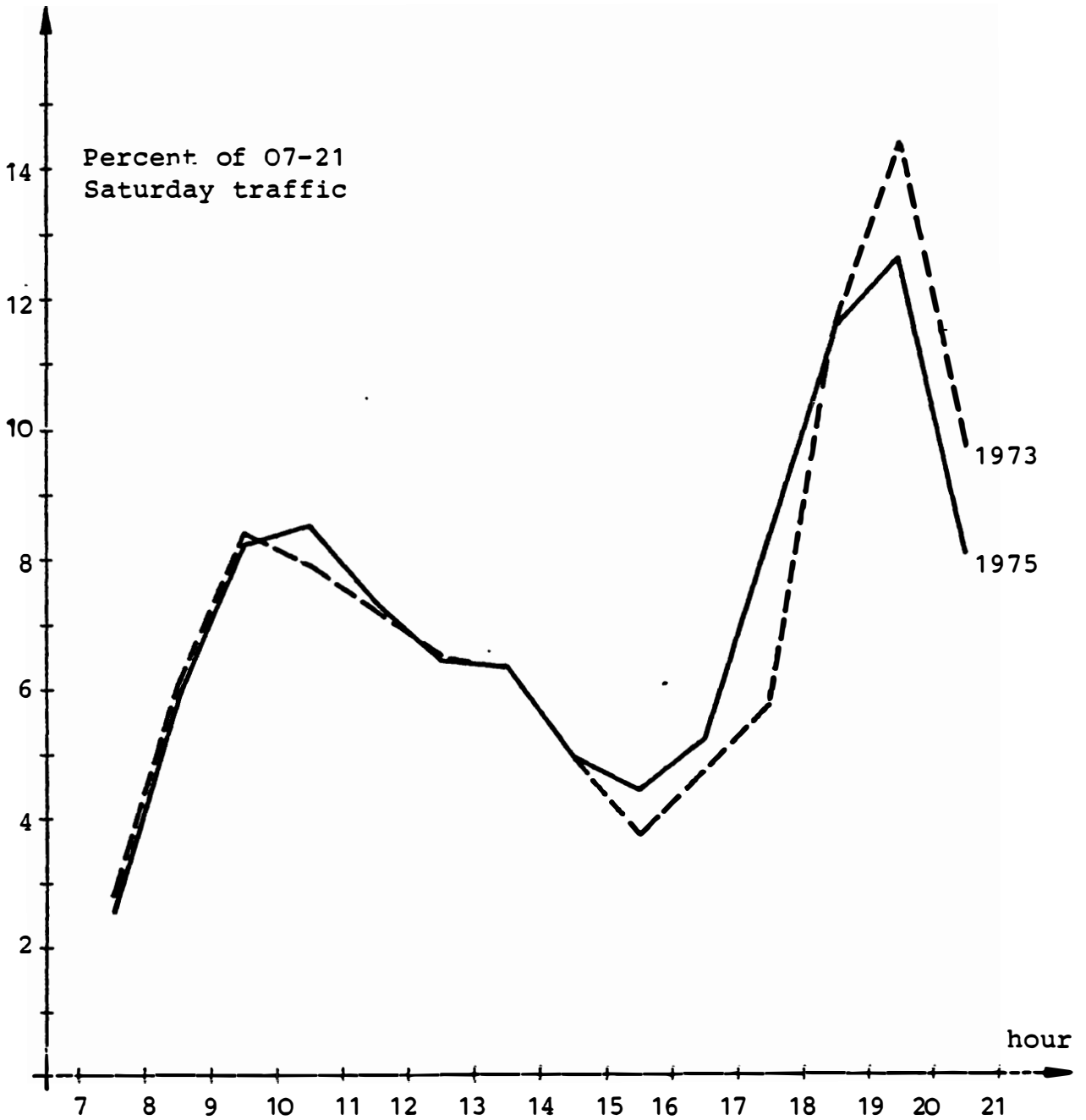


Figure 2b. Saturday Trunk Traffic in Switzerland



Rate Structure

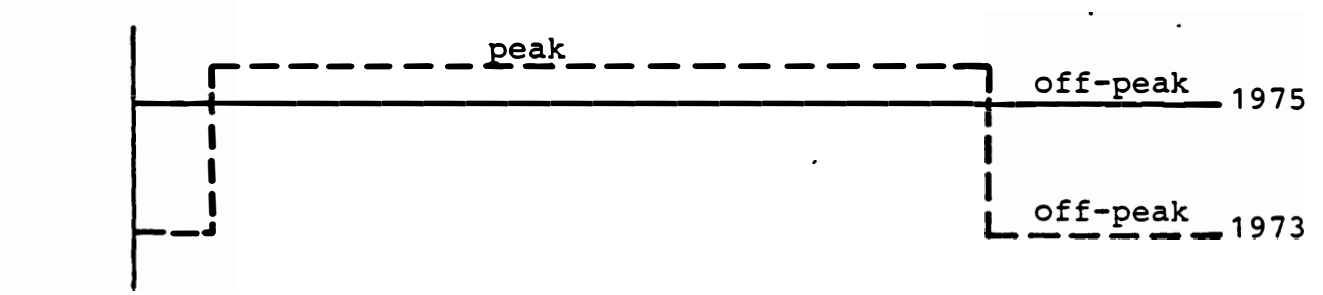
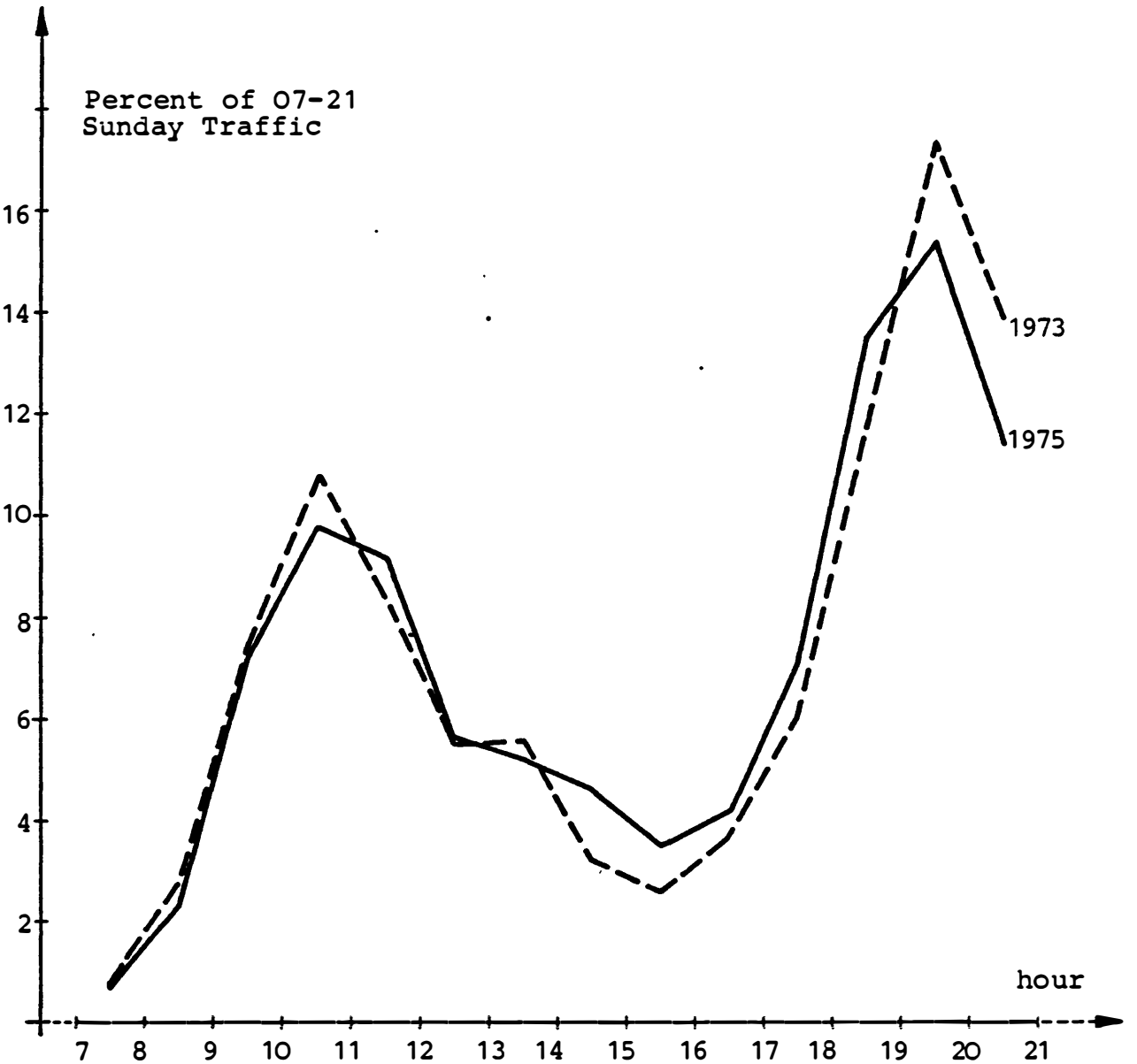


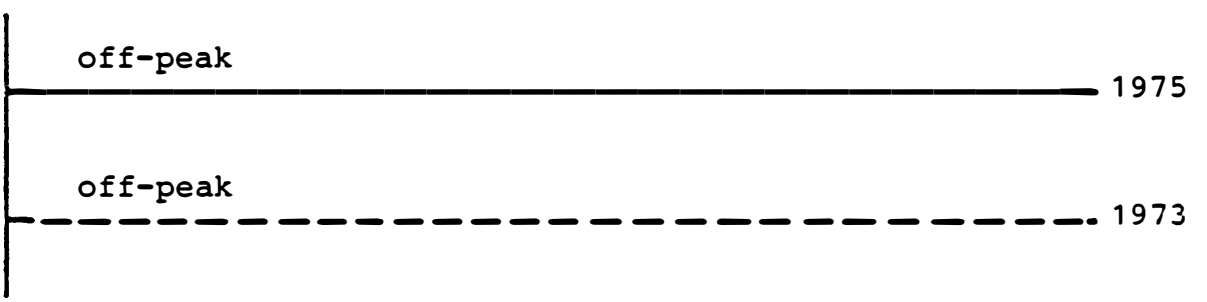
Figure 2b suggests that in relative terms the change in the Saturday rate structure reduced evening calling and led to higher volume after about 3 p.m.

Apart from the shortened pulse interval for all off-peak calls, no change was made in the Sunday tariff, which had had off-peak rates at all hours. Over the 1973-75 period small changes in the shape of the load curve can be seen (Figure 2c), and there is again a (somewhat smaller) reduction in the late evening peak load. The qualitative similarity of the daily and Sunday changes in load at the evening peak hours indicates the difficulties of inferring the effect of a single change in tariff structure. Is the relative reduction in 8 p.m. traffic on Sunday the result of an exogeneous trend that would have manifested itself with no change in rates? Or is the Sunday evening reduction an "echo" of a tariff-induced change in weekday behavior that occurs either because subscribers establish the timing of their calling on a daily cycle, or because they are ignorant of the rate differences on weekends?

Figure 2c. Sunday Trunk Traffic in Switzerland



Rate Structure



United Kingdom

Before 1970 the rate structure for trunk calls in the United Kingdom had a standard charge from 8 a.m. to 6 p.m. on weekdays and a discount rate at other hours. To encourage subscribers to shift some calls away from the mid-morning peak, the Post Office introduced a peak rate from 9 a.m. to 12 noon in July 1970.

Since then there has been one minor revision in the rate structure: on April 28, 1975 the hour from noon to 1 p.m. was switched from the standard (shoulder) to the peak rate. The level of all telephone rates was raised later that year, on October 1, from 1.8p to 3p per telephone unit.

The small April 1975 rate structure adjustment provides only a limited opportunity to measure consumer responsiveness to midday tariff changes. In Figure 3 we compare the quarterly total number of trunk calls per half-hour before and after the noon - 1 p.m. hour was repriced. In most cases a small shift of calls out of the peak period is observed.

The research staff at the British Post Office develop and maintain a series of econometric models to forecast telephone variables of major importance. Predictions for trunk calls are based on separate models for the weekday hours of 8 a.m. to 6 p.m. and for all other hours (when only off-peak rates apply).

In the "full-rate model" the quarterly number of weekday 8 a.m. to 6 p.m. calls is explained as a function of an index of the peak and shoulder trunk rates, the number of business subscribers, the extent of automatic dialing, and the output level of the service sector (Cracknell, 1977). The model incorporates quarterly and annual moving-average disturbance parameters. Currently estimated for 63 observations, it yields a price elasticity of -0.10. The distribution of calls between the peak and shoulder periods is modeled in ratio form as a function of the ratio of the peak to shoulder period prices. This equation is estimated from monthly data beginning in July 1970 and includes a first-order moving-average residual.

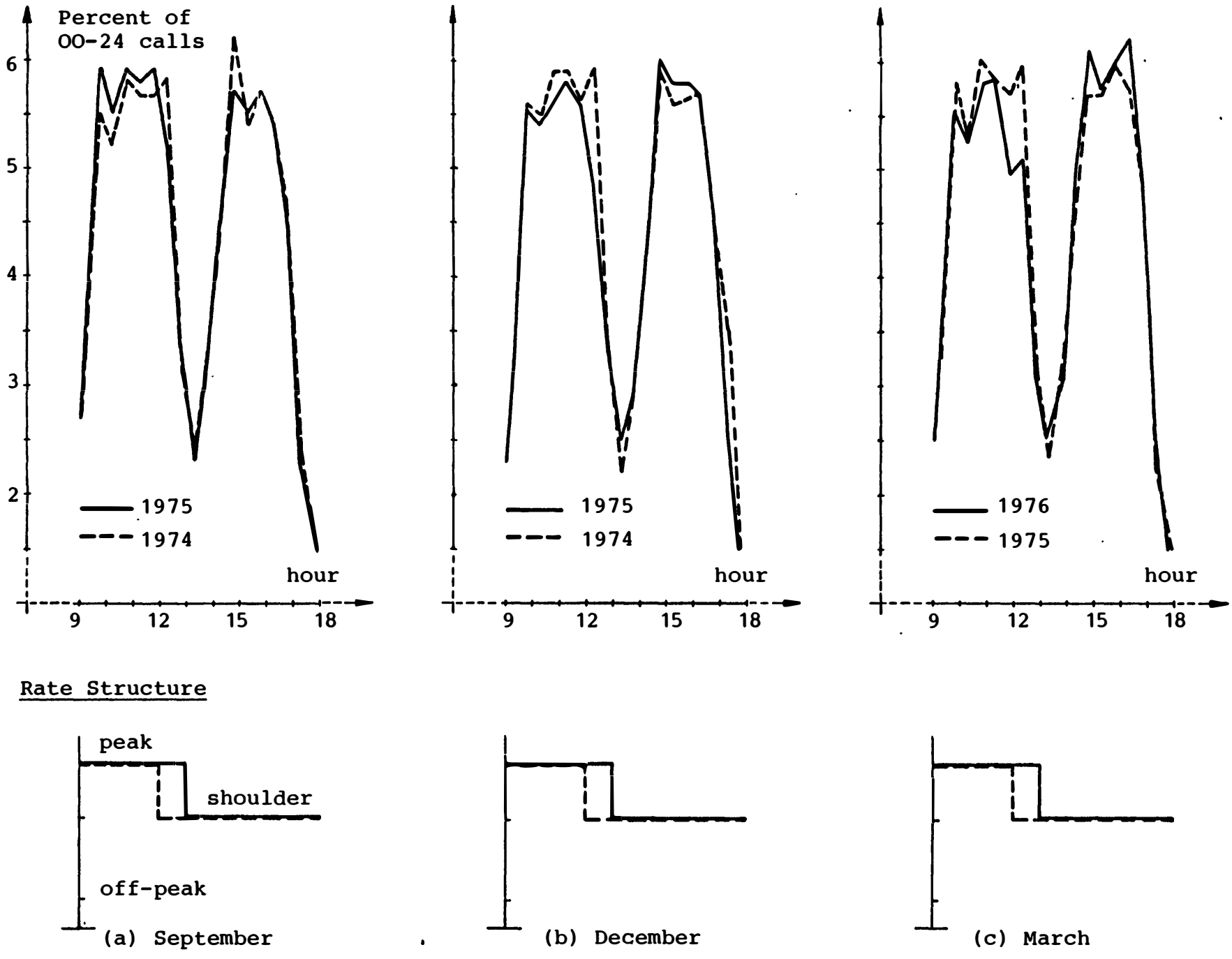


Figure 3. Quarterly Trunk Calls on Weekdays in the United Kingdom

For off-peak calls the "cheap-rate model" explains the quarterly number of off-peak calls as a function of the off-peak rate, the number of residential subscribers, the extent of automatic dialing, and aggregate consumer expenditure (Drew and Cracknell, 1976). Estimated with quarterly and annual moving average error coefficients, the model produces a price elasticity of -0.08.

In their present form the models provide for tariff-induced shifts in traffic within business weekday hours but not otherwise. In later staff research these models were linearized to assess the effects of reducing peak rates so as to increase the use of current excess trunk call capacity. At the mean values of the volume of calls forecasted for 1977/78, the own- and cross-price elasticities are:

variable	Elasticity with respect to	
	peak rate	shoulder rate
peak rate calls	- .35	+.18
shoulder rate calls	+.23	-.26

Thus, the econometric findings are that daytime calling patterns are susceptible to some degree of control through tariff policy.

West Germany

On July 1, 1974, the West German telephone administration made a major revision in its tariffs. Charges for virtually all services were increased, in many cases very substantially. Monthly subscription rates were raised 25 percent and installation fees by 67 percent. The price of a telephone unit was, by comparison, increased by about 10 percent, from 21 Pf. to 23 Pf.

In this climate the Bundespost was under political pressure to provide some indications of rate reductions. It used this occasion to introduce an important change in the rate structure for trunk calls (Table 7). The so-called "moonlight" or off-peak rate, which has been designed to stimulate data traffic and had been in effect only between 1 a.m. and 6 a.m. every night, was reset to begin at 10 p.m. Monday through Saturday. The moonlight rate was also established for all hours on Sundays and federal holidays. Because no change was made in the pulse intervals (Table 4), this liberalization of the moonlight hours did provide significantly reduced rates, especially over longer distances. For calls beyond 100 km. subscribers could talk for 67.5 seconds for 23 Pf. (11.4 ¢) rather than 18 seconds for 21 Pf. (10.5¢), a price reduction of 60 percent.

The effects of the change in tariff structure can be seen by comparing the May 1974 and November 1976 weekday load curves in Figure 4a. At 10 p.m., when the off-peak rate now takes effect, there has been a very abrupt, threefold increase in measured network traffic. In fact, this needle peak indicates the existence of overload conditions in local segments of the network and therefore understates the actual demand for trunk calls at the moonlight rate. Over this two and a half year period the late-afternoon traffic has also increased, starting about one hour before the shoulder rate takes effect at 6 p.m. As this rate has (in relative terms) not changed, the observed increase in shoulder-hour traffic may reflect a relatively more rapid secular growth in residential trunk calling that is concentrated outside of business hours. During the same period the load curve during normal business hours has remained unchanged.

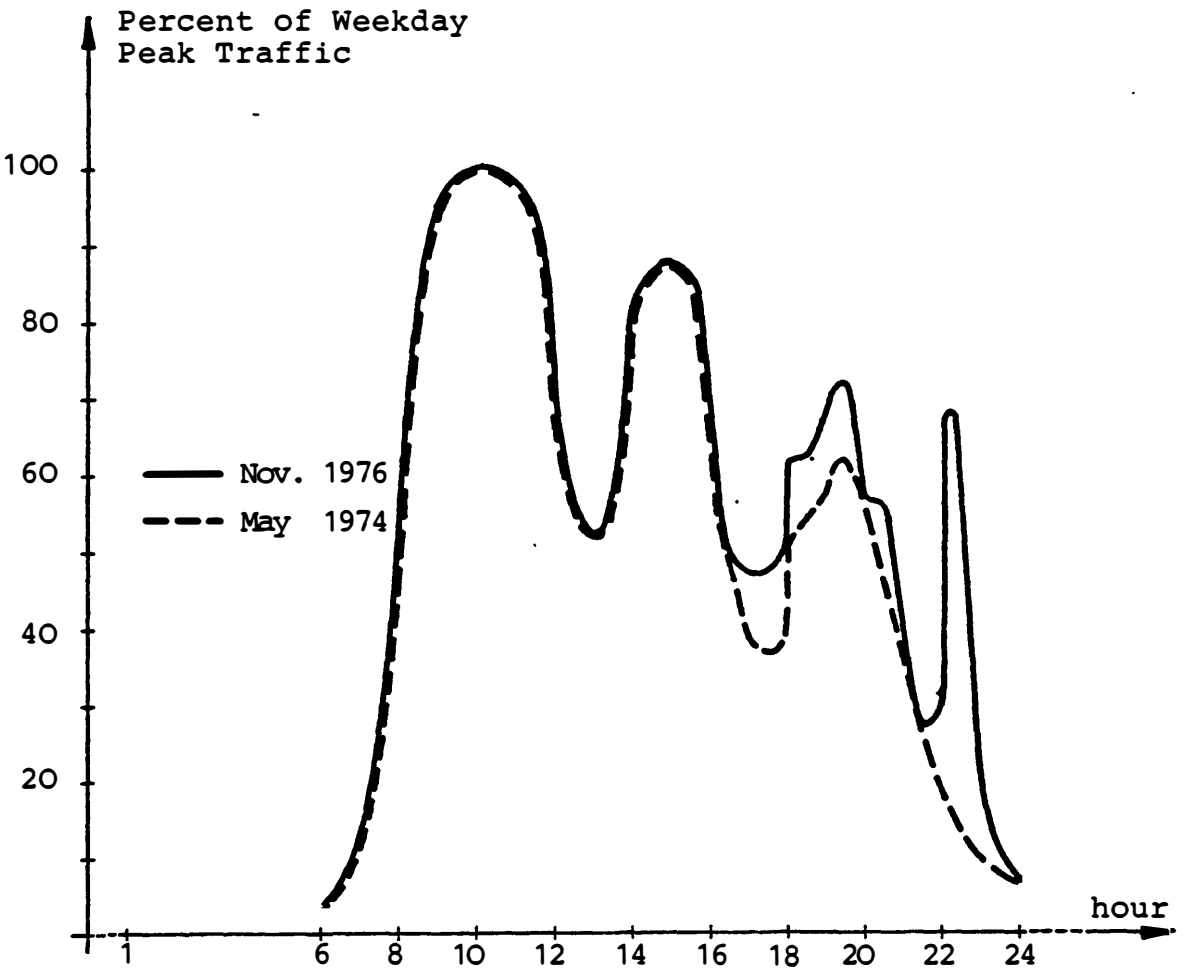
As indicated above, the mid-1974 tariff revision allowed the moon to shine for 24 hours every Sunday and holiday. Between May 1974 and November 1976 Sunday trunk traffic has almost tripled, and as shown in Figure 4b the network peak in both the morning and early evening now exceed the weekday peak. In these instances, measured traffic again understates actual consumer demand, as the network is effectively blockaded in the peak hours. Figure 4b also shows that there is a sizeable "echo" effect at 10 p.m. when a needle peak appears

TABLE 7

Hours of Tariff Periods for Trunk Calls, West Germany

Period	July 1971-June 1974	July 1974-June 1978	July 1978-
peak	06-18 Mon-Fri. 06-14 Sat.	06-18 Mon-Fri. 06-14 Sat.	06-18 Mon-Fri. 06-14 Sat.
shoulder	18-01 Mon-Fri. 14-01 Sat. 06-01 Sun.	18-22 Mon-Fri. 14-22 Sat.	18-22 Mon-Fri.
off-peak	01-06 Mon-Sun.	22-06 Mon-Sat. 00-24 Sun.	22-06 Mon-Fri. 14-24 Sat. 00-24 Sun.

Figure 4a. Weekday Trunk Traffic in West Germany



Rate Structure

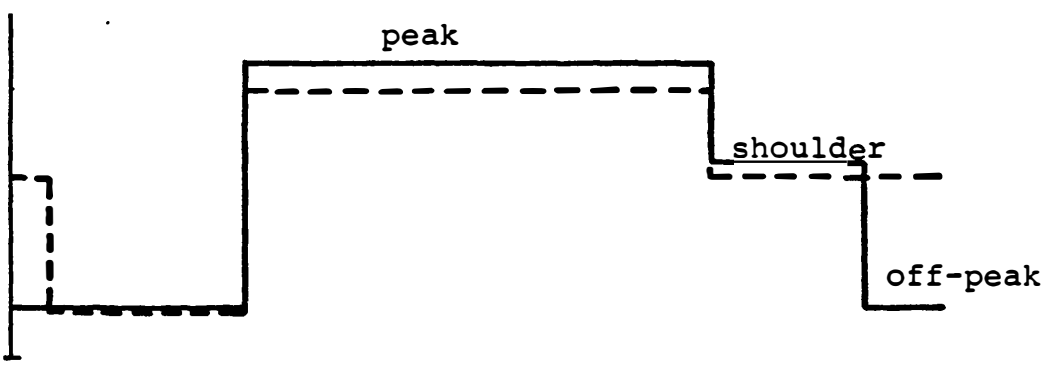
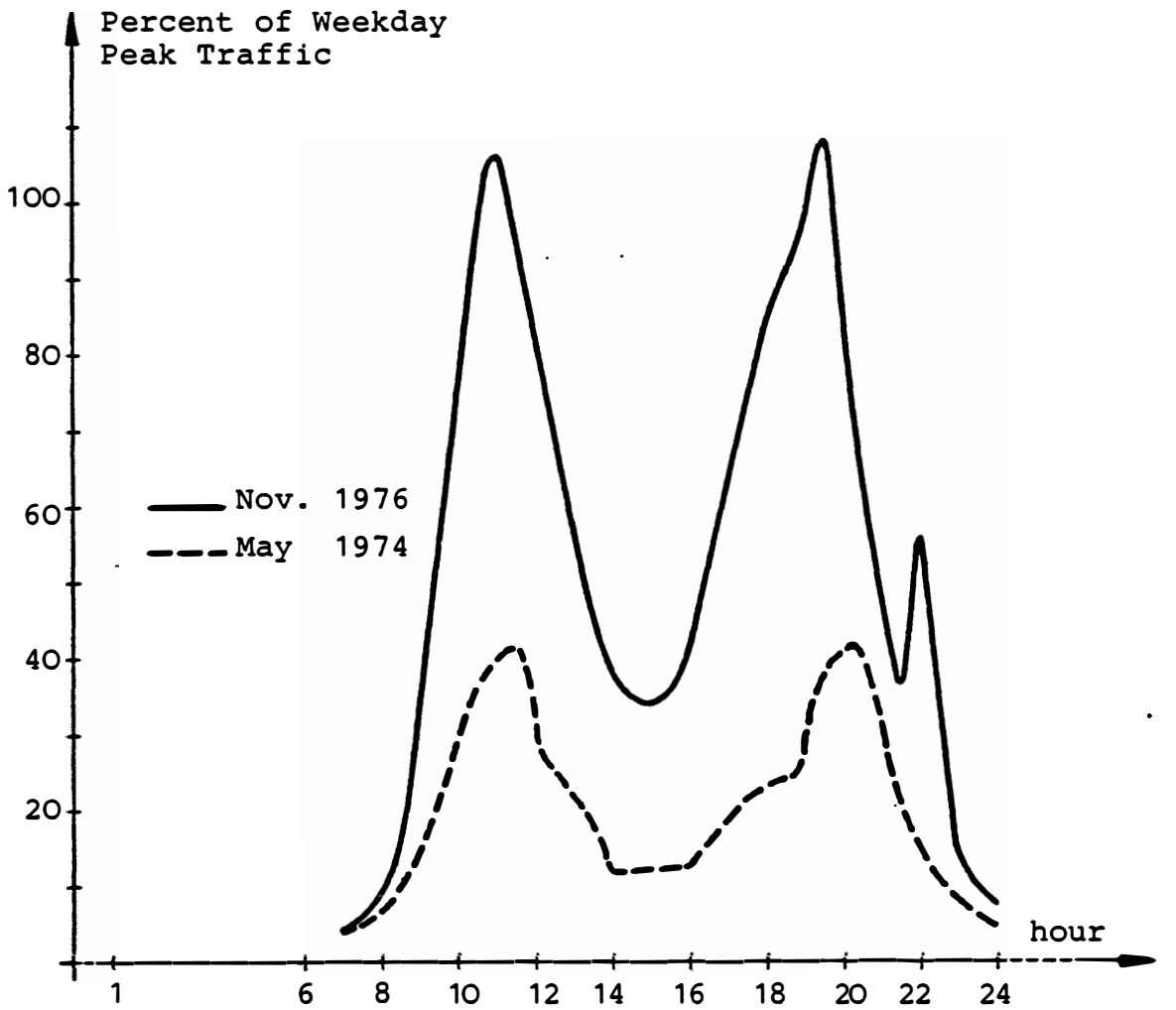
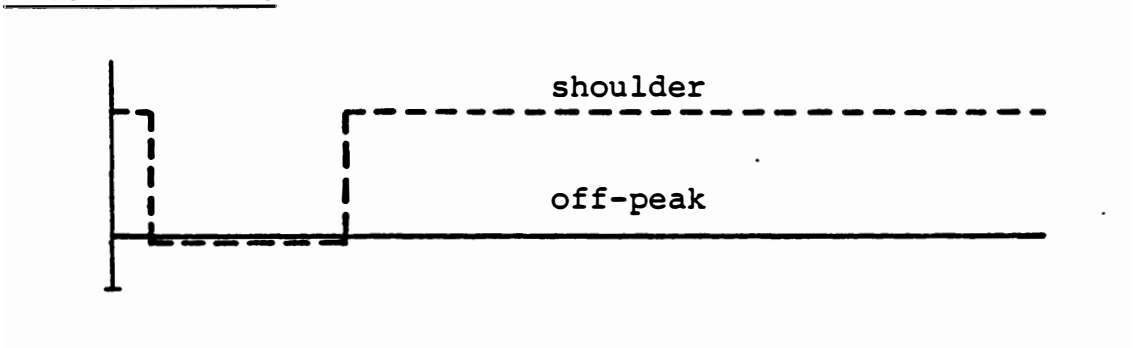


Figure 4b. Sunday Trunk Traffic in West Germany



Rate Structure



despite the fact that the off-peak rate has been in effect the entire day. Both a combination of weekday habits and misinformation about the true rate structure may account for this behavior.

The Bundespost has committed itself publicly not to raise telephone rates before the early 1980's. Therefore, despite the overload conditions at some moonlight hours, the tariff revisions it has announced for July 1978 will leave the off-peak rate unchanged. However, on Saturday the off-peak moonlight rate will begin at 2 p.m. (rather than 10 p.m.) and during the weekday the shoulder-hour rate will be reduced some 20 to 25 percent. These adjustments are intended to ease the growing problem of a shifted peak - - first, by encouraging Sunday calls to be made on Saturday afternoon, and second, by providing an incentive to move some late-evening weekday calls into the early evening period.

Aggregate traffic measurements combine call frequency and call duration into a single statistic. Data from a recent traffic sample of 861 households conducted for a two-week period by the Bundespost suggest that there is some price elasticity of demand with respect to both the number of calls as well as the mean duration. Figure 5a shows that the number of trunk calls as a proportion of total calls rises in the lower-priced periods for households headed by white-collar and blue-collar employees, and to a lesser extent for self-employed persons who presumably also use the telephone for business calling. Furthermore, as shown in Figure 5b, the duration of trunk calls is also inversely related to price. While suggestive, such patterns are doubtless also influenced by non-tariff factors.

West Berlin

The economic problems of matching capacity to demand vary across different types of public utilities. Most utility services are provided through a supply network in which individual components must be sized according to local conditions. However, centralized capacity is of major importance in supplying services such as electric power, where every customer's demand adds to the generating plant capacity that is needed. In contrast, the capacity required in a telephone system is decentralized among many local switching centers and individual routes.

Figure 5a: Trunk Calls as a Percent of Total Calls for Residential Subscribers in West Germany

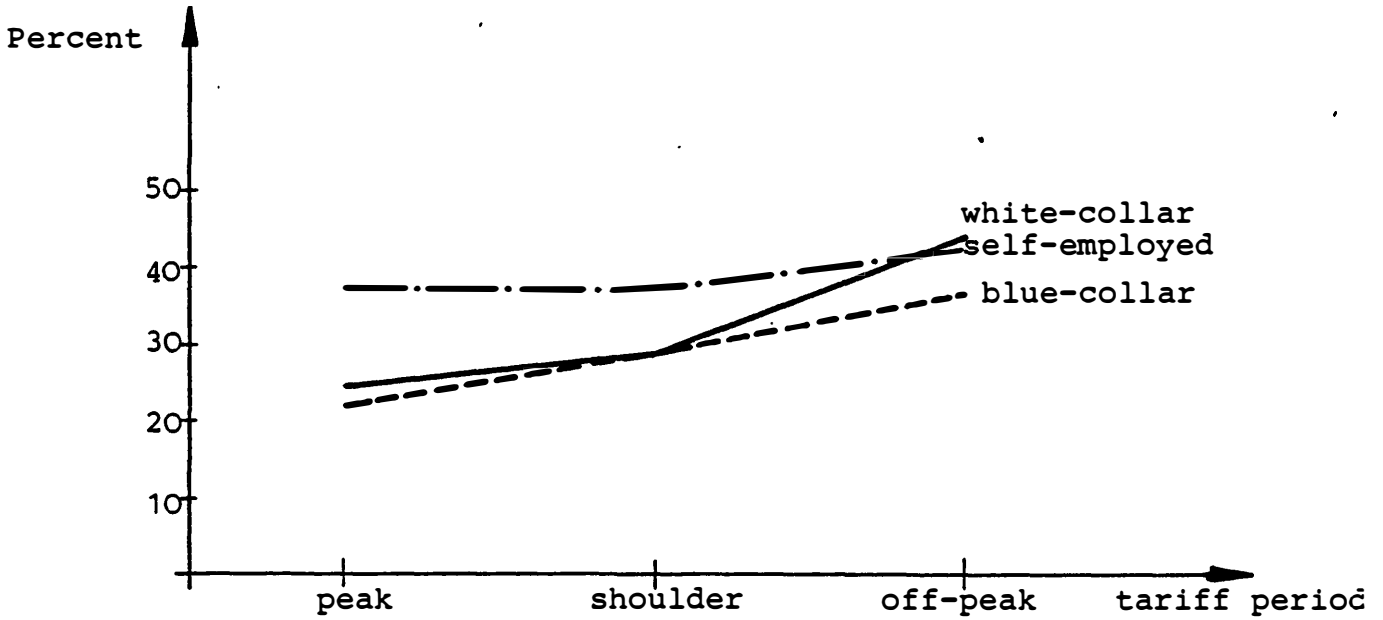
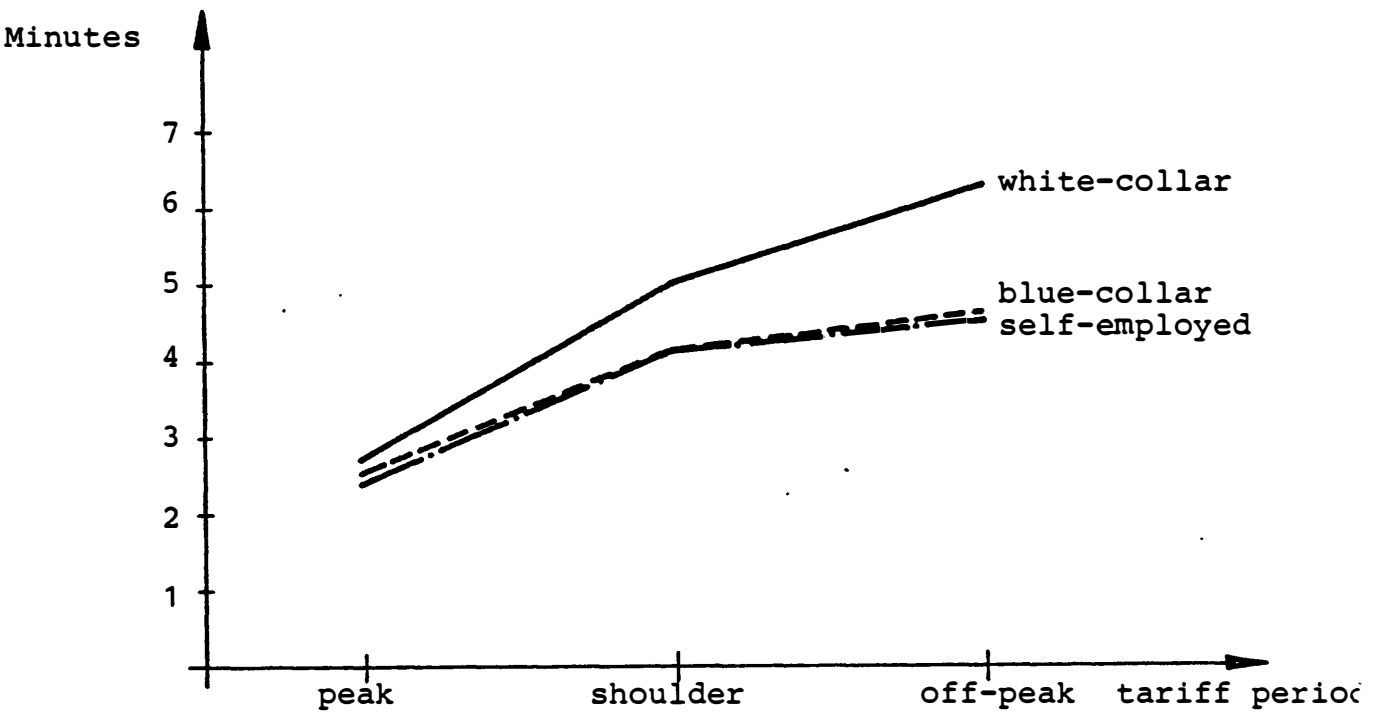


Figure 5b: Average Duration of Residential Trunk Calls in West Germany



The development of trunk traffic loads in West Berlin provides an especially interesting opportunity to examine one component of the aggregate West German traffic curves. West Berlin, located 225 km inside of East Germany, has a high proportion of long-haul trunk traffic. Because most of the telecommunication routes are provided by radio rather than microwave relay or cable, a longer than average amount of time is required to install additional trunk capacity.

Figures 6, 7, and 8 are based on quarter-hour measurements of all outgoing calls from West Berlin. In each figure the upper graphs show traffic as a percentage of the Sunday peak demand observed in December 1976, while the lower diagrams depict the rate structure in effect. Unlike the aggregate traffic in the entire West German network, West Berlin weekday traffic peaked in the early evening (7 p.m.) before July 1974 (Fig. 6a). The introduction of the off-peak moonlight rates at 10 p.m. caused an immediate surge in the late evening traffic from West Berlin. This demand quickly exceeded the available capacity and resulted in a blockaded network for the first half hour that the off-peak rate was in effect (Fig. 6b). And at the end of 1976, despite the addition of a significant amount of capacity, the growth in demand continued to overload the network at 10 p.m. (Figure 6c).

The new off-peak hours also stimulated Saturday evening traffic after 10 p.m. (Figure 7) and likewise resulted in excess demand by the end of 1976. In West Germany as a whole, the greatest growth in aggregate traffic occurred on Sundays. In West Berlin, the new Sunday off-peak rate had the particularly dramatic effect shown in Figure 8. By 1975, the network was overloaded from 9:30 a.m. to noon, and again at 8 p.m., and by the end of 1976 almost total overload conditions prevailed from 9 a.m. until after 10 p.m.

When a market is in disequilibrium and supply is insufficient, the measurement of demand poses problems. In the figures for West Berlin, the traffic values that exceed the indicated capacity included attempted calls that were not successful due to overload conditions.

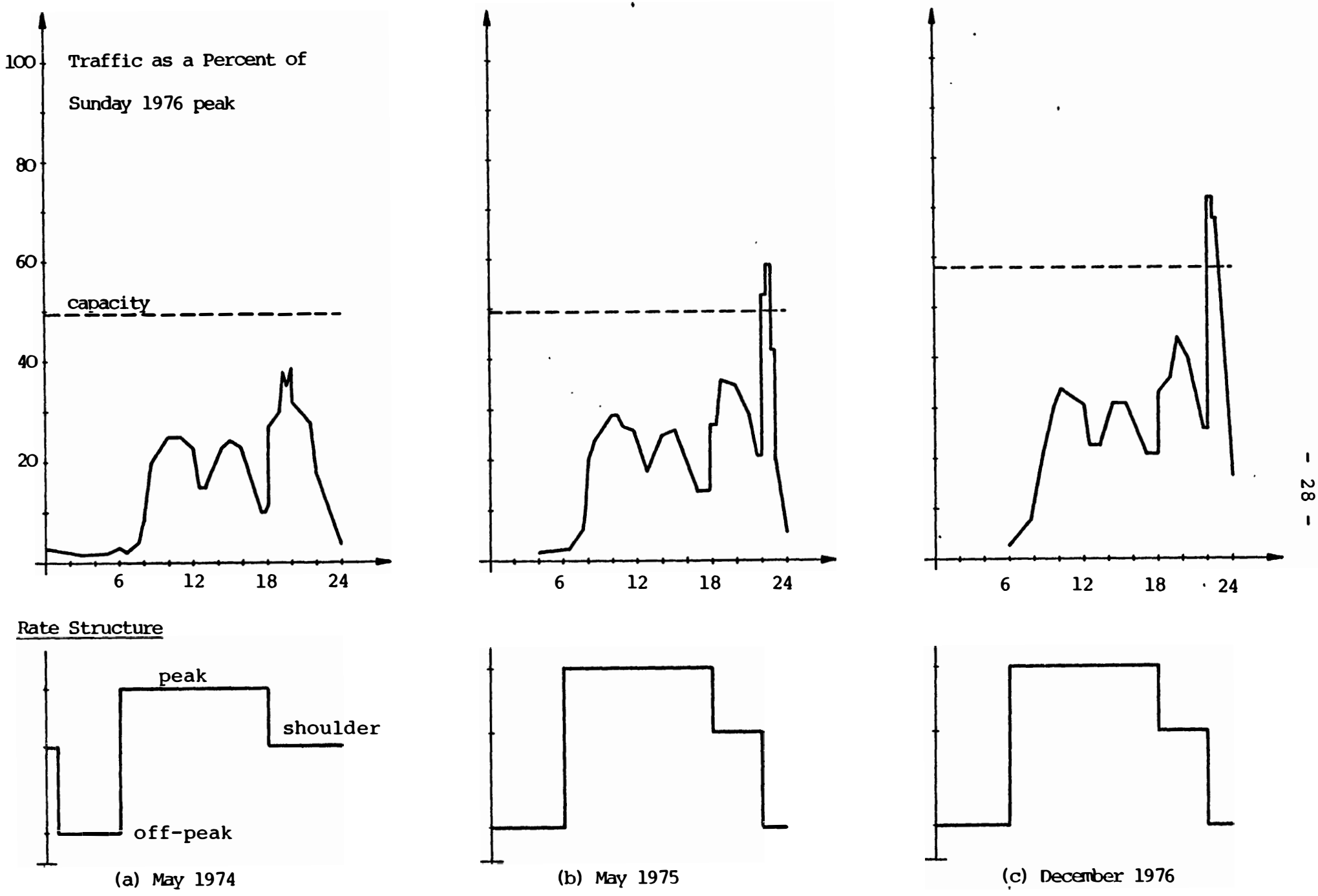


Figure 6. Weekday Trunk Traffic in West Berlin

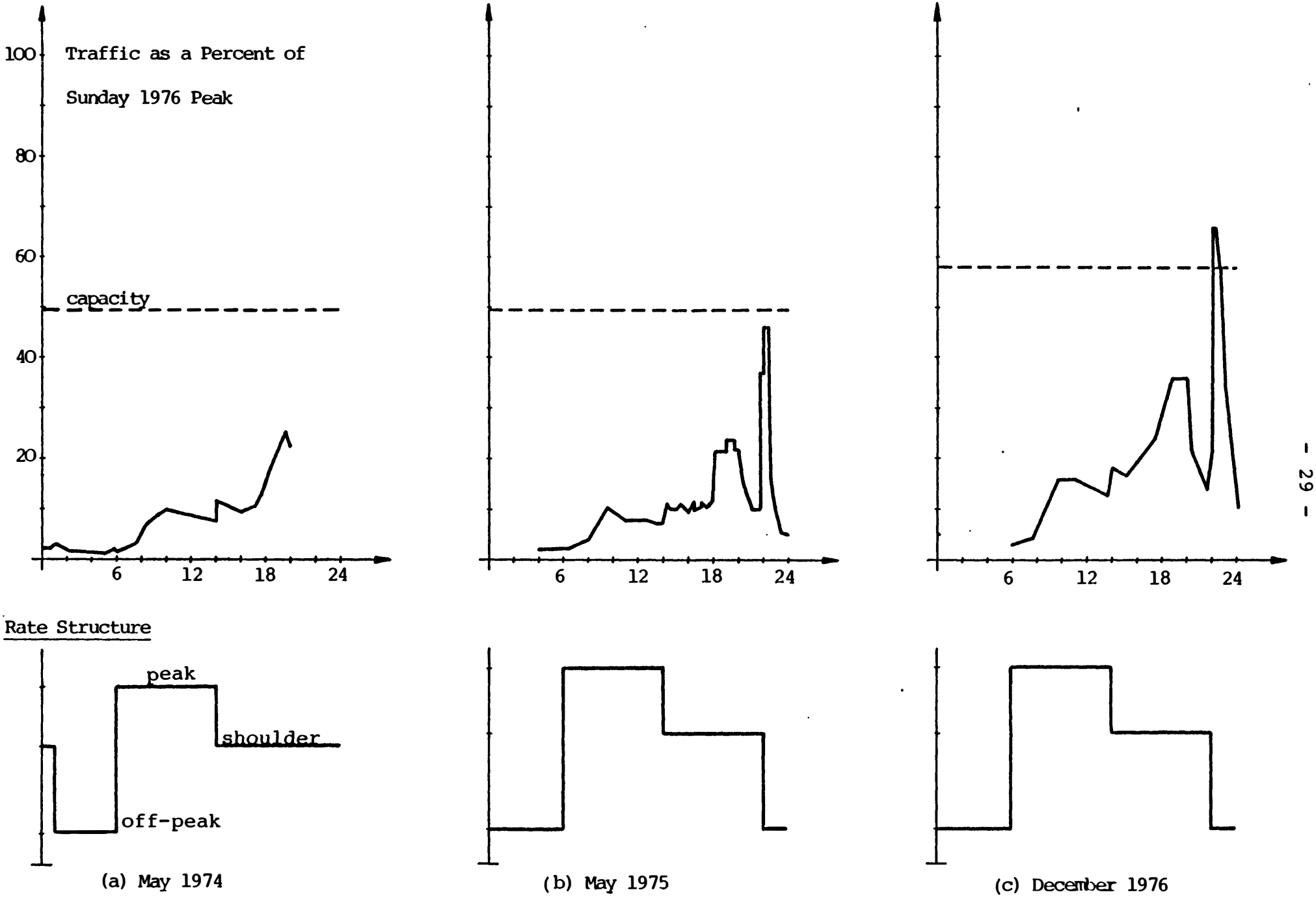


Figure 7. Saturday Trunk Traffic in West Berlin

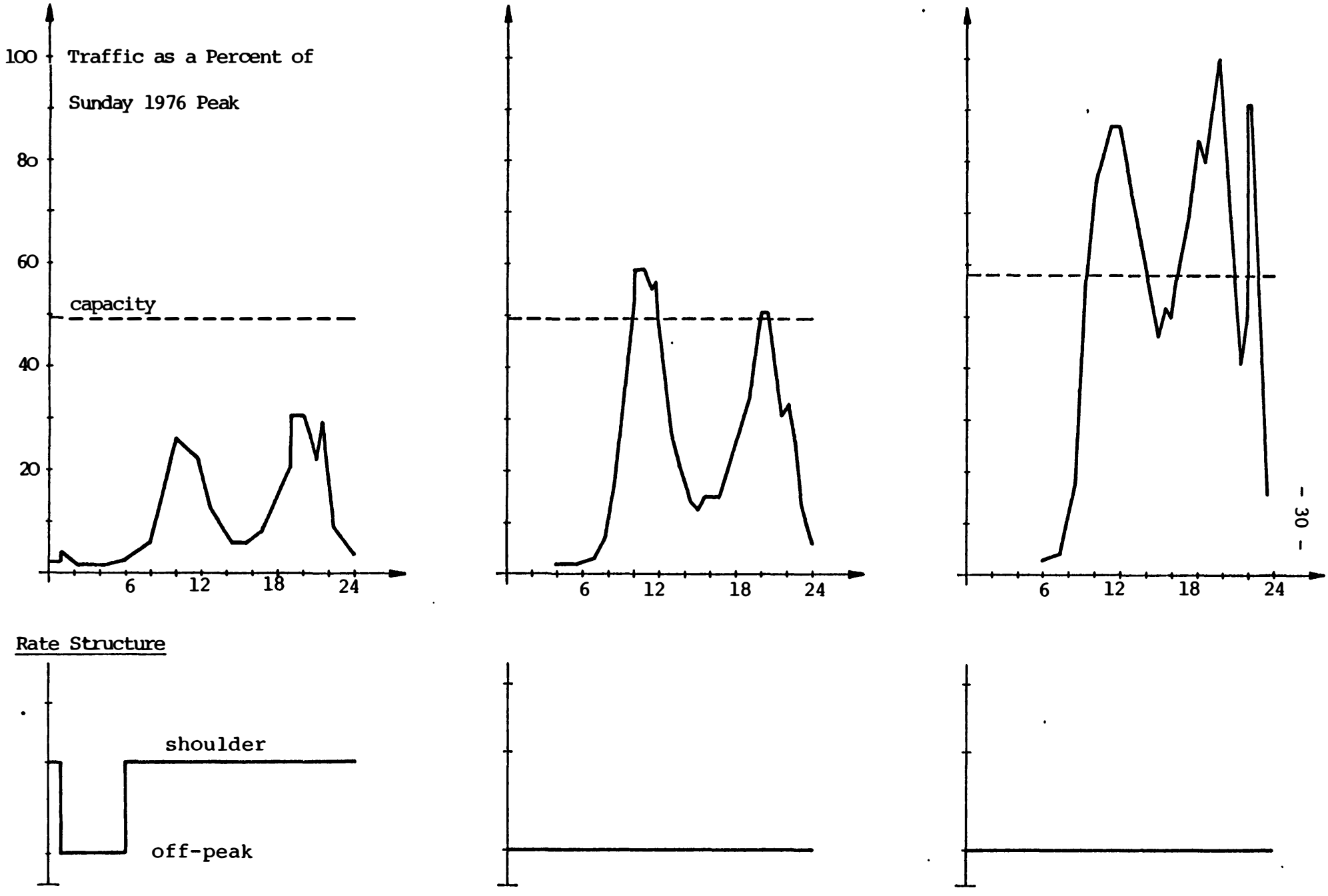


Figure 8. Sunday Trunk Traffic in West Berlin

The measurement equipment that was used to collect these data records a call attempt as soon as the subscriber dials the initial "0" digit that indicates that a trunk call is being placed.

The recorded amount of "invisible traffic" - - traffic in excess of available capacity - - may be greater than, about equal to, or less than the traffic that would exist were sufficient capacity available to connect all attempted calls. In overload periods, subscribers are known to dial the same number repeatedly in an attempt to obtain a connection, thus increasing the number of attempts. On the other hand, the well-known difficulty of completing a call on Sunday may discourage calls that would otherwise be made. And in some cases, local circuits feeding into the trunk center may also be full, so that no attempt is recorded. Increased understanding of consumer behavior in excess demand markets would be of considerable value in planning capacity expansion, as well as for analysis of market demand. However, gathering the requisite data presently requires the use of costly special-purpose equipment.

United States

The Long Lines department of the American Telephone and Telegraph Company (AT & T) has made several changes in the structure of trunk call rates, and some data are now available on the volume of messages by time of day over the 1960-1967 period, during which two changes in rate structure occurred.*

Table 8 shows the basic configuration of AT & T's rates. Prior to April 1963 a two-period structure was in use. "Evening" rates, representing about a 30 percent discount for calls over 100 miles, took effect at 6 p.m. Monday through Saturday and also applied at all hours Sunday. The range of prices shown in the table reflects the tapering of rates with distance; in the full rate schedule there are 32 separate distance bands between 25 and 3000 miles. With the ticketing technology used by the Bell System trunk calls were billed for a minimum initial 3-minute period, with lower marginal rates applying for all additional minutes.

*These data were first analyzed by Auray (1977).

TABLE 8

Rate Structures for Interstate Trunk Calls, United States, 1959-1967
(Prices for initial 3 minutes, station to station)

Rate Period and Mileage Bands	Sept.19, 1959 - Apr.3,1963	Apr.4,1963 - Jan.31,1965	Feb.1,1965 - Oct.31,1967
Peak	04:30 - 18 Mon-Sat.	04:30 - 18 Mon-Sat.	04:30 - 18 Mon-Fri.
25-220 mi.	$0.30 - 0.80	unchanged	unchanged
221-506 mi.	$0.85 - 1.25	unchanged	unchanged
507-3000 mi.	$1.30 - 2.25	unchanged	$1.30 - 2.00[a]
Shoulder	18 - 04:30 Mon-Sat. 00 - 24 Sun.	18 - 21 Mon-Sat. 04:30 - 21 Sun.	18 - 20 Mon-Fri- 04:30 - 20 Sat.
25-220 mi.	$0.30 - 0.60	$0.30 - 0.60	unchanged
221-506 mi.	$0.65 - 0.95	$0.65 - 0.95	$0.65 - 0.90
507 -3000 mi.	$1.00 - 1.75	$1.00 - 1.75	$0.90 - 1.50
Off-Peak		21 - 04:30 daily	20 - 04:30 Mon-Sat. 00 - 24 Sun.
25-220 mi.	- - - - -	$0.30 - 0.60	unchanged
221-506 mi.	- - - - -	$0.60 - 0.65	unchanged
507-3000 mi.	- - - - -	$0.65 - 1.00	unchanged

a) The rates for distances beyond 600 miles took effect April 1, 1965.

The first change in the rate structure occurred in April 1963 when a third, off-peak rate period was introduced between 9 p.m. and 4.30 a.m. every day. For calls over 220 miles these rates provided further discounts that increased with distance.

The second change came two years later, in February 1965 when the off-peak period was enlarged. On weekdays it began at 8 p.m. rather than 9 p.m. Furthermore, all hours on Sunday were now at off-peak rates. Small reductions of about 10 percent were made in the level of shoulder-period rates.*

Selected data on trunk message volume are available from measurements in October 1960, 1963, 1965 and 1966. Unfortunately, only partially aggregated weekday observations are presently available, so that the analysis of demand responses that is possible is quite limited. In particular, because messages are aggregated into a single value for the 8 a.m. - 5 p.m. period and into another value for 5 p.m. to 8 p.m., one cannot detect any shifting of demand that may have occurred near the beginning or end of a tariff period, nor can one establish the relationship between the actual daytime peak and the traffic levels in shoulder and off-peak periods. These data do, however, distinguish between business and residential customers.

Figure 9 shows the evolving pattern of evening trunk messages in the longest-haul markets, 507-3000 miles, juxtaposed against the prevailing tariff structure. Beginning at 8 p.m. the number of hourly messages is shown as a percent of the total number of messages in the 8 a.m. to 5 p.m. period. However, because hourly data were not available, the dotted line shows only the mean volume per hour during the 5 p.m. to 8 p.m. period. (The appearance of an abrupt increase in messages at 8 p.m. in 1960 is presumably an artifact produced by this deficiency).

The 1963 introduction of new off-peak rates at 9 p.m. had a dramatic effect, more than doubling the number of 9 p.m. - 10 p.m. calls but also stimulating greater traffic later in the evening as

*In addition, consolidation of the 601-675 and 676-800 mile bands resulted in reductions in peak period rates for all higher distances, as of April, 1965.

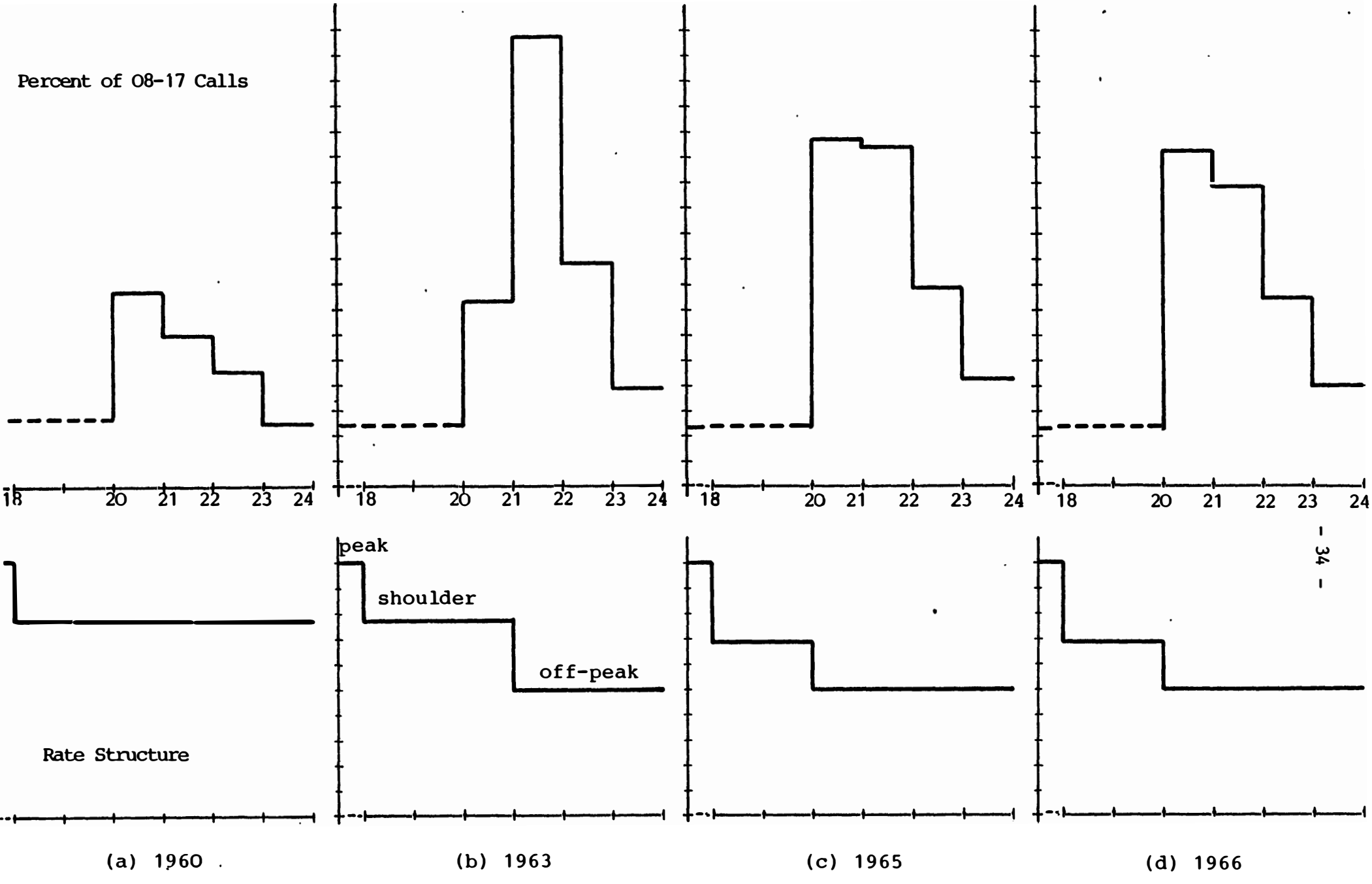


Figure 9. Distribution of Weekday Evening Calls in the United States October 1960-1966 (507-3000 miles)

well. Then, as can be seen in the third panel of the figure, the 1965 advancement to 8 p.m. of the starting hour for the off-peak rate led to an effective leveling of the 8 p.m. - 10 p.m. demand. One year later, the demand during the first off-peak hour had again grown relatively faster and was determining the evening peak-load.

* * * * * * * * * * *

The empirical evidence just discussed suggests several hypotheses about consumer behavior when telephone rate structures are changed and how such behavior might be included in an analytic model. The data themselves, however, should be regarded as only approximate indicators of the economically relevant measures of consumer demand.

For some purposes an aggregate measure of demand is both appropriate and necessary, as practical considerations require that a single, quite simple rate structure apply to all consumers. Nevertheless, a more detailed examination of consumer responses is desirable. There can be important differences between measures of the number of calls and total traffic. Similarly, actual demand may not be accurately reflected by measured demand statistics at peak hours. Also, in a network spanning several time zones the definition of common tariff periods may have varying implications for traffic loads in different regions. Finally, the variations across the network in the marginal costs of meeting peak loads should also be considered in developing an aggregate measure of trunk call demand. Continued interchange between economists and engineers should lead to increased understanding of these factors.

TOWARD AN APPLIED MODEL OF PEAK-LOAD PRICING

In the previous section we surveyed a variety of data on changes in traffic patterns that have resulted from revisions in trunk call rate structures. The combined experience accumulated by several telephone administrations and the detailed data they possess should enable a quantitative model of the demand for telephone calls under peak-load rates to be constructed and calibrated to national parameters. The development of such a model could be of value to the telephone administrations in their forecasting and revenue planning activities, to national authorities and public utility regulators in assessing the performance of telephone enterprises, and to the general public who would benefit from the increase in efficiency of the telephone network that could be achieved under improved rate structures.

In this section we discuss some of the major elements that need to be incorporated into a model of peak-load pricing applicable to a telephone system. In order to be reliably used for quantitative forecasting and evaluation, such a model must incorporate the most important specific characteristics of telephone technology and call markets in addition to the general principles developed in the literature of optimal pricing. Nevertheless, some of the suggestions advanced here may be of use in other sectors, such as electric power, in which peak-load considerations are important.

Most of the discussion assumes that it is desirable to base prices on marginal costs, subject to a budget constraint that total costs be recovered, and that the level of service quality is exogenously given. We conclude, however, with a short remark about the recognition of consumption externalities and consumer valuation of telephone service.

The Peak-Load Pricing Problem

In the classic peak-load pricing problem, first set out by Boiteux (1949) and Steiner (1957), one assumes that the quantities demanded are at uniform levels $Q_1 < Q_2$ in each of two equal-length time periods T_o (off-peak) and T_p (peak). To supply the service demanded requires resource expenditures of b (marginal operating costs) per unit consumed plus c (marginal capital costs) per unit of capacity.* Telephone service is perhaps the extreme form of this problem, as almost all call-related costs are due to the provision of capacity, so that b = o. Letting x(t) be the rate of calls demanded per unit time, the cost of capacity per call-minute is:

$$\beta = c \frac{\max x(t)}{\int_{T_p} x(t)\, dt} = c \frac{Q_2}{Q_2 \int_{T_p} dt} = \frac{c}{\text{number of peak period minutes}}$$

Welfare-optimal pricing results if prices are set equal to the marginal costs of a call in each period: $p_1 = b = 0$ and $p_2 = b + \beta = \beta$. This result is correct provided that there is a "firm peak", i.e. that at these prices Q_1 is still less than Q_2. If, however, the peak shifts so that $Q_1 > Q_2$, then the optimal prices are those that lead to full utilization of capacity in each period and recover total costs, i.e. $Q_1 = Q_2$ and $p_1 + p_2 =$ c/total number of minutes.

The realistic peak-load pricing problem consists of a (large) number of periods n, each with different levels of demand, and the constraint that there can be at most $m < n$ distinct prices. Multipl periods are not, in themselves, a difficulty (Williamson, 1966) and the optimal pricing rules of the classical model are readily generalized to handle n periods. For the firm-peak case the price in the peak period is set equal to the per-call cost of capacity, and the prices in off-peak periods are set to zero. Note that if the peak period is shorter than in the two-period model, the per-call peak

*In this discussion we leave aside the effect of economies of scale (Mohring, 1970).

price β must be higher to cover the same capacity cost. In the shifting peak case, one must find those prices that equate demand in a set of periods and jointly sum to the capacity cost divided by the combined lengths of the peak periods.

However, the constraint that there be a limited number of distinct prices is the crux of the practical peak-load pricing problem. Craven (1971) and Rees (1976) provide the theoretical framework of calculating the optimal number of pricing periods. In practice, the maximum number of price levels used for trunk telephone calls is three. In the pricing of electric power three is also the maximum number of distinct rates, although rate levels may be reset seasonally (Mitchell, Manning and Acton, 1978). The fact that public utilities have so widely limited themselves to only two or three price levels is not accidental. It reflects their experience in dealing with millions of customers, and their subscribers' willingness to and interest in processing price information. Even with three price levels consumer surveys report a significant degree of ignorance and actual misinformation about the periods at which discount rates apply. In economic terms, consumers' transactions costs of processing detailed price information climb very rapidly, and presumably exceed the efficiency gains that might otherwise be achieved by a more complex rate structure.*, **

The immediate implication of the pricing constraint is that there will be non-uniform levels of demand within a pricing period, and that the peak-load pricing problem becomes one of simultaneously finding prices and pricing methods that satisfy an optimality criterion.

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*It may be that a more detailed rate structure will be of interest to subscribers with specialized telecommunications needs, such as data transmission. In such cases optional rates could be designed to cater to their individual load characteristics, much as interruptible power tariffs are offered to selected large industrial users of electricity.

**If consumers could be provided with price quotations at the moment they demand telephone service, a dynamic rate structure could be used, with price levels varying to reflect the level of capacity actually available when the call is placed. Proposals for dynamic pricing have met with widespread scepticism, but with fully electronic networks such an idea could be cost-effective. As a two-way medium, telephone service is well suited to such a fundamental innovation.

If a narrowly-defined peak period is chosen, the per-call price must be very high to recover capacity costs over a small number of calls. The high price, however, increases the likelihood that, because of the own-price elasticity of demand, the peak will shift. Moreover, a narrow period means that through the cross-price elasticity of demand a relatively high proportion of calls initially within the period could be shifted to adjacent periods of time, thereby increasing the likelihood of a shifting peak. On the other hand, if a wide peak-price period is selected, then charging the peak price for calls during subperiods when demand is less than capacity results in unnecessary rationing, and at the same time there is no price incentive to shift calls from the subperiod in which the peak occurs to the adjacent subperiods where excess capacity is available.

It should be clear from the evidence on consumer responses to rate structure changes that the shifting peak case is more than a theoretical curiosity. Shifting peaks for trunk traffic, both intraday and to the weekend, have occurred at off-peak prices well above zero.* If one considers the peak-load problem to originate from the weekday peak, the requirement that weekend price levels be chosen from those used during the 24-hour weekday pricing periods can be an important constraint. In this case the higher own-price elasticity of demand from residential customers during weekend hours reduces the possibilities for leveling weekday loads.

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*Evidence of shifting peaks under time-of-day rate structures is also found in some European electric utilities (Mitchell, Manning, and Acton, 1978).

Modeling the Trunk Call Market

The task of constructing a realistic model for applying peak-load pricing to telephone systems can be divided into two parts -- the measurement of demand functions by time-of-day and day of week, and the solution of an optimization problem that incorporates constraints on the number of prices to be charged and the requirement that revenues cover total costs.

Two rather separate problems in evaluating the development of telephone traffic may be distinguished:

1) forecasting under constant rate structure, and
2) evaluating alternative rate structures.

Several telephone administrations have developed extensive data bases and econometric models to forecast revenue growth and guide investment planning. In such models, total traffic or messages are disaggregated by consumer class or sector of economic activity and in some cases by region or by call distance. The principal explanatory variables are the number of active main stations and PBX trunklines, the national or regional level of economic activity, the rate of growth of key sectors (e.g. services), disposable income, and a trunk call price index. For examples of this type of model see Auray (1977), Cracknell (1977), David, Caccappolo and Chaudry (1973), Drew and Cracknell (1976), and Pousette (1976).

In contrast, there has been little research to date directed toward modeling the effect of changes in the peak-load structure of telephone rates.* Changes in rate structure occur relatively infrequently. In the past, such innovations have primarily been resulted from a perceptible imbalance between demand and capacity or a political need to offer a lower price in some part of the rate structure, rather than a deliberate attempt to improve the efficiency of the network.

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*Littlechild (1970) represents a first step in this direction. Willig and Bailey (1977) consider repricing day, evening and night calls by assuming that demand functions are independent; their major interest is the structure of call prices as it relates to distance.

The major questions to be answered in considering a change in rate structure concern the alterations in the level and timing of peak loads and the effects on total revenues. To a first approximation, these effects will primarily modify the ongoing growth trends that are central to conventional traffic and revenue forecasting models. A useful model for analyzing rate structures should, by the principle of parsimony, emphasize a rather different set of major variables than are employed in a forecasting model. Such an applied model of peak-load pricing will give primary attention to the detailing of own- and cross-price elasticities of demand.

How best to solve the model, once constructed, will presumably depend to some extent on its particular mathematical structure and require numerical search or iterative procedures. The model can incorporate several alternative objective functions and be used, for example, to maximize profits, social welfare, or benefits to particular subscriber groups.

The major problem is to simultaneously determine the optimal prices and pricing periods. Initial feasible solutions can readily be calculated from an ad hoc establishment of the pricing periods. One can then test for local optimality by perturbing the boundaries of the periods, calculating new optimal prices, and comparing values of the maximands.

Although the properties of such an iterative procedure will need to be investigated to determine whether they produce a global optimum, iterative methods will be of practical importance in indicating the direction of improvement of proposed changes in rate structures and enabling the user to evaluate the changes in traffic flows that would result.

Own-price Elasticities

It is a priori clear that, just as business and residential subscribers have widely been found to have different total traffic demand elasticities, they are certain to have different time-of-day characteristics. It would, therefore, be desirable to have separate hourly (or more frequent) measurements of trunk traffic for each

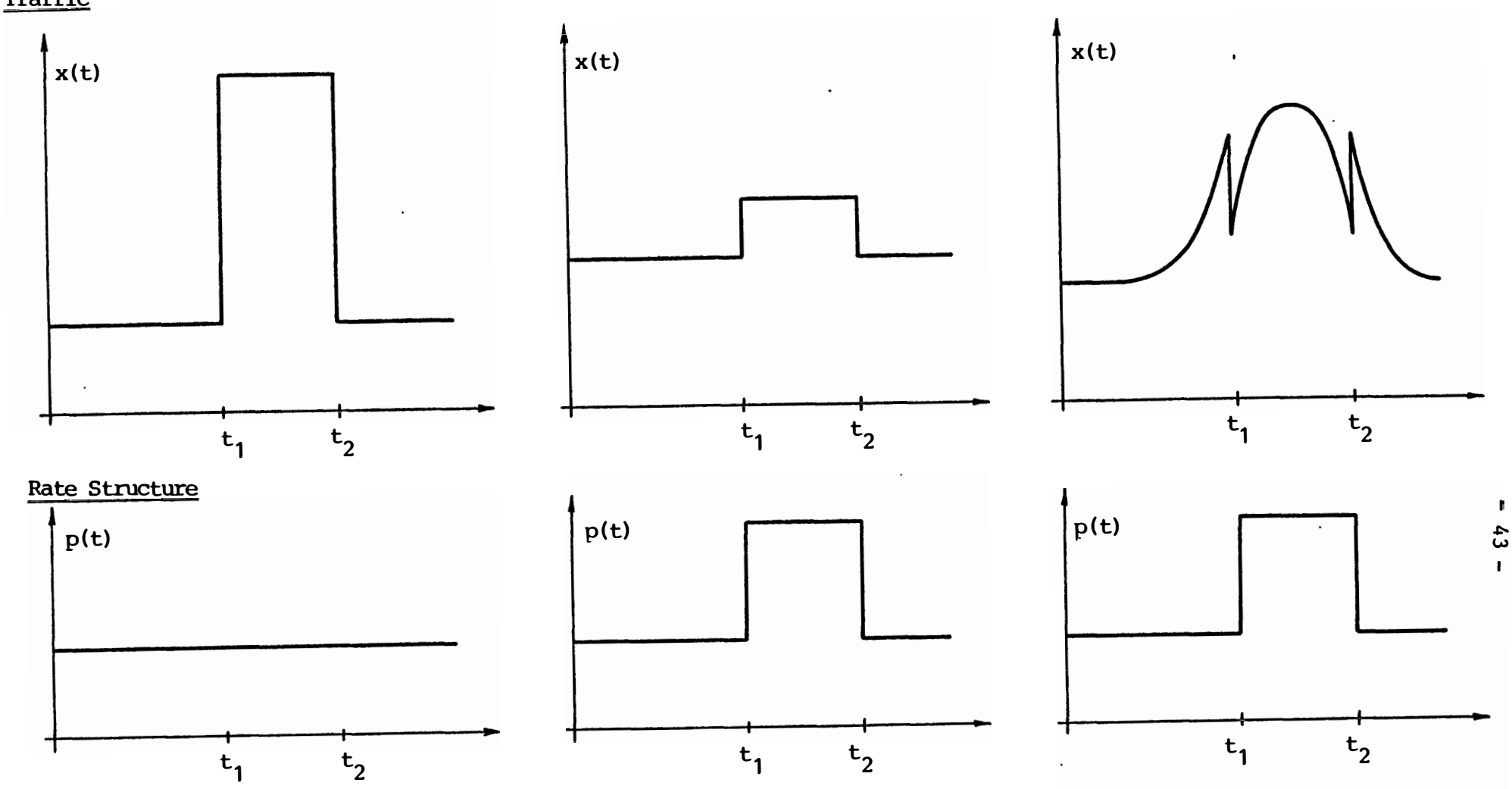
customer class, but such data are unlikely to be available in time-series form except when special traffic or marketing surveys have been conducted. Nevertheless, when it is necessary to work with aggregate load curves, one should keep in mind the changing composition of total traffic. For example, in systems that have not yet reached a high level of main station penetration one should allow for a relative increase in the number of residential subscribers.

Separate own-price elasticities will be needed for almost all hours of the typical weekday. While some adjacent hours can probably be combined into subperiods with a single average elasticity, at the outset it is not obvious which periods should be grouped together, except, perhaps, for the early morning hours. One possibly interesting technique would be to fit the hourly elasticities in terms of a smoothing function, such as a cubic spline, using a relatively small number of parameters. Because there will be less time differentiation of rates on weekends, it should suffice to work with only a few elasticities for multi-hour weekend periods, or to use a parsimonious smoothing function.

Cross-Elasticity Effects

The evidence of consumer responses to traffic changes strongly indicates that, at least within a 24-hour period, the introduction of time-of-day rates has a highly non-uniform effect on traffic at different hours. As a generalization, it appears that the greatest load changes occur during the minutes just preceeding and following the time that the new price takes effect, smaller changes are found at greater distances in time, and little or no effect is discernable more than a few hours before or after the price-switching time.

In order to focus most clearly on the interhour cross-elasticity effect, it is convenient to assume that all own-price elasticities are zero, so that price changes merely redistribute a fixed total amount of traffic during the 24-hour day. Further, for clarity, assume that the initial load curve $x(t)$ which prevails under a uniform price $p(t) = p_o$ is the simple two-level curve shown in Figure 10a. In the conventional peak-load pricing model the introduction of a peak-load price, $p(t) = p_1$ for the period



(a) Load Curve under Uniform Pricing

(b) Uniform Cross-elasticity Effect under Peak-Load Pricing

(c) Non-uniform Cross-elasticity Effect under Peak-Load Pricing

Figure 10. Theoretical Effects of Peak-Load Pricing

$T_p \varepsilon (t_1, t_2)$, would uniformly depress the curve in the peak period and uniformly raise it at other times (Figure 10b). For telephone traffic, however, the result is something like that shown in Figure 10c. The greatest load changes occur in the minutes just after the peak price takes effect and just before the lower price again become effective. Most of this load is shifted just outside the peak period and the added load diminishes rapidly as the distance in time from the peak-pricing period increases.

This non-uniform cross-elasticity effect might be modeled from a number of perspectives. One approach would begin with a consumer whose preferences for a particular pattern of calling over the day can be summarized in a utility function. A call placed at a time other than the preferred moment is of lesser utility, and this disutility increases with the magnitude of the call's displacement in time. The consumer maximizes his utility function subject to the budget constraint, trading off disutility of call displacement for the savings on peak-period charges. Such an approach would represent an extension of a model introduced by Koenker (1977). It would then be necessary to aggregate over individual consumers, but unlike the approach used by Mitchell (1978), this would probably require explicitly including stochastic factors, as the average consumer makes only about four calls in a 24-hour period.

An alternative approach is to impose a suitable structure directly on the market demand functions, sacrificing the elegance of deriving demand relationships from formal consumer theory but shortcutting some formidable aggregation problems. Because the most readily-available data for empirical estimation or calibration of a model are aggregate observations on calls or traffic, this may initially be the more promising approach.

How might non-uniform cross-elasticity effects be introduced in a peak-load pricing model? Consider a simple example, using again the initial load curve x(t) of Figure 10a. Let the amount

of load shifted (Figure 11) from a moment within the peak period, at time $t + \tau$, to the moment t be $z(t,\tau)$. We assume that this amount is equal to a cross-elasticity coefficient $\varepsilon(\tau)$ times the relative increase in price multiplied by the initial volume of calling at time $t + \tau$.

$$z(t,\tau) = \varepsilon(\tau) \frac{p(t+\tau) - p(t)}{p(t)} x(t+\tau)$$

The coefficient $\varepsilon(\tau)$ decreases (absolutely) with the length of time τ by which the calling is displaced. An exponential $\varepsilon(t) = \varepsilon e^{-\lambda t}$ or some other simple function will probably be satisfactory for empirical work.

The displacement $\Delta x(t)$ of load at a time t in the off-peak period is the total of such amounts integrated over the period of price change:

$$\Delta x(t) = \int_{t_1 - t}^{t_2 - t} z(t,\theta)d\theta, \quad t \notin (t_1, t_2).$$

During the peak period the displacement is:

$$\Delta x(\tau) = \int_{0}^{t_1} z(t,\tau)dt + \int_{t_2}^{T} z(t,\tau)dt, \quad \tau \in (t_1, t_2).$$

The formulation of <u>interday cross-elasticity</u> effects can be more straightforward. From the empirical evidence available to date, it seems reasonable to assume that there are no significant demand shifts between days, except perhaps between Saturday and Sunday*. For this case, a uniform cross-elasticity from each Saturday hour to the same hour on Sunday may be satisfactory. However, in empirically establishing the model's parameters, one should also check carefully for the existence of weekend "echos" at the hours that lower rates take effect on the weekdays. However irrational, such an increase in demand represents a particular

*This simplification is, of course, also justified by the fact that traffic peaks are sufficiently similar Monday through Friday that the same rate structure is almost certain to apply on every weekday.

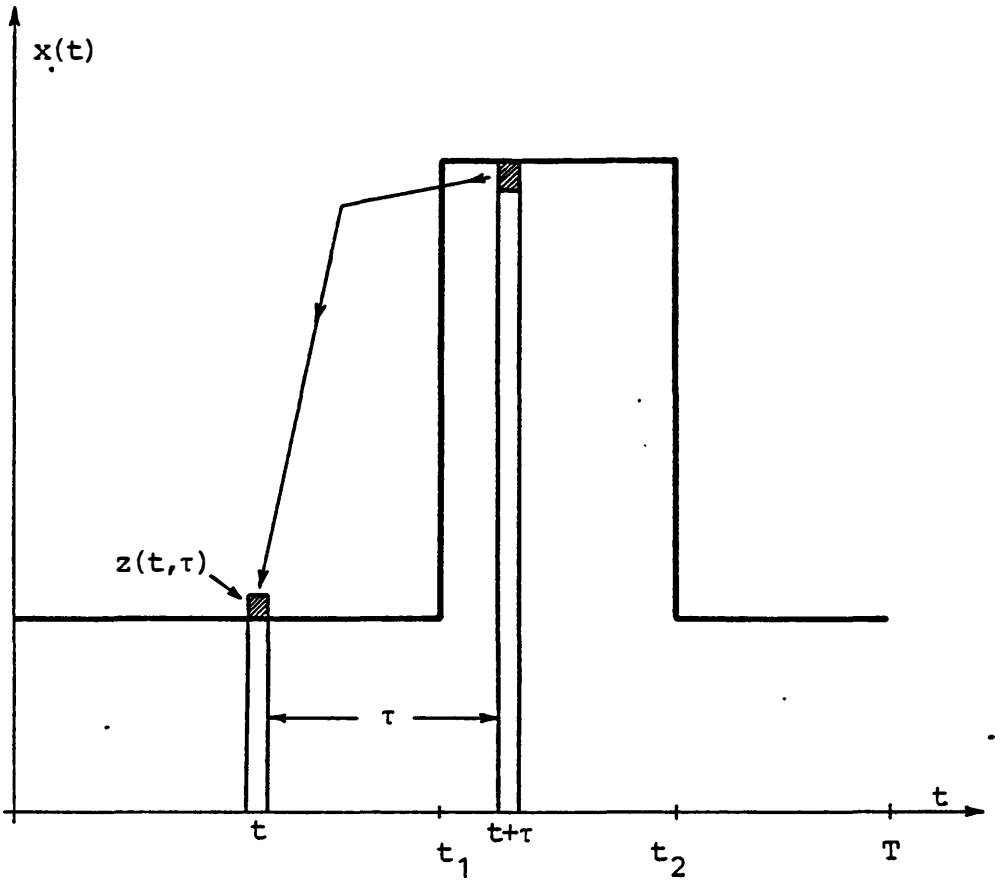


Figure 11. Displacement of Peak Traffic to Off-Peak Period

form of cross-elasticity which, if it does not fade away shortly after the new tariff takes effect, could result in capacity shortages.

Trends

A new long-run equilibrium load curve is no doubt reached more rapidly in telephone call markets than, say, in the electricity sector, where changes in long-lived appliance stocks can continue to have a significant effect several years after a new rate structure has been introduced. Nevertheless, it is important to establish the speed of market adjustment, both in order to use data in the first months following a rate change to test model predictions against actual developments, and to be able to separate the effects of the structural change from ongoing trends in other variables affecting traffic growth. For these purposes, the methods used by Pioger (1977) to decompose the Electricité de France load curve and estimate the annual trend at each hour could be adapted to monthly observations. By comparing trend rates before and after a tariff change, this approach could also be used to estimate hourly elasticity parameters.

Externalities

As we noted in the opening section of this paper, telephone administrations have historically tended to price the subscription service below its costs. They and the parliamentary bodies that approve their rates have justified this policy in terms of making telephone service widely available, insuring that it is affordable by economically disadvantaged groups, etc. Moreover, when rate increases are necessary there may be greater public resistance to increasing the fixed monthly charge than the unit charge.

A telephone provides valuable service only if there is someone at the other end of the line to talk to. This simple observation suggests the general proposition that the value of an individual telephone subscription increases with the total number of subscribers, or with the number of subscribers who belong to an individual interest group. If the costs of supplying telephone

service consist simply of a fixed cost per subscriber plus a constant marginal cost per call, it is welfare-optimal to recognize this externality in individual consumption functions and to set the subscription fee below marginal cost in order to enlarge the number of telephone subscribers (Littlechild, 1976). This cross-subsidy pattern is reinforced when the heterogeniety of consumer tastes is considered and a subscriber's willingness to pay depends on the number of calls made (Mitchell, 1978).

Some telephone administration studies have taken account of the role of the number of telephone connections in stimulating demand for subscriptions as well as increasing total traffic (see, e.g. Böhm and Wacker). However, to date empirical studies have not been able to quantify the extent of the externality or to calculate what degree of subsidy to the subscription price would optimize the development of the network over time.

Once they have been measured, it is straightforward to incorporate externality effects into the applied model for peak-load pricing. The revenue constraint is modified to include a subsidy to cover a specified amount of shortfall from subscription fees. Other constraints - - for example, a required amount of "separations" payment to state jurisdictions - - can as easily be added to the costs that must be covered.

Congestion and Service Quality

In the short run, the capacity of the telephone system is fixed, and the allocation of scarce telephone resources is optimally guided by pricing at the opportunity costs of those resources. As demand approaches the technical capacity of the network, the stochastic process of arrival and duration of calls will result in a rapidly increasing proportion of attempts and calls that are incomplete. Because such attempts consume dialing and waiting time of subscribers, they impose a congestion cost like that created by the extra car entering the freeway at rush hour.

In this situation, it would be optimal to set the price of a call equal to the marginal congestion cost that it caused (Pyatt, 1972). Note that such a pricing rule is obtained solely by considering valuations derived from consumers' demands, and is not directly related to the marginal capacity or running costs of supplying additional calls. However, the optimal investment policy requires that the capacity of the telephone network be expanded wherever marginal investment costs are not greater than the marginal congestion costs (which have been set equal to the optimal prices). As a result, this pricing rule is similar to pricing at long-run marginal cost.

There is, however, one important difference between congestion pricing and marginal-cost pricing. In the congestion pricing model, the quality of service is endogenous, and routes that have high marginal expansion costs will tend to have lower service quality (Kay, 1968). For this reason, it would appear that service quality would be lowest on long-distance routes. However, the declining importance of distance in the total cost of supplying trunk calls may diminish the practical significance of this factor.

An important and unanswered empirical question is whether residential consumers value service quality less highly than business subscribers. If they do, it is indeed desirable to ration capacity in off-peak hours by allowing some increase in congestion to occur,* and the practice of dimensioning the trunk network to meet peak demands during weekday business hours is consistent with this view. Nevertheless, households are, no doubt, willing to pay somewhat higher rates to reduce congestion, and the persistently blockaded network that exists on Sundays in regions of West Germany is unlikely to be optimal.

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*For distributive reasons, political decision-making may also prefer this outcome to the alternative of higher off-peak prices.

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