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Research Memorandum

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THE COST OF ELECTRIC-POWER INTERRUPTIONS TO RESIDENCES IN THE TENNESSEE VALLEY

Robert W. Gilmer
Richard S. Mack

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THE COST OF ELECTRIC POWER INTERRUPTIONS TO RESIDENCES IN THE TENNESSEE VALLEY

Robert W. Gilmer
Richard S. Mack

March 1982

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Oak Ridge Associated Universities
Oak Ridge, Tennessee 37830

Research memorandums document substantive work in progress and receive internal review.

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ABSTRACT

This report assesses the cost of electric power outages to residential customers of the Tennessee Valley Authority (TVA). The assessment focuses primarily on costs associated with rationing electric power by means of rotating blackouts of 1 to 3 hours, exercised several times per year and perhaps as often as once each month. The cost of these blackouts is assessed in terms of several measures of lost consumer's surplus and lost production within the home. Estimates are developed by season for the typical home, for homes in different parts of the Tennessee Valley, and for homes with different mixes of appliances. Estimates for a typical home in the TVA region vary from 20¢ to 50¢ per kilowatthour depending upon the season and the method of measurement used. These valuations for the TVA region are compared to cost estimates for the United States as a whole. The implications of outages lasting longer than 3 hours are considered, and costs sustained in such outages are outlined.

CHAPTER 1. THE TENNESSEE VALLEY AUTHORITY

INTRODUCTION

This report is part of a comprehensive effort to assess the costs of electrical outages in the Tennessee Valley. The scope of this report is limited to the valuation of power outages in the residential sector; commercial and industrial outages are assessed in companion studies. Assessment is made of the costs associated with rationing electric power by means of rotating blackouts of 1 to 3 hours each, exercised several times per year and perhaps as often as once each month. Estimates of the cost of such blackouts in the residential sector are derived from existing data; the methodology and/or new data needed to refine these estimates are also outlined. The implications of outages lasting longer than 3 hours are considered, and the various costs involved in sustained outages are outlined.

The assessment of costs in all sectors is to be used by the Tennessee Valley Authority (TVA) for planning purposes. Although TVA has no plans to implement scheduled outages, valuation is useful for capacity planning purposes, for maintenance scheduling, and for other planning applications. Figure 1.1 illustrates the use of outage costs for planning reserve margins. The total customer costs are the vertical sum of environmental costs, fixed costs, fuel and other variable costs, and outage costs. The total outage costs fall downward to the right as the size of the reserve margin grows, whereas capital costs rise. The minimum point on the summation of these curves is the optimal reserve margin in the sense that total costs are minimized. Similarly, the gross reserve margin is affected by maintenance routinely scheduled on generators and by outage costs that will vary by season and time of day. The outage costs are necessary to determine how a utility such as TVA should schedule maintenance throughout the year to minimize total customer costs.

This study does not attempt to make capacity planning and maintenance scheduling assessments but rather provides input into such decisionmaking. Similarly, the study is not explicitly concerned with alternative means of

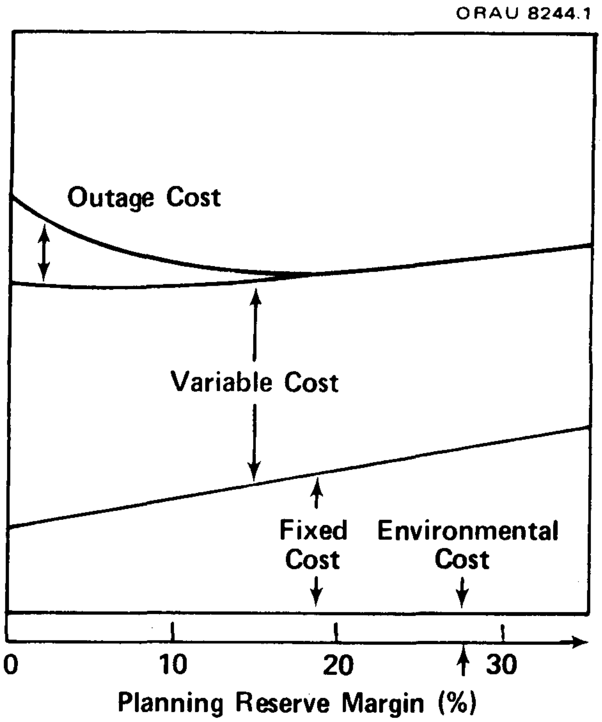

Figure 1.1. Cost to Consumers as a Function of Planning Reserve Margin

Source: Edward G. Cazalet, "Costs and Benefits of Over/Under Capacity in Electric Power Systems Planning," in Proceedings of the Sixth Annual Illinois Energy Conference, 27-29 September 1978, Chicago: University of Chicago, CONF-7809138.

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rationing power such as direct load control or time-of-day pricing, with questions of equity or fairness in deciding which households should be cut off, or with sectoral curtailment priorities. The focus is narrowed to the estimation of costs of a lack of electric power for use as an input into analysis of these broader policy questions.

There is no evidence on the cost of electric power outages that applies directly to the TVA region. Even if such evidence existed, a review of literature shows that it almost certainly would not lead to a simple expression (or even a narrow band) of these costs in dollars or cents per kilowatthour. Most studies that have assessed outage costs have used crude, simplistic approaches that draw on easily obtainable data.

They have made little or no pretense of realistically reflecting the effects of an electrical outage.

Unlike commerce or industry, where an outage disrupts all or part of the production of goods and services, the residential sector has no output routinely measured by the market or other means. Measurement must be indirect, and two basic methods are used to assess the cost. Consumer's surplus measurement is the traditional means of nonmarket valuation, and it is applied here to develop a lower bound for the value of electrical outages. A second approach to the valuation of the costs of electrical outages is through the valuation of home production. The dependence of home production upon electrical usage and an assessment of the extent to which power interruptions disrupt home production lead to estimates of the value of lost electrical service. Both methods are applied to TVA and to the United States as a whole.

The demographic and economic characteristics of the TVA region influence outage costs, and Chapter 1 describes residential electric use in the study area. Both appliance inventory and appliance contribution to electrical use by time of day and by season are described. This background is applied as the consumer's surplus estimates are developed in Chapter 2. Chapter 3 describes the theory and application of the household production method to both the national and the TVA data. Long-run effects upon the purchase of backup generators and other means of offsetting the effects of shortages, as well as the effect of outage duration, are considered in Chapter 4. The study concludes with a synopsis of findings and implications.

TVA is a corporate agency of the United States government, possessing considerable autonomy from federal control and having many of the operating characteristics of a private corporation. TVA was established in 1933, and its activities are concentrated within the watersheds of the Tennessee and Cumberland rivers (see Figure 1.2). Originally formulated as part of the New Deal policies of Franklin Roosevelt, its primary objectives were to stop out-migration from the Tennessee Valley, to modernize agricultural production, to prevent flooding and develop navigation systems along the

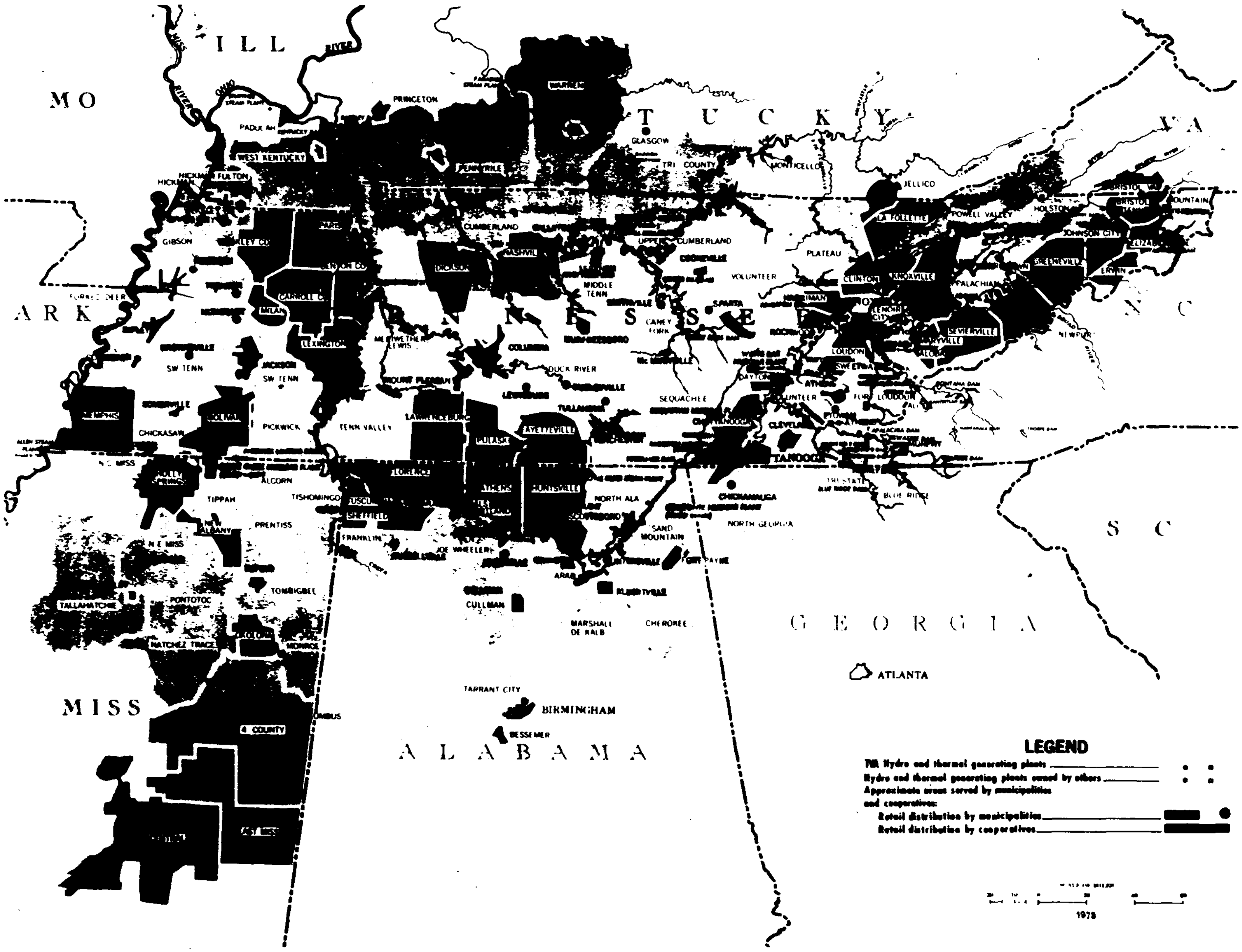

Figure 1.2. Power Service Area of the Tennessee Valley Authority

Tennessee River, and to stimulate industrialization and promote economic development. Electric power production was originally ancillary to dam construction along the Tennessee River, but, as other TVA goals have been met, electric power production has become the primary task of the agency. In the 1950s a major construction program augmented the hydropower resources with large coal-fired facilities (TVA currently has over 60 coal-fired units). In 1976 the Browns Ferry Nuclear Plant joined the system, the first of 23 nuclear units originally planned. By the end of 1978 there were 28,300 MW in service, making TVA the largest bulk power producer in the United States. In 1978, TVA sold 112.6 billion kWh of electricity to customers in a seven-state area; 66.5 percent of the electricity (and all residential electricity) was sold through 160 municipal distributors, cooperatives, and one privately owned distributor. The remaining 33.5 percent was sold directly to large commercial and industrial customers.

RESIDENTIAL ELECTRIC CUSTOMERS IN THE TENNESSEE VALLEY--HOUSING

In 1978 TVA served nearly 2.4 million residential customers who purchased 27.5 billion kWh. These residential sales were about one-third of TVA's total electric power sales, a proportion similar to that for residential electric sales in the United States as a whole (see Table 1.1).

Table 1.1. Sales of Electricity to Economic Sectors, United States and TVA Region, 1978

	TVA		United States	
Sector	Billion kWh	%	Billion kWh	%
Residential	37.5	33.3	670	33.4
Commercial	20.1	17.9	460	22.9
Industrial	55.0	48.8	873	43.5
Total	112.6	100.0	2,003	99.8

Source: Tennessee Valley Authority, Annual Energy Model and a computer printout of data provided by Martha Brosius, System Forecasting and Analysis Branch, Division of Power Utilization; Energy Information Administration, Annual Report to Congress: 1979 (Washington, D.C., Government Printing Office, 1980), Table 61.

The typical household in the TVA region had an income that averaged about 80 percent of the national average throughout the 1970s; as Figure 1.3 shows, this stability relative to national income came after 16 years of steady comparative increases in the Tennessee Valley. Table 1.2 shows the distribution of the size of the living quarters in the region as a whole and for four standard metropolitan statistical areas (SMSAs)--Chattanooga, Knoxville, Memphis, and Nashville. The median size of living quarters in the Tennessee Valley is 1100 square feet, compared to the national median of 1600 square feet.* Table 1.3 shows the number of occupants of households served by TVA. For the region as a whole and for each SMSA shown the median number of occupants is 2, compared to the national median of about 2.5 persons (family members and unrelated individuals) per household.

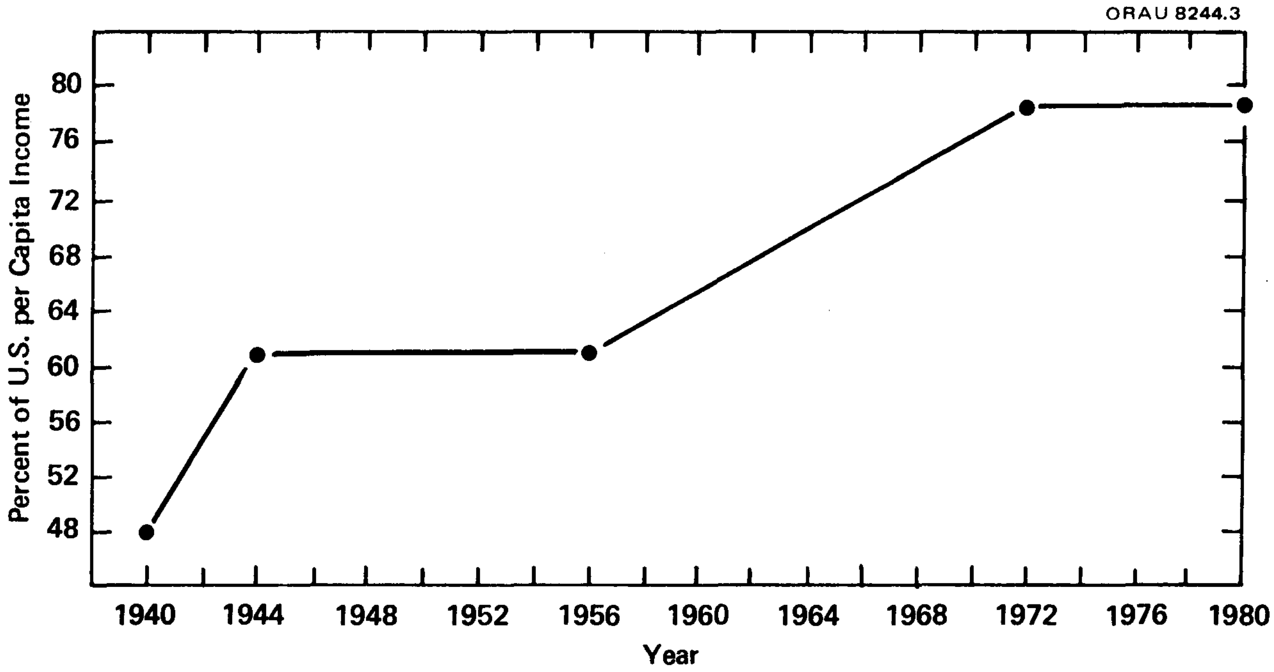

Figure 1.3. Per Capita Income in the TVA Region Relative to U.S. Per Capita Income, 1940-1978

Sources: Tennessee Valley Authority, Regional Economics Project Staff, and U.S. Bureau of Economic Analysis.

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*U.S. Bureau of the Census and U.S. Department of Housing and Urban Development, Construction Reports: 1978, series C24, "Characteristics of New Housing."

Table 1.2. Size of Living Quarters in the TVA Region, 1978

(Percent of Responding Households)

Size of Living Quarters (ft^2)	TVA Region	Chattanooga	Knoxville	Memphis	Nashville
<500	9	15	9	14	9
500-1100	40	41	47	32	42
1100-2000	38	29	34	39	36
2000+	13	15	10	15	13

Source: Westat, "Residential Survey: Customers of Local Electric Systems Distributing TVA Power." Summary reports provided by Ann Cudd, Office of Power, Tennessee Valley Authority.

Table 1.3. Number of Occupants in the Household, Tennessee Valley Region, 1978

(Percent of Responding Households)

Number of Occupants	TVA Region	Chattanooga	Knoxville	Memphis	Nashville
1	17	19	20	20	24
2	33	36	32	31	29
3	19	20	23	21	21
4	16	15	15	15	19
5	7	7	6	7	6
6 or more	8	3	4	6	3

Source: Westat, "Residential Survey: Customers of Local Electric Systems Distributing TVA Power." Summary reports provided by Ann Cudd, Office of Power, Tennessee Valley Authority.

The 1970 Census of Housing classified over 500,000 housing units (nearly 25 percent of the total) in the TVA region as substandard. By comparison, 6 percent of housing units are substandard in the United States as a whole and 14 percent in the South. The Census of Housing defines a substandard house as one that does not meet certain standards set by the Federal Housing Administration, or that does not have complete plumbing, a complete kitchen, or some form of central heat, or that does not meet local building codes where such codes exist. As Table 1.4 shows, this is clearly a rural problem as 83 percent of these substandard houses were located outside the region's 10 SMSAs. It is not known how many units require only a bathroom or minor repairs to meet minimum standards.

RESIDENTIAL ELECTRIC USE IN THE TENNESSEE VALLEY

Patterns of Appliance Ownership in the Tennessee Valley

The most striking aspect of residential electricity in the TVA region is its intensity. The average household in the Tennessee Valley used 15,973 kWh in 1978, nearly 80 percent more electricity than the typical household in the United States (Table 1.5). This intensity of electric power use is reflected in the saturation of electric applicances in the Tennessee Valley. Table 1.6 shows the percentage of households having various electric appliances in the Tennessee Valley and in the region's four large SMSAs. Table 1.7 compares these saturation levels to those for the United States as a whole for 1970 and 1978. For electric heating, air-conditioning, hot water heating, and cooking fuel, the TVA region has a considerably greater saturation than the United States as a whole; for other appliances, the region and the United States are broadly comparable. Space heating consumes an estimated 63 percent of the energy used in the home, air-conditioning 27.8 percent, water heating 18.4 percent, and cooking 5.9 percent; other uses (refrigeration, lighting, clothes drying, and other miscellaneous) together contribute only 15.3 percent (Energy and Environmental Analysis, Inc., 1977; Dole, 1975). It is clear that the

Table 1.4. Condition of Year-round Housing Units in the Tennessee Valley Region, 1970

	Location		
Condition	SMSA	Non-SMSA	Total
Standard	886,289	695,632	1,581,921
Substandard	87,666	429,674	517,340
Total	973,955	1,125,306	2,099,261

Source: U.S. Department of Commerce, Bureau of the Census, "Census of Housing: Characteristics for States, Cities, and Counties, Volume 1," (Washington, D.C.: U.S. Department of Commerce, 1970) Parts 2, 12, 19, 26, 35, 44, and 48.

Table 1.5. Kilowatthours Used per Household in the TVA Region and the United States, 1970 and 1978

Year	TVA	United States
1970	14,399	7,066
1978	15,973	8,901

Source: Tennessee Valley Authority, Power Annual Report: 1978; EBASCO Business and Economic Charts, "Residential Electricity," p. 25.

Table 1.6. Households Having Electric Appliances in the Tennessee Valley Region, 1978

(Percent of Responding Households)

Appliances	TVA	Chattanooga	Knoxville	Memphis	Nashville
Primary heat	45.8	66.5	72.8	21.4	64.2
Air-conditioning					
Central	31.6	33.1	34.8	51.1	44.1
Window/wall[a]	45.0	46.3	36.4	43.2	51.0
Water heater	82.0	88.7	96.8	35.3	81.3
Range	82.9	93.6	99.0	51.9	95.3
Dishwasher	35.5	60.6	34.5	44.1	49.0
Refrigerator					
Single door	48.3	41.3	47.0	42.1	42.2
Freezer/refrig. Combination	62.9	67.9	67.3	69.1	66.6
Food freezer	55.1	63.8	39.1	45.7	37.6
Clothes washer	78.1	74.9	70.9	79.0	68.6
Clothes dryer	63.4	64.1	59.3	56.6	59.7
TV sets	97.0	96.1	97.5	98.4	98.3

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[a] Includes some gas air-conditioning.

Source: Westat, "Residential Survey: Customers of Local Electric Systems Distributing TVA Power." Summary reports provided by Ann Cudd, Office of Power, Tennessee Valley Authority.

Table 1.7. Comparison of the United States and TVA Region, Penetration of Electric Appliances, 1970 and 1978

(Percent of Homes Owning Electric Appliances)

	1970		1975-78	
Appliances	TVA[a]	United States	TVA[b]	United States[c]
Electric heating	40.4	7.7	45.8	14.8
Air-conditioning				
Central[d]	12.2	10.7	31.6	21.5
Window units	28.1	25.0	45.0	29.6
Hot water	66.9	25.4	82.0	40.4
Cooking fuel	76.8	40.6	82.9	49.2
Clothes washer	58.6	71.1	78.1	75.2
Clothes dryer	37.3	29.4	63.4	60.3
Dishwasher	14.7	18.9	35.5	41.9
Freezer	37.3	28.2	55.1	44.9
Television	94.8	95.5	97.0	99.9

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[a] Tennessee only.

[b] From Table 1.6. Data are for 1978.

[c] Data on electric heating, air-conditioning, and cooking fuel are from the 1977 Housing Survey; other data in this column are from Merchandising. All merchandising data for 1978 except hot water which is 1975.

[d] Includes some gas air-conditioning.

Source: Table 1.6. Bureau of the Census, Census of Housing, "United States Summary," Table 41; Bureau of the Census, Annual Housing Survey: 1977, part A; and Merchandising, annual statistical issue.

saturation of the large electricity-consuming devices in the Tennessee Valley accounts for the high per-household use of electric power in the region.

Why is electricity used so intensively? In part this is due to the historically low prices paid by TVA consumers. Table 1.8 compares TVA's average residential rate to the U.S. average rate for 1970 and 1978. Though the gap between them has narrowed since 1970, the 1978 TVA rate was two-thirds the average rate for the nation. Hydropower and the regional abundance of coal are responsible for these lower rates.

Table 1.8. Residential Electric Rates, Average per Kilowatthour, TVA Region and the United States, 1970 and 1978

(c/kWh)

Year	United States	TVA
1970	2.10	1.03
1978	4.03	2.68

Source: Tennessee Valley Authority, Power Annual Report: 1978; EBASCO Business and Economic Charts "Residential Electricity," p. 25.

Other historical factors affect the intensity of electricity use, chief among them the availability of natural gas. In those areas where natural gas was available earlier, the penetration of electric power has been reduced. Kentucky developed its own natural gas resources early in the century, and pipeline gas was brought to Memphis and western Tennessee in the late 1920s by what is now the Texas Gas Transmission Company. Similarly, Southern Natural Gas Company built pipelines across northern Mississippi and Alabama in the 1930s. Not until well after World War II, and well after the advent of TVA, did gas reach the rest of Tennessee.

This timing is reflected in the penetration of electricity among Tennessee's four major SMSAs (Table 1.6). Memphis, in particular, lags the region by a considerable margin. A similar pattern, relating the penetration of electricity to the timing of the arrival of natural gas, can also be seen in Table 1.9, which compares the penetration of gas and electricity for TVA's seven power regions.

Residential Uses of Electricity by Time of Day and Season

Two surveys conducted by TVA, the Knoxville Time-of-Day Study and the Chattanooga Load Survey, make it possible to draw some inferences about how residential consumers vary their use of electricity by time of day and by season. Both surveys deal with individual cities within the TVA region--Knoxville and Chattanooga--and so the extrapolation of results to the TVA region as a whole must be done selectively. The studies provide insight into the relationship between appliance ownership and the variation in electricity use across different time periods.

Knoxville Time-of-Day Study

In this study nearly 200 households in Knoxville, Tennessee, were sampled. Each household was surveyed to determine socioeconomic and other household characteristics as well as the ownership of various appliances that consume large quantities of electricity. Table 1.10 compares the characteristics of the sampled households with all Knoxville* and with the TVA region. The sample would seem to reflect the Knoxville area well, though electricity is used more intensively in Knoxville than the TVA region as a whole.

For a 15-month period (January 1978 through March 1979), the electricity consumption of each household was monitored during certain on-peak and off-peak periods. On-peak periods varied by season and were defined only

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*Actually, the comparison is to a more carefully controlled sample, the Westat survey, cited above in Table 1.2.

Table 1.9. Comparison of TVA Power Districts, Penetration of Gas and Electric Space Heating, 1978

(Percent Households Having Electric Space Heat)

District	Electricity	Natural Gas
Western	26.9	58.9
Mississippi	28.2	30.1
Kentucky	35.6	40.0
Alabama	45.8	22.5
Southeastern	54.2	13.5
Central	55.4	22.2
Appalachian	62.4	8.6

Note: The Mississippi, Kentucky, and Alabama districts describe those parts of the states served by TVA; the Western and Central districts refer roughly to the western and central thirds of Tennessee; the Appalachian and Southeastern districts divide East Tennessee and include small parts of Virginia, North Carolina, and Georgia. Only space heating is shown, but hot water, air-conditioning, and electric ranges are correlated with the presence of electric space heat. The pattern is similar to that shown for the SMSAs in Table 1.6.

Source: Westat, "Residential Survey: Customers of Local Electric Systems Distributing TVA Power." Summary reports provided by Ann Cudd, Office of Power, Tennessee Valley Authority.

Table 1.10. Comparison of Households in the Knoxville Time-of-Day Study with All Knoxville and the TVA Region, by Appliance Ownership and Other Characteristics

Value	Knoxville Time-of-Day Study[a]	All Knoxville[b]	TVA Region[b]
Household Data			
Income	$16,882	n.a.	$20,000+
Square footage of home	1,526	1,100+	1,100+
Number of people living in house	2.95	2-3	2-3
Appliance Saturation (%)			
Space heat	61.2	72.8	45.8
Space cooling	78.5	~70.0+	~70.0+
Electric hot water heater	94.6	96.8	82.0
Food freezer	73.1	39.1	55.1
Range	95.1	99.0	82.9
Clothes washer	90.9	70.9	78.1
Dryer	80.6	59.3	63.4
Dishwasher	46.8	34.5	35.5
Color TV	109.2	97.5	97.0
Black-and-white TV	83.8	}	}
Refrigerator	119.5	100.0	100.0

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[a] Knoxville Time-of-Day Study. The appliance saturation figure is the ratio of the number of appliances in the sampled households to the number of households.

[b] Tables 1.2, 1.3, and 1.6. The appliance saturation figure is the percentage of households having at least one such appliance.

n.a. = not available.

for weekdays; all hours were off-peak during weekends.* The applicable hours were defined as follows:

	On Peak	Off Peak
Summer	11:00 a.m. - 9:00 p.m.	9:01 p.m. - 10:59 a.m.
Winter	7:00 a.m. - 1:00 p.m.	1:01 p.m. - 5:59 p.m.
	6:00 p.m. - 10:00 p.m.	10:01 p.m. - 6:59 a.m.

Winter months are October through March; summer months April through September.

Table 1.11 summarizes the use of electricity during the study for the average household by time of day and by month. Both the average load during the month (in kilowatts) and energy consumption (in kilowatthours) are shown. The winter months (January 1978 and 1979) show the highest electric use, reflecting the high penetration of electric space heating in the study. July is the second highest, reflecting the use of air-conditioning, and the spring and fall months (in which modest amounts of space heating occur) have the smallest load and lowest energy consumption.

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*The Knoxville Study was designed as a time-of-day pricing experiment. Two groups of households were established: a control group subject to differential pricing between on-peak and off-peak periods and a control group subject to TVA's usual rates. TVA's own analysis of the data revealed small (if any) effects of the differential pricing. Our own analysis concurred in this finding. Separate regression equations were run (similar to those specified in the text in Table 1.13) for experimental and control groups for on-peak and off-peak periods during each of five months (January 1978 and 1979, April, July, and October 1978). In no case did we find statistically significant differences between the two groups. Their use of electricity never differed significantly. Accordingly, the pooled data for both groups are presented in the text. A description of the tests used to compare the control and experimental groups is contained in S. Kullback and H. M. Rosenblatt, "On the Analysis of Multiple Regression in k Categories," Biometrika, 44 (1957), pp. 67-83.

For a description of TVA's analysis of the data (as well as a sketch of problems in the design of the study that led to its failure as a pricing experiment), see Division of Energy Conservation and Rates, Rate Design Branch, "Knoxville Residential Time-of-Day Rate Test" (Chattanooga, Tennessee: Tennessee Valley Authority, 1979).

Table 1.11. Comparison of Average Household Uses of Electricity in Knoxville Sample Houses, By Month, On Peak and Off Peak

Period	January 1978	April 1978	July 1978	October 1978	January 1979
Average Load during Month (kW)[a]					
On peak	4.95	1.81	2.70	2.08	4.49
Off peak	4.66	1.79	2.00	1.82	4.10
Electric Consumption during Month (kWh)[b]					
On peak	1,089	398	594	458	988
Off peak	2,330	895	1,000	910	2,050
Total	3,419	1,293	1,594	1,368	3,038

---

[a] Average kW is computed as follows:

$$\left(\frac{\text{kWh in peak/off-peak period}}{\text{billing cycle}} \Big/ \frac{\text{hours in peak/off-peak period}}{\text{billing cycle}} \right)$$

[b] The kWh figure assumes each month is 30 days in length with 8 weekend days.

Contribution of Individual Appliances to Load

The contribution of individual appliances to the household electric load is important in estimating the impact of power outages. For 186 households in Knoxville the monthly consumption of electric power during on-peak and off-peak periods was regressed on the number of appliances owned by the household as well as certain socioeconomic characteristics. Several important and foreseeable statistical problems arose:

- The high intensity of electricity use in Knoxville makes it difficult for an analyst using this procedure to separate the effects of various appliances. To a significant degree, ownership of one appliance (such as a space heater) implies that many other electric appliances are also owned (e.g., a hot water heater, clothes dryer, etc.). This high intercorrelation among appliances makes it difficult to sort out the contribution of one appliance, especially if ownership is widespread among those sampled. (See Table 1.10). The result of this intercorrelation is an instability in the estimated coefficients from one equation to another.
- A similar problem arises with regard to the individual effects of the hot water heater and the two appliances that use hot water--the washing machine and the dishwasher. The use of these appliances will trigger the hot water heater to begin recovery. The data used here could not be used to sort out these effects, and there were real problems of interpretation with the coefficients for these appliances.

Several steps were taken to ameliorate these difficulties. A stepwise regression package was used to limit the level of entry of variables to those having at least a .25 partial correlation with the electric load variable.* Because of the problem with the dishwasher and clothes washer

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*Several runs were used, successively reducing the level of significance until nonsensical results began to appear as a result of intercorrelation among appliances, e.g., sign switching and large swings in the values of coefficients.

explained above, the load contribution of these appliances was set a priori to predetermined values.* Their energy consumption (because they are infrequently used) is fairly low if their use of hot water is not counted. Finally, to sort out abnormal or unstable coefficient values as they appeared, certain expectations were formed from published sources about how these appliances use energy. Table 1.12 outlines these values.

Table 1.13 shows the results of the data estimated for Knoxville. The equations were estimated for on-peak and off-peak periods for January 1978 and 1979, and for April, July, and October of 1978. Each coefficient is the change in kilowatt load associated with a unit change in the variable listed in the left-hand side of Table 1.13. The number in parentheses below the coefficient is the probability that the coefficient differs from zero. The parameter values for dishwashers and clothes washers were predetermined by analysis.

The coefficients in Table 1.13 show the expected instability, but there is also enough regularity to permit the data to be useful if compared to the data in Table 1.12. Table 1.13 was more useful in examining seasonal and time-of-day effects for heating and cooling, effects that could not be predicted from national, aggregated data; it was less useful in sorting out the impacts of small appliances on load. Using both Tables 1.12 and 1.13, we worked out estimates to reflect the use of appliances by season and time of day. In these estimates we used selectively the results of Tables 1.12 and 1.13, especially for the total load and space heating components. Some irreproducible guesswork and judgment were involved in setting the seasonal contribution of small appliances; the total nonheating load is a constraint on the values of the coefficients and is derived from the regression equations of Table 1.13. The results are shown in Table 1.14. For each season and for the appliances shown in the leftmost column, a kilowatt contribution to load is shown on- and off-peak. These results are of interest in themselves but will be used further below to derive specific outage costs.

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*The values are shown by season and time of day in Table 1.14.

Table 1.12. Average Contribution to Load of Various Appliances--Various Published Sources, United States

(kW)

	Mother Earth News[a]	Energy & Environmental Analysis[b]	ORNL Data Book[c]
Water heater	.56	.40	.50-.92
Freezer			
Manual defrost	.14	--	.10-.17
Automatic defrost	.20	--	.13-.22
Range			
Oven	.14		
Burners	--		
All	--	.14	
Washer	.01	--	
Dryer	.12	.08	
Dishwasher	.04		
Color TV	.06		
Black-and-white TV	.04		
Refrigerator			
Manual defrost	.13	} .17	.07-.11
Automatic defrost	.21		.14-.21
Lights			
Per bulb	.004-.012	--	
All	--	.12	

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[a] Mother Earth News, as cited in David R. Meyers, et al., Impacts from a Decrease in Electric Power Service Reliability (Menlo Park, Calif., Stanford Research Institute, 1976), Table 5.

[b] Energy and Environmental Analysis, Inc., Energy Consumption Data Base, Household Sector, Final Report, vol. III (Arlington, Va.: 1977), Table III-7.2, as cited in J. L. Blue et al. Buildings Energy Use Data Book, ORNL-5552 (Oak Ridge, Tenn.: Oak Ridge National Laboratory, 1979), Table 7.4).

[c] J. L. Blue, Buildings Energy Use Data Book, ORNL-5552 (Oak Ridge, Tenn.: Oak Ridge National Laboratory, 1979), Tables 2-14, 2-29, and 2-32.

Table 1.13. The Contribution of Socioeconomic Factors and the Appliance Mix to the Average Electric Load, by Season and by Time of Day, Knoxville Survey[a]

Value	On-Peak January 1978	 April 1978	 July 1978	 October 1978	 January 1979	Off-Peak January 1978	 April 1978	 July 1978	 October 1978	 January 1979
Socioeconomic Factors										
Number living in home	.373 (.999)	.236 (.999)	.246 (.999)	.189 (.999)	.167 (.999)	.264 (.979)	.171 (.999)	.106 (.972)	.154 (.998)	.160 (.999)
Square footage of home (10^3 ft^2)	.597 (.989)	.123 (.838)	.283 (.975)	.182 (.946)	.792 (.999)	.597 (.993)	.095 (.999)	.180 (.946)	.118 (.790)	.574 (.995)
Income ($\$10^3$)	.011 (.522)	.004 (.467)	.039 (.945)	.010 (.880)	dne —	.020 (.817)	.016 (.707)	.044 (.999)	.015 (.974)	.017 (.767)
Appliances (number in home)										
Space heating	4.319 (.999)	.412 (.999)	— —	.563 (.999)	3.489 (.999)	3.740 (.999)	.445 (.999)	— —	.444 (.999)	3.117 (.999)
Space cooling	— —	— —	.806 (.999)	— —	— —	— —	— —	.278 (.943)	— —	— —
Hot water heating	.284 (.491)	.128 (.551)	.405 (.873)	.361 (.956)	.185 (.335)	.379 (.365)	.225 (.810)	.302 (.915)	.365 (.957)	.373 (.675)
Food freezer	dne[b] —	.119 (.852)	.576 (.999)	.141 (.895)	.107 (.392)	dne —	.107 (.800)	.281 (.999)	.083 (.656)	dne —
Range	dne —	.197 (.567)	.508 (.776)	.109 (.317)	dne —	.389 (.474)	.235 (.643)	.447 (.918)	.281 (.706)	dne —
Clothes washer[c]	.030 —	.010 —	.010 —	.010 —	.030 —	.030 —	.010 —	.020 —	.010 —	.030 —
Clothes dryer	dne —	.220 (.859)	.448 (.927)	.239 (.868)	dne —	.309 (.606)	.268 (.922)	.284 (.984)	.165 (.699)	.149 (.339)
Dishwasher[c]	.040 —	.040 —	.040 —	.040 —	.040 —	.080 —	.040 —	.080 —	.040 —	.080 —
Color TV	.682 (.999)	.202 (.991)	dne —	.291 (.998)	.691 (.999)	.580 (.997)	.205 (.981)	.045 (.388)	.287 (.998)	.599 (.997)
Black-and-white TV	dne —	dne —	.130 (.753)	.129 (.891)	.156 (.569)	dne —	.058 (.513)	.060 (.552)	.109 (.828)	.064 (.282)
Refrigerator	1.130 (.989)	.615 (.999)	.533 (.985)	.467 (.999)	1.162 (.999)	1.342 (.999)	.492 (.999)	.307 (.972)	.422 (.997)	1.082 (.999)
Goodness of fit (R^2)	.706	.556	.569	.599	.630	.715	.561	.632	.549	.659

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[a] The coefficients are shown in each cell with the probability they differ from zero below them in parentheses. The coefficients are the change in kilowatt load (as defined in Table 2.11) if a unit change occurs in the variables listed in the left-hand margin of this table.

[b] dne = did not enter the stepwise regression used at a .75 level of significance or above.

[c] These parameter values were predetermined by analysis and assumption and inserted in the estimating equation.

Table 1.14. Estimated Contribution of Individual Appliance to Household Load by Season and Time of Day

(kW)

Appliance	Summer		Winter		Spring		Fall	
	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
Hot water heater	.70	.70	.60	.65	.55	.55	.65	.65
Freezer	.30	.25	.20	.20	.15	.15	.20	.15
Range	.25	.16	.30	.30	.25	.20	.30	.25
Clothes washer	.01	.02	.01	.03	.01	.01	.01	.01
Dryer	.12	.18	.18	.25	.15	.12	.15	.15
Dishwasher	.04	.08	.04	.12	.04	.04	.04	.04
Color TV	.10	.15	.20	.15	.12	.15	.15	.15
Black-and-white TV	.05	.05	.10	.05	.05	.05	.05	.05
Refrigerator	.40	.35	.30	.30	.25	.25	.30	.25
Lights	.05	.15	.20	.10	.10	.14	.15	.12
Other	.03	.04	.13	.06	.01	.01	.04	.06
Total nonspace conditioning load	2.05	2.13	2.26	2.21	1.68	1.67	2.04	1.88

Season Peak Period

The Chattanooga Load Survey and Electricity Consumption in Peak Periods

TVA has an ongoing program to monitor the load demand of customers in Chattanooga, Tennessee.* The load of approximately 600 customers is recorded on magnetic tape every 15 minutes. About 100 of these customers are residential, with the remainder split between "general service" customers with peak loads under 50 kW and larger customers with peak loads over 50 kW. These customers are selected on the basis of stratified random sampling and are meant to be statistically representative of electricity customers in Chattanooga.

Associated with this monitoring of load data, TVA has conducted a survey of the electricity-using devices and other characteristics of the homes and businesses monitored. For households, the stock of electric appliances, housing characteristics, and other data on income and family size were collected. This information can be matched against the hourly electric consumption data collected on magnetic tape. These data were analyzed for certain days during which the TVA system "peaked." TVA typically reaches an annual peak during cold winter days, but energy use was examined during summer, fall, and spring as well as winter. The "peak" days within these other months were studied as was the winter peak.** Figure 1.4 shows the critical effect of the residential sector in determining the load during a typical winter peak for the TVA system; Figure 1.5 does the same for a typical summer peak day.

To determine how appliances are used during peak periods, regressions were run for hourly electricity consumption by Chattanooga households against appliance holdings and the socioeconomic characteristics of the

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*The program is being extended to include Knoxville, Nashville, and Memphis, Tennesse, and to Huntsville, Alabama, in addition to Chattanooga.

**The Knoxville data dealt with daily consumption during peak periods, unlike these data which deal with the 1 day of the month coinciding with a system peak.

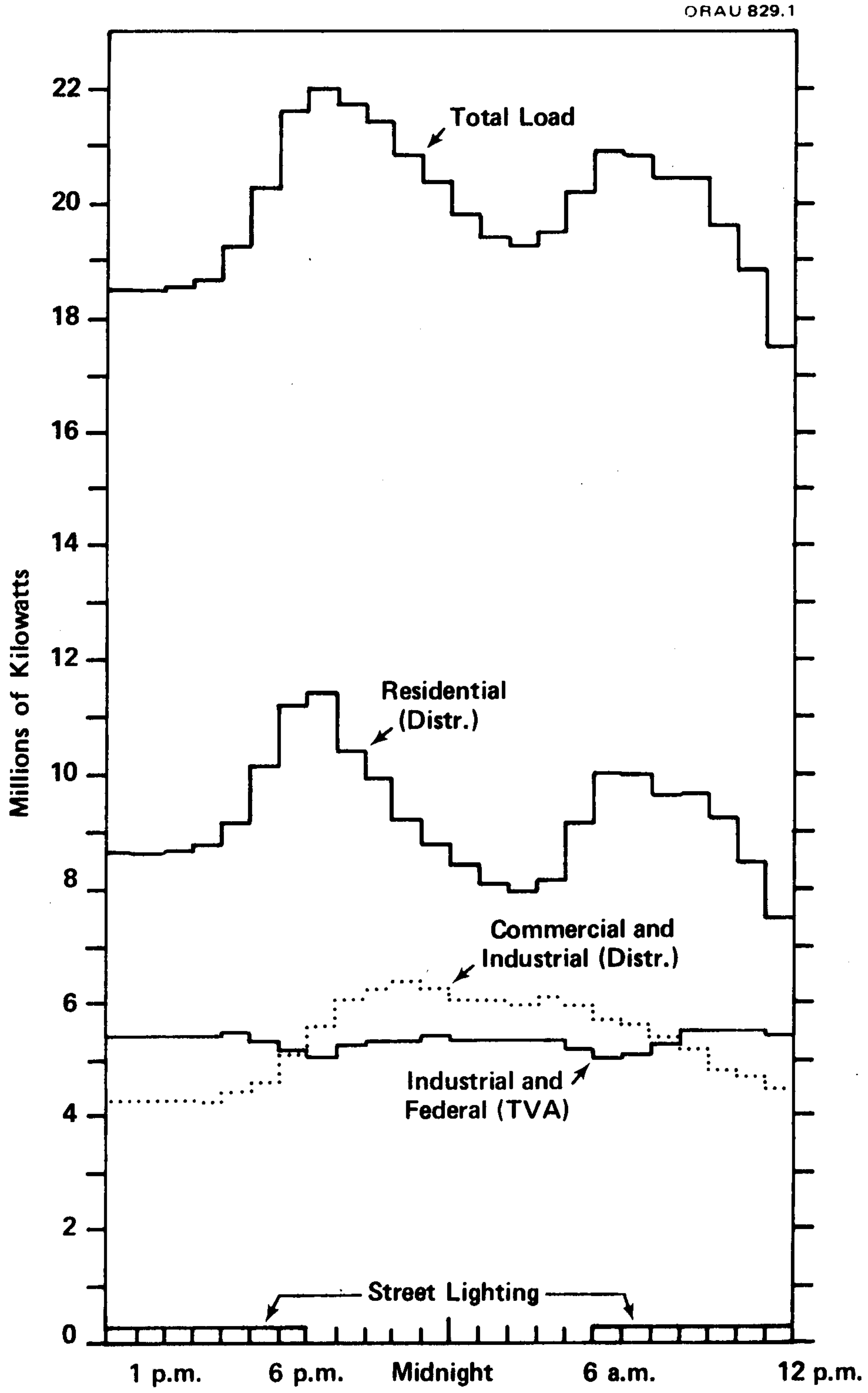

Figure 1.4. TVA System Winter Peak Day

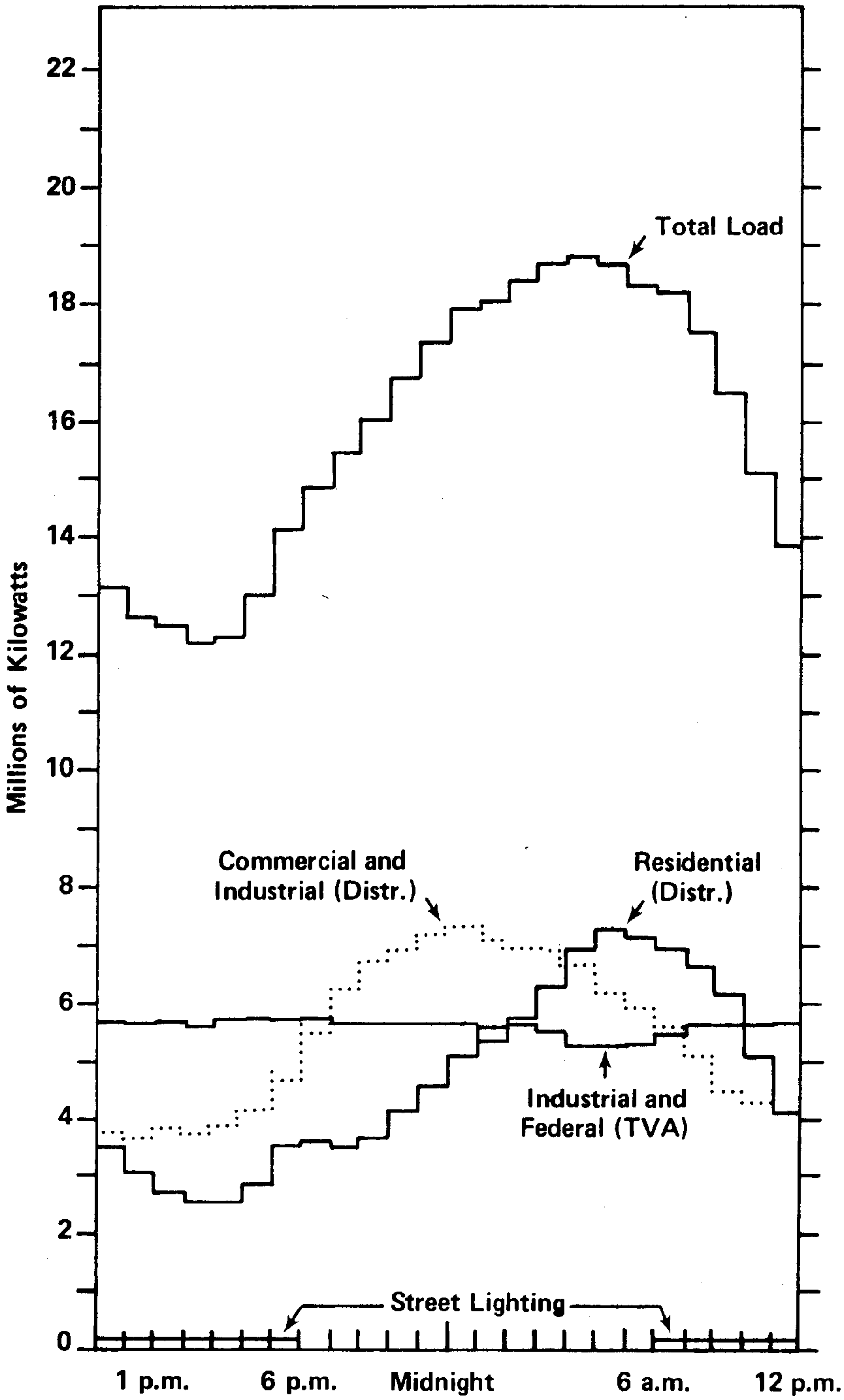

Figure 1.5. TVA System Summer Peak Day

household. The format was very similar to that used for the Knoxville data described above, and similar statistical precautions were taken. The results did not show any regular pattern in appliance use across the day except for space heating. This seemingly negative result may have a useful interpretation in the context of electrical outages and blackouts, however. The failure to find a regular relationship between hourly load and the appliance mix by hour may simply reflect the diversity of family schedules. Heating and cooling are imposed exogenously on all households by weather, but the use of other appliances is determined by daily schedules within the home and would not be expected to show great hourly regularity among households.*

Tables 1.15 to 1.18 summarize the relationship between electric power consumption and various household characteristics during January, April, July, and October of 1979. The load during each of 6 hours during the day was correlated with the variables shown in the left-hand column of these tables. Each table shows the simple correlation coefficient between hourly load and the variables listed, the probability that the correlation differs from zero, and the number of households in the sample. Except for space heating and cooling, the coefficients are generally weak, though some meaningful patterns can be picked out (e.g., greater use of the electric range and TV set in the evening).

The lesson to be drawn from these data is that a particular outage will interrupt a multiplicity of individual schedules. Given the circumstances within one home, the cost of an outage may be determined. The inability to find more than weak regularity among household appliance use during the day suggests that the impact of an outage, in terms of interrupted household functions, will be difficult to forecast for any individual household or for any single hour. In the analyses of outage costs below, we will assume (1) that the households exhibit a typical mix of appliance holdings as found in the TVA region and (2) that average energy consumed per day across typical winter or summer days rather than peak-hour values or values at particular hours on peak days.

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*Averaged over a month, the Knoxville data did show some regularity.

Table 1.15. Relationship Between Electric Power Consumption and Various Household Characteristics, Chattanooga Load Survey, January[a]

	Time of Day					
Variable	Midnight	7 a.m.	9 a.m.	Noon	7 p.m.	9 p.m.
Income	-0.00923	0.19506	0.09924	0.01127	0.38637	0.37527
	0.9304	0.0624	0.3466	0.9151	0.0001	0.0002
	92	92	92	92	92	92
Size of house	-0.07983	0.13010	0.10711	-0.01055	0.42140	0.39651
	0.4519	0.2190	0.3122	0.9209	0.0001	0.0001
	91	91	91	91	91	91
Space heating	0.51500	0.56129	0.44519	0.49129	0.56204	0.50883
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	91	91	91	91	91	91
Water heater	0.23650	0.14636	0.20032	0.33813	0.16806	0.18741
	0.0397	0.2071	0.0827	0.0028	0.1467	0.1050
	76	76	76	76	76	76
Freezer	-0.09410	0.01192	-0.00100	-0.08045	0.18333	0.09048
	0.3777	0.9112	0.9926	0.4510	0.0837	0.3964
	90	90	90	90	90	90
Range	0.18353	0.21477	0.19064	0.11558	0.21848	0.24356
	0.0799	0.0398	0.0687	0.2726	0.0364	0.0193
	92	92	92	92	92	92
Washer	-0.01834	0.07984	0.11818	0.10675	0.15215	0.12313
	0.8622	0.4493	0.2619	0.3111	0.1477	0.2423
	92	92	92	92	92	92
Dryer	-0.04705	0.09806	0.13329	0.10650	0.21228	0.20458
	0.6561	0.3524	0.2053	0.3123	0.0422	0.0505
	92	92	92	92	92	92
Dishwasher	-0.12653	0.09000	0.14666	0.10915	0.27114	0.23458
	0.2294	0.3936	0.1630	0.3003	0.0089	0.0244
	92	92	92	92	92	92
Television	-0.13589	-0.17106	-0.22666	-0.22485	0.28355	0.31023
	0.2324	0.1317	0.0446	0.0463	0.0113	0.0054
	79	79	79	79	79	79

[a] Each cell shows the simple correlation between electric power consumed and household characteristics and the number of appliances owned. The number below the correlation is the probability that the correlation differs from zero. The third number is the number of households in the sample. Correlations are shown for each of 6 hours during the day.

Table 1.16. Relationship Between Electric Power Consumption and Various Household Characteristics, Chattanooga Load Survey, April[a]

	Time of Day					
Variable	Midnight	7 a.m.	9 a.m.	Noon	7 p.m.	9 p.m.
Income	0.13603 0.2063 88	0.35266 0.0008 88	0.19187 0.0733 88	0.00598 0.9559 88	0.32666 0.0019 88	0.43983 0.0001 88
Size of house	0.18658 0.0836 87	0.29486 0.0056 87	0.23439 0.0289 87	0.04278 0.6940 87	0.16300 0.1314 87	0.24023 0.0250 87
Space heating	0.34740 0.0010 87	0.45860 0.0001 87	0.31809 0.0027 87	0.21992 0.0407 87	0.45962 0.0001 87	0.48811 0.0001 87
Water heater	-0.02371 0.8400 75	0.04380 0.7090 75	0.08952 0.4450 75	0.15746 0.1773 75	-0.04834 0.6805 75	-0.02293 0.8452 75
Freezer	0.04708 0.6669 86	0.26030 0.0155 86	-0.01282 0.9067 86	-0.12053 0.2690 86	0.16623 0.1261 86	0.14704 0.1767 86
Range	0.11796 0.2737 88	0.17015 0.1130 88	0.13861 0.1978 88	0.00144 0.9894 88	0.23147 0.0300 88	0.24227 0.0230 88
Washer	0.15171 0.1583 88	0.20069 0.0608 88	0.24596 0.0209 88	0.16671 0.1206 88	0.08621 0.4245 88	0.11531 0.2847 88
Dryer	0.15371 0.1528 88	0.29448 0.0054 88	0.21059 0.0489 88	0.04051 0.7079 88	0.12655 0.2401 88	0.14027 0.1924 88
Dishwasher	0.26634 0.0121 88	0.37753 0.0003 88	0.22262 0.0371 88	0.21069 0.0488 88	0.26577 0.0123 88	0.28227 0.0077 88
Television	0.12378 0.2934 74	0.05636 0.6334 74	0.12591 0.2851 74	0.11557 0.3268 74	0.02643 0.8231 74	0.03354 0.7766 74

[a] Each cell shows the simple correlation between electric power consumed and household characteristics and the number of appliances owned. The number below the correlation is the probability that the correlation differs from zero. The third number is the number of households in the sample. Correlations are shown for each of 6 hours during the day.

Table 1.17. Relationship Between Electric Power Consumption and Various Household Characteristics, Chattanooga Load Survey, July[a]

	Time of Day					
Variable	Midnight	7 a.m.	9 a.m.	Noon	7 p.m.	9 p.m.
Income	0.30844 0.0041 85	0.37273 0.0004 85	0.30104 0.0051 85	0.28122 0.0091 85	0.61665 0.0001 85	0.59118 0.0001 85
Size of house	0.18961 0.0841 84	0.36875 0.0006 84	0.34878 0.0011 84	0.29776 0.0059 84	0.54560 0.0001 84	0.50336 0.0001 84
Space cooling	0.28662 0.0086 83	0.26780 0.0144 83	0.21853 0.0472 83	0.28220 0.0097 83	0.46669 0.0001 83	0.46397 0.0001 83
Water heater	-0.06104 0.6157 70	0.11520 0.3423 70	0.02840 0.8155 70	-0.00927 0.9393 70	0.08085 0.5058 70	0.14465 0.2322 70
Freezer	0.14827 0.1837 82	0.21296 0.0547 82	0.21320 0.0545 82	0.16948 0.1280 82	0.24578 0.0260 82	0.23805 0.0313 82
Range	0.11704 0.2861 85	0.16029 0.1428 85	0.11067 0.3133 85	0.08037 0.4647 85	0.13134 0.2308 85	0.05635 0.6085 85
Washer	0.06368 0.5626 85	0.19303 0.0767 85	0.07157 0.5151 85	0.07088 0.5192 85	0.18072 0.0979 85	0.14576 0.1832 85
Dryer	0.13085 0.2326 85	0.23732 0.0287 85	0.09426 0.3909 85	0.12999 0.2357 85	0.28314 0.0086 85	0.28005 0.0094 85
Dishwasher	0.17212 0.1152 85	0.27439 0.0110 85	0.12887 0.2398 85	0.14817 0.1760 85	0.41760 0.0001 85	0.33083 0.0020 85
Television	0.13498 0.2617 71	0.12242 0.3091 71	0.22336 0.0611 71	-0.06704 0.5786 71	0.19401 0.1050 71	0.21434 0.0727 71

[a] Each cell shows the simple correlation between electric power consumed and household characteristics and the number of appliances owned. The number below the correlation is the probability that the correlation differs from zero. The third number is the number of households in the sample. Correlations are shown for each of 6 hours during the day.

Table 1.18. Relationship Between Electric Power Consumption and Various Household Characteristics, Chattanooga Load Survey, October[a]

	Time of Day					
Variable	Midnight	7 a.m.	9 a.m.	Noon	7 p.m.	9 p.m.
Income	0.22276 0.0435 79	0.33057 0.0029 79	0.30155 0.0069 79	0.11616 0.3080 79	0.25979 0.0208 79	0.35729 0.0012 79
Size of house	0.22427 0.0409 79	0.29561 0.0082 79	0.28692 0.0104 79	0.23784 0.0348 79	0.16149 0.1651 79	0.20819 0.0656 79
Space heating	0.32282 0.0039 78	0.39435 0.0004 78	0.42437 0.0001 78	0.26849 0.0175 78	0.30306 0.0070 78	0.26923 0.0171 78
Water heater	-0.04958 0.0926 66	0.00114 0.9925 66	-0.05008 0.0897 66	0.20783 0.0940 66	-0.16606 0.1827 66	-0.18335 0.1406 66
Freezer	0.20171 0.0708 78	0.18740 0.1004 78	0.27499 0.0148 78	0.12815 0.2035 78	0.04819 0.0752 78	0.09583 0.4039 78
Range	0.16926 0.1359 79	0.17529 0.1223 79	0.19338 0.0877 79	0.11849 0.2983 79	0.25416 0.0238 79	0.24250 0.0313 79
Washer	-0.00389 0.9729 79	0.22402 0.0472 79	0.21483 0.0578 79	0.13200 0.2462 79	0.08658 0.4480 79	0.01203 0.9162 79
Dryer	0.02442 0.8306 79	0.27406 0.0145 79	0.21241 0.0602 79	0.11533 0.3115 79	0.09021 0.4292 79	0.12760 0.2624 79
Dishwasher	0.23827 0.0345 79	0.23805 0.0340 79	0.22037 0.0510 79	0.16192 0.1640 79	0.07770 0.4981 79	0.03530 0.7575 79
Television	0.19047 0.1317 84	0.28859 0.0210 84	0.22970 0.0879 84	0.33847 0.0062 84	0.17051 0.1780 84	0.29854 0.0166 84

[a] Each cell shows the simple correlation between electric power consumed and household characteristics and the number of appliances owned. The number below the correlation is the probability that the correlation differs from zero. The third number is the number of households in the sample. Correlations are shown for each of 6 hours during the day.

CHAPTER 2. CONSUMER'S SURPLUS APPROACH

According to the methodology of the consumer's surplus approach, the consumer's demand curve for electricity is interpreted as reflecting his willingness to pay for electric power; the elasticity of the demand curve is a measure of the difficulties each consumer would have in doing without electricity. The consumer's surplus approach has the distinct advantage of providing a broad theoretical framework with which to assess the consumer's response to outage costs. It clearly distinguishes between short-run and long-run responses and separates the effects of one outage from those of a general policy allowing continued outages, due perhaps to relaxed reliability standards on the part of the electric utility.

The consumer's surplus concept has a checkered history in economic analysis. Invented by Jules Dupuit in 1844 (International Economic Papers, 1952), it has been both greatly refined (Hotelling, 1938; Hicks, 1941) and greatly villified as theoretical nonsense (Graaff, 1957; Samuelson, 1965). Widely accepted and used today, the concept is the theoretical basis of all cost-benefit studies (Harberger, 1973).

In this report, consumer's surplus is used to sort out the various problems posed to consumers by electric power shortages, easily differentiating short-run effects such as work stoppages from longer-term effects such as fuel switching, conservation, or internal generation of electricity. This approach has several advantages. First, this theoretical structure provides a standard against which to judge other proposed measures of the cost of outages and a means of interpreting data gathered by survey. Second, the method can be applied directly to examples both for the United States as a whole and the TVA region. The shortcomings of consumer's surplus in application will be considered as the examples are developed. This chapter includes a review of methodology and various applications of the concept to both the United States as a whole and to the Tennessee Valley.

METHODOLOGY

Demand and Consumer's Surplus

A demand curve shows the maximum quantity of a commodity that will be purchased by a group of customers per unit time as the price of the commodity is allowed to vary. Figure 2.1 shows a demand curve for electricity, with quantity on the horizontal axis and price on the vertical axis. At each point on the curve customers are willing to buy the indicated quantity (e.g., Q) at the given price (P). The prices of other products and their quantities are taken to be constant, as is the income or money expenditure of customers. The curve diminishes to the right, an indication that customers find fewer uses for electricity as the price rises and that fuel switching or conservation occurs as the price rises.

The demand curve is influenced by the time period for which it is defined. First, the quantity of electricity purchased is defined per unit of time. Second, the alternatives to electricity--substitute fuels, internal electric generation or storage, and conservation--are dependent on the length of time available. More adjustments will be possible as longer time periods are considered. The slope of the demand curve remains negative but falls as the time period available is lengthened. Figure 2.2 shows how the slope might change for a demand curve over a very short period, over a short period, and over the long run. How these periods are defined will depend on the customer and the specific application of electricity, but the very short run implies that virtually no adjustment is possible, except minor operational changes; the long run means that extensive readjustments to higher prices through capital expansion or other significant changes in capital stock are possible; and the short run falls between these two extremes, with operational changes and minor capital projects completed.

The usual interpretation of the demand curve--quantity adjustments in response to price changes--can be turned around in a way that is particularly useful when one is considering shortages or other situations in which the quantity of the commodity is controlled. The demand curve is the

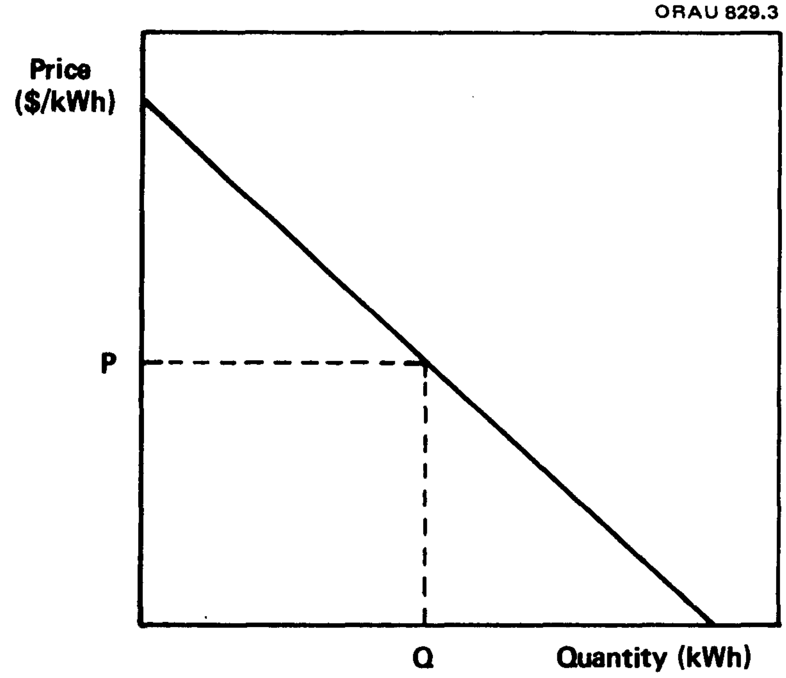

Figure 2.1. Demand for Electricity

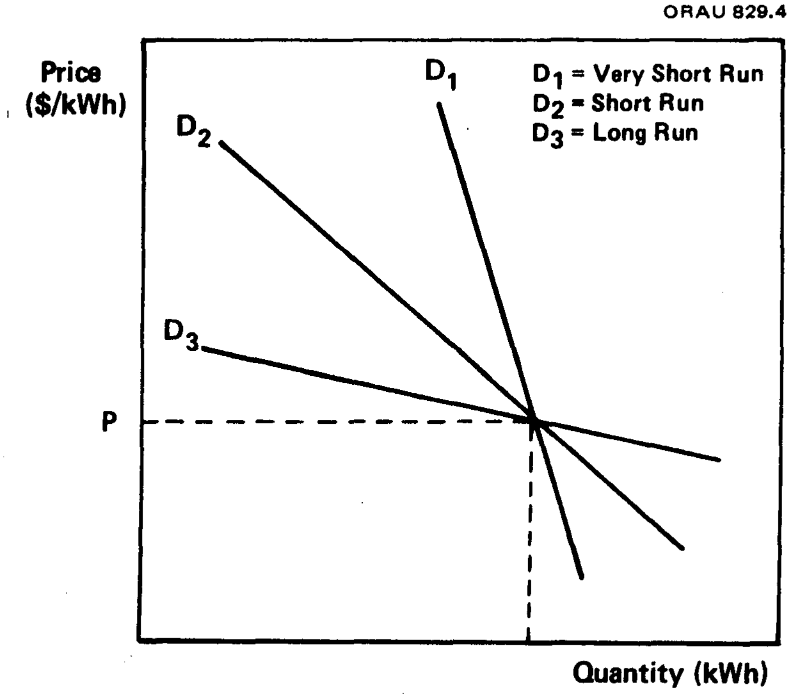

Figure 2.2. Demand for Electricity as a Function of Time

maximum price a group of consumers would be willing to pay for a quantity of a commodity brought to market during a specified period of time. Each point on the curve shows the price the consumer would be willing to pay for that quantity. Substitution possibilities are still taken into account, and the quantities of other goods and their prices remain fixed. The downward slope to the right now indicates that, as more of the commodity is brought to market, consumers apply it to uses for which it is less uniquely suited and are willing to pay only a falling price for greater quantities.

This second interpretation leads to the concept of consumer's surplus. This is the triangular area abP_0 in Figure 2.3 if Q_0 units are brought to market and if consumers are willing to pay P_0 for this last or marginal unit. Every unit sells for P_0 dollars, though consumers would have been willing to pay far more for some of the units if supply had been restricted--P_1 for Q_1 units or P_2 for Q_2 units. The area under the demand curve from 0 to Q_0 units represents the amount consumers would have been willing to pay for the quantity Q_0; the area P_0Q_0 is the quantity they did in fact pay; and the difference (abP_0) is the consumer's surplus. If economic conditions change, the change in consumer's surplus is a frequently used measure of the welfare loss or gain resulting from the new conditions.

Consumer's Surplus and Electricity Outages--Short-Run Effects

Figure 2.4 shows an electric utility customer in long-run economic equilibrium.* The vertical axis measures the price of electric power purchased from the electric utility, and the horizontal axis measures the quantity purchased by the residence per time period. The curve DD is the long-run demand schedule, relating the quantity purchased to the price. DD, as a long-run demand curve, allows the customer to make whatever adjustments are possible for conservation or fuel switching as the price of

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*The problem posed in this section is analogous to a nation dividing its consumption between domestic production and imports, where the imports are subject to embargo. The analysis follows Tolley and Wilman (1977).

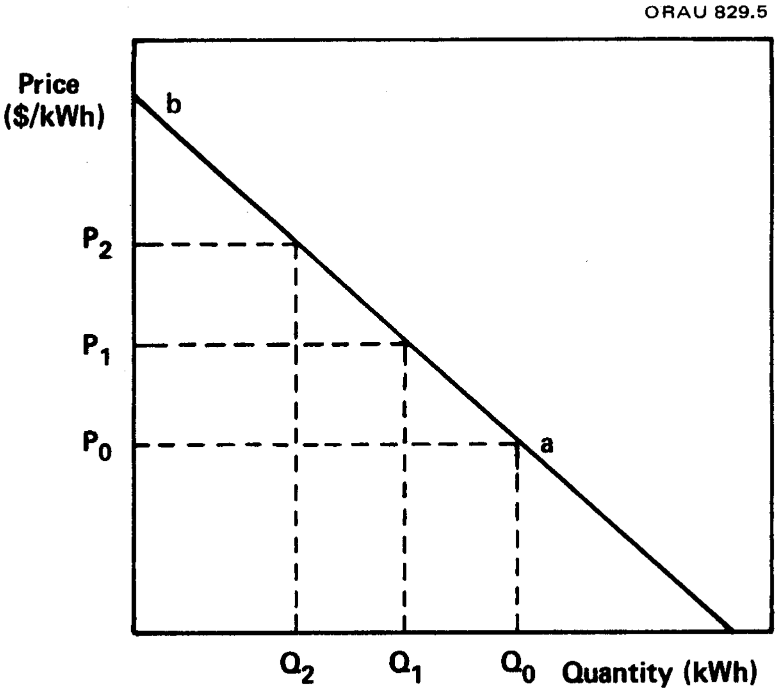

Figure 2.3. Consumer's Surplus

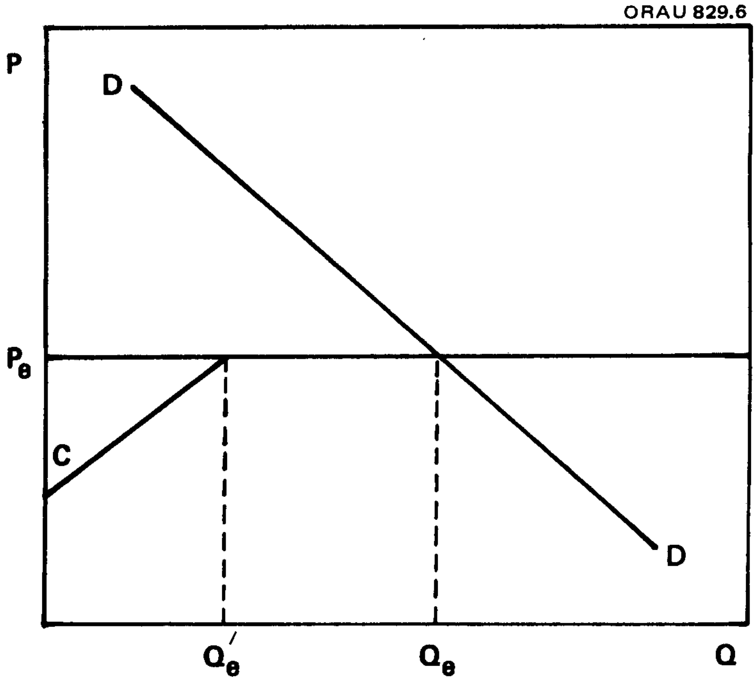

Figure 2.4. The Customer in Long-Run Equilibrium

electricity varies. The curve C is the marginal cost of electricity production by the firm or home, showing the cost of internally produced electricity rising as production is scaled upward; P_e is the prevailing price charged by the utility for purchased power; Q_e is the long-run quantity of electricity demanded by the customer. An amount Q_e will be produced internally by the customer,* and Q_e-Q_e will be purchased from the utility.

Figure 2.5 is the same as Figure 2.4, except that a very short-run demand curve for electricity, curve DD, has been added. The very short run is defined as the length of the customer's electric outage, perhaps a few hours or days at most. This curve is far less elastic than curve DD, because the ability to switch fuels, conserve, or adopt alternate technologies is sharply limited in this time period. In the event of an interruption in electric service, the customer's electric power supply falls to Q_e, i.e., to internally produced sources only. The losses sustained during the outage are measured by the triangular area xyz. This area is the loss of consumer's surplus, or the amount the customer would be willing to pay to avoid the outage.

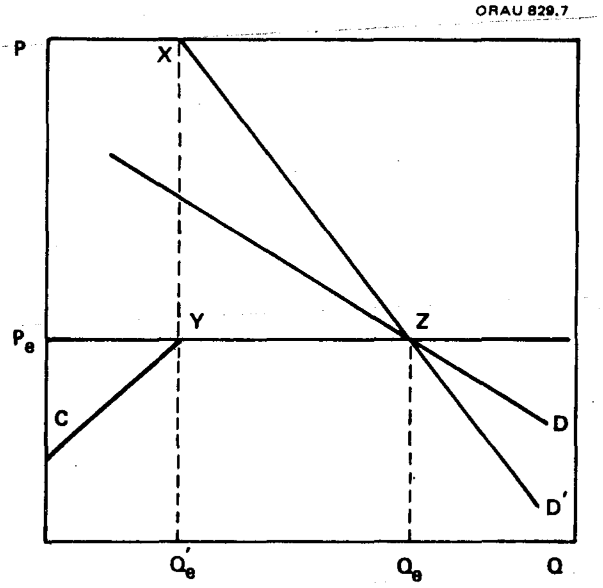

Figure 2.5. Short-Run Cost of Electricity Outage

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*If the intercept of C lies above P_e (the cost of purchased power), then no internal production occurs.

Consumer's Surplus and Electricity Outages--Long-Run Effects

The loss measured in Figure 2.5 was a short-run loss resulting from a single outage. It is a product of conditions prevailing within homes, stores, and plants at the time an outage occurs; and it is based on the assumption that adjustment possibilities are sharply limited by the short time period. These costs are relevant to the larger problem posed by the study for TVA, but they do not really address the question of how consumers respond to a deliberate policy of increasing the frequency and/or duration of electrical outages.

To consider this larger question, it is necessary to refine the definition of the cost of electric power to the customer. Rather than taking this cost to be simply the price of purchased power, one should also include the cost of very short-term outages:

$$\hat{P}_e = (1 - \pi)\, P_e + \pi\, P_o$$

where $\hat{P}_e$ = the cost of electric service, including the cost of outages,

π = the probability of an outage of utility-provided electricity over an extended planning horizon for the firm,

P_o = the value of the last unit of energy produced within the firm during an outage, measured on the very short-run demand curve.

Figure 2.6 shows the long-run response of a consumer to a change in the probability of an outage. If this probability rises from π to π', the cost of electric service rises from $\hat{P}$ to $\bar{P}$:

$$\hat{P} = (1 - \pi)P_e + P_o$$

$$\bar{P} = (1 - \pi')P_e + \pi' P_o$$

The customer's immediate response to these increased costs will be to decrease the short-term costs of an outage from P_o to P_o, reducing overall costs to P :

$$P = (1 - \pi)\ P_e + \pi\ P_o$$

After these adjustments are made (as outlined in the next paragraph), the horizontal supply curve for utility power has shifted upward from P to P as shown in Figure 2.6.

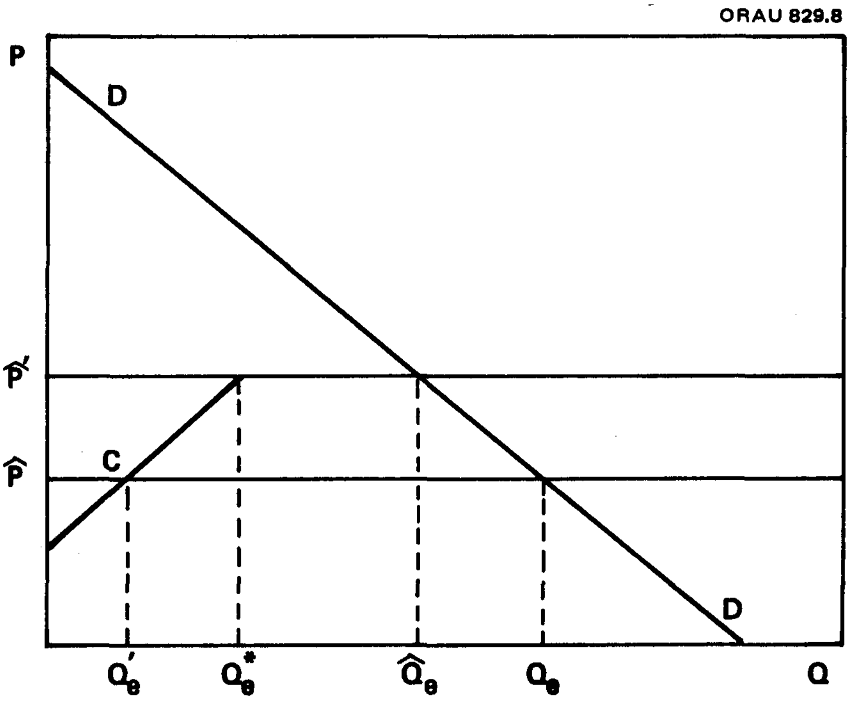

Figure 2.6. Customer Adjustment to Decreased Reliability

The customer's response to this increase in the cost of purchased power takes several forms, all having the effect of reducing the costs of an electrical outage.

1. It increases the scope for internal production of electricity. The marginal cost curve for this electricity (c) extends to the right, and internal production rises from Q_e to Q_e.
2. Substitution of capital for electricity through conservation or the introduction of new technologies is made possible by the higher cost of using electricity. Overall consumption of electric power will fall from Q_e to Q_e.
3. The reduction in the use of electric power is borne completely by the utility. If internal production of electricity is feasible, this effect is doubly enforced by (1) rising internal production and (2) substitution away from electric power or conservation.

Figure 2.7 is the same as Figure 2.6, showing the shift in long-run equilibrium at price P and quantity Q_e. To temporarily simplify matters, curve c for internal generation of electricity is removed. If the time period for which Figure 2.7 is defined is taken to be a year, the annual

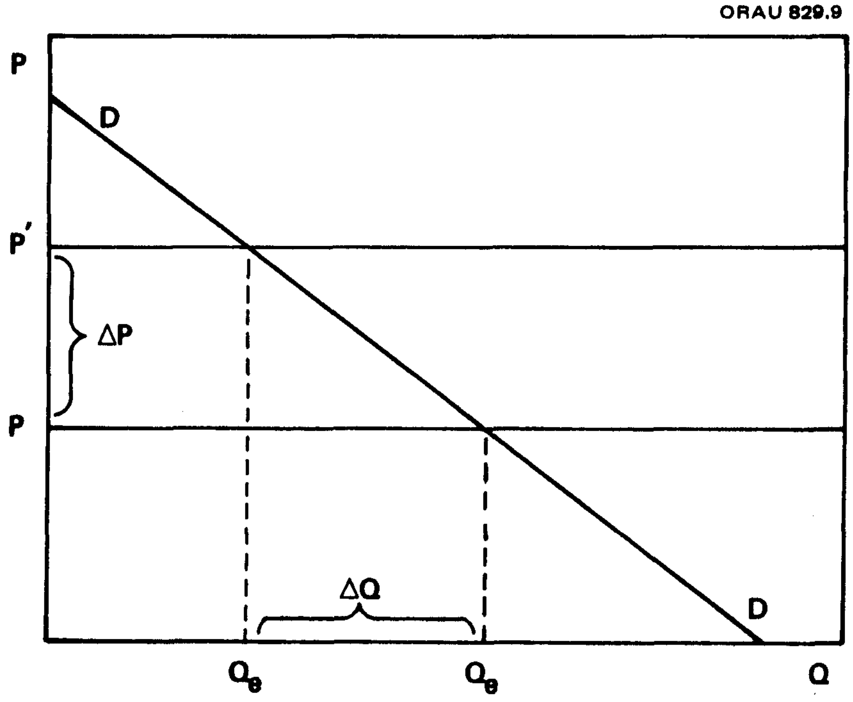

Figure 2.7. Losses Due to Decreased Reliability

savings to the utility and costs to the customer from relaxed reliability standards can be defined in terms of the geometry of this figure.

Before relaxing reliability standards, the utility collected $\hat{P}Q_e$ in revenues, and total costs were KQ_e*. Afterward, the utility collects $\hat{P}Q_e$ in revenues (remember ΔP is not a tariff change, only a change in cost to the customer imposed by lower reliability) and will have lower costs, $K_o\hat{Q}_e$, because of its reduced standards for reliability. The customer, before the change, paid $\hat{P}Q_e$ in revenues (Figure 2.7). After reliability standards are relaxed, the consumer perceives an increased cost (ΔP) due to outages, rising on the average from K to K_o per kilowatthour delivered to the home or business. The customer will see a decrease in his electric bill of $\hat{P}\Delta Q$; there will be a loss of consumer's surplus of 1/2 $\Delta P\Delta Q$. If the utility is to implement a change in reliability that is cost-effective (i.e., that can reduce its own costs more than it raises the costs of its customers), the following condition must be met:

$$\text{Utility Cost Saving} \geq \text{Customer Losses}$$

$$\hat{P}(Q_e - \hat{Q}_e) + (K\hat{Q}_e - K_oQ_e) \geq -\hat{P}\Delta Q + 1/2\Delta P\Delta Q$$

$$-\hat{P}Q_e + (KQ_e - K_o\hat{Q}_e) \geq \hat{P}\Delta Q + 1/2\Delta P\Delta Q$$

$$KQ_e - K_o\hat{Q}_e \geq 1/2\Delta P\Delta Q$$

This simple criterion is the cost effectiveness standard to be met by a change in electrical reliability. The utility must be able to generate sufficient annual cost savings to reimburse its customers for their losses, including consumer's surplus. If the utility is regulated and required to pass cost savings along to the consumer, the customer's cost of decreased reliability is described by the equation above.

Figure 2.8 is similar to Figures 2.6 and 2.7, but the shift in the short-term demand curve D'D' to D"D" has been included. Short-term losses

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*KQ_e is not shown in Figure 2.7.

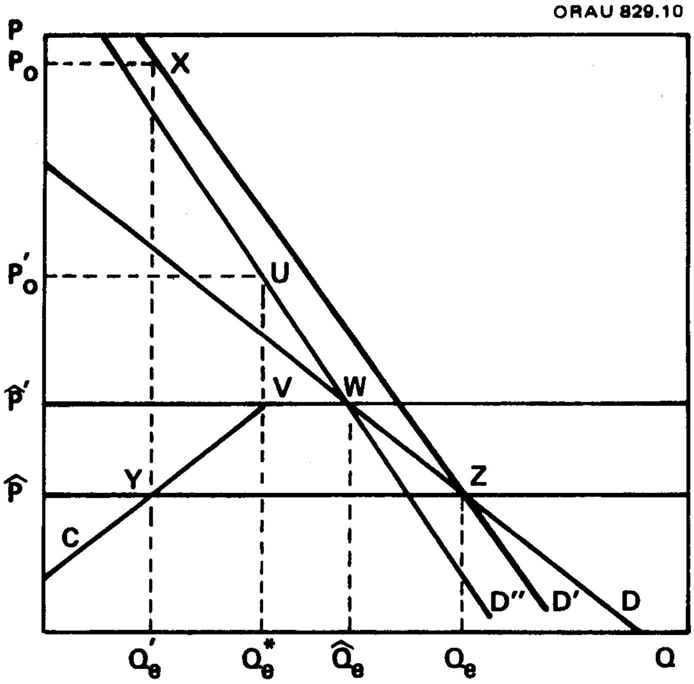

Figure 2.8. Smaller Short-Run Losses After Adjustment

before the change in reliability were the triangle xyz, with the marginal kilowatthours of electricity during an outage costing P_o. After the effective cost increase for electricity due to decreased reliability, after internal generation rises from Q_e to Q_e, and after conservation and fuel switching reduce overall consumption, the possible short-term losses have been reduced to the triangle uvw. The value of the marginal unit of electricity during an outage is P_o. All of the adjustments in response to lowered reliability clearly worked to reduce the customer's vulnerability in the event of an outage.

CONSUMER'S SURPLUS IN THE SHORT RUN--APPLICATION TO THE UNITED STATES

An application of the consumer's surplus concept to the electricity shortages occurring over short-run periods of time has been made by National Economic Research Associates (NERA), Inc. (NERA, 1976; Shew, 1977). The NERA study attempts to estimate the cost of large-capacity shortages (5 to 20 percent) that are assumed to occur in the United States in 1983 and continuing throughout the year. The assumed prices of electricity to residential, commercial, and industrial customers; the sales of electricity to these sectors; and the elasticity of demand for each sector are shown in Table 2.1. The elasticities are taken from short-run (1-year) estimates by NERA and are arbitrarily reduced by 25 percent to reflect the 1-year time period.*

Table 2.1. Parameter Values for the NERA Example of Capacity Shortages in the United States in 1983

Parameter	Sector Residential	 Commercial	 Industrial
Price of electricity (¢/kWh)[a]	4.19	4.14	2.26
Electric sales (10^9 kWh)[a]	877.7	727.3	1198.1
Price elasticity of demand	-.16	-.19	-.13

[a] 1975 Dollars

Source: William B. Shew, "Cost of Inadequate Capacity in the Electric Utility Industry," Energy Systems and Policy, 2 (1977), Table 1.

The most interesting part of the NERA methodology is its assumption of price rationing to eliminate the shortage. Given the price elasticities (α_1) for each sector in Table 2.1, a shortage of $\Delta Q/Q$ percent can be eliminated if electricity prices are raised by an amount ΔP, and ΔP is calculated from the definition of an elasticity and the prevailing price P:

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*See the next section of this chapter for further discussion of adjustments to elasticity coefficients.

$$\frac{\Delta Q}{Q} = \alpha_1 \frac{\Delta P}{P}$$

i = 1 for residences, 2 for industry, or 3 for commerce.

NERA assumes that each customer is immediately and costlessly notified of the new price (the price sufficient to ensure a cutback in electricity consumption of 5 to 20 percent), and that he responds to this price. Given ΔP and ΔQ, the loss in real income from the implementation of these price increases is the loss of consumer's surplus equal to 1/2ΔPΔQ. Figure 2.9 illustrates this loss.

Total loss of electric sales (ΔQ) and the income loss from using price rationing (ΔPΔQ)/2 for the United States in 1983 are given in Table 2.2 for shortages of 5, 10, 15, and 20 percent of the electric generating

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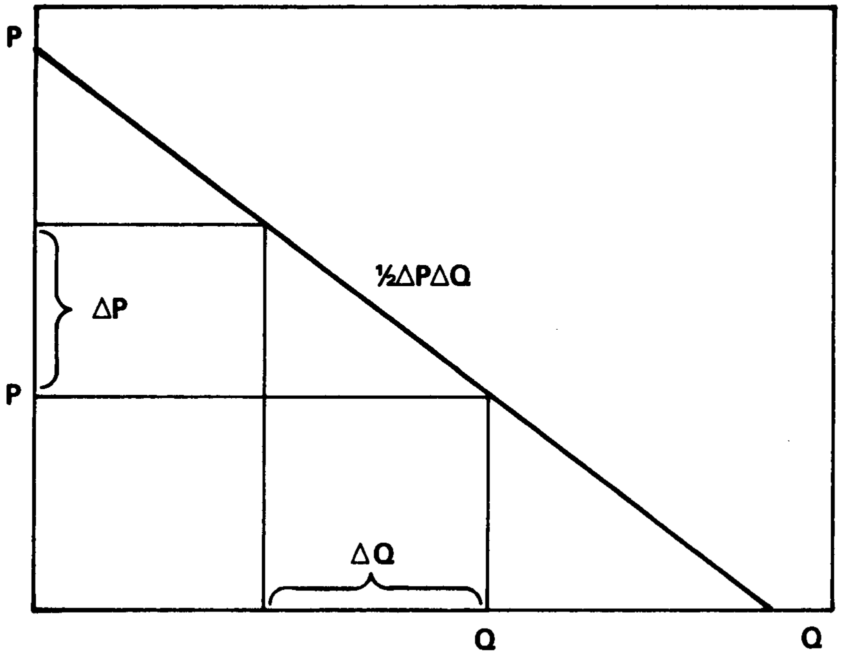

Figure 2.9. Loss in Real Income Due to Price Rationing

Table 2.2. Total Losses from All Sectors from Capacity Shortages of 5 to 20 Percent, United States, in 1983

Shortage (%)	Loss of Electric Sales (10^6/kWh)	Loss from Price Rationing (10^6/\$)[a]
5	140,155	745.7
10	280,310	2983.0
15	420,465	6711.8
20	560,620	11959.5

[a] Constant 1975 dollars.

Note: The losses reported in column 3 differ from those reported by Shew (1977). The difference stems from the measure of loss used here ($1/2\Delta P\Delta Q$) as opposed to that used by Shew. (See, in particular, note 7 in his paper.) The measure used here is an approximation but is more transparent than Shew's measure. It is certainly adequate for the discussion here.

Source: Calculated from the assumptions of Table 2.1.

capacity.* The income loss is quite substantial, ranging from $745.7 million for a 5 percent capacity shortage to nearly $12 billion for a 20 percent shortage. Table 2.3 shows data for each of the residential, commercial, and industrial sectors, giving the loss of electric sales, the change in price necessary to effect the cutback in consumption, and the income loss under varying shortage conditions.

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*The utility industry will collect an enormous amount of revenue through the implementation of the price increases. Geometrically the revenue increase is $\Delta P(Q + \Delta Q) + P\Delta Q$ in Figure 2.9. For the NERA assumptions of a 5- to 20-percent shortage in capacity, these revenues would amount to $25 to $80 billion. It must be assumed that this money is returned to consumers as lump-sum rebates or funneled to the public treasury as general revenue.

Table 2.3. Effects on Various Sectors of Capacity Shortages of 5 to 20 Percent, United States, in 1983

Shortage (%)	Loss of Electric Sales (ΔQ) (10^6 kWh)	Change in Electricity Price (ΔP)[a] ($/kWh)	Loss from Price Rationing[a] (10^6 $)
		Residences	
5	43.9	.013	287.2
10	87.8	.026	1149.2
15	131.7	.039	2585.8
20	175.5	.052	4597.0
		Commerce	
5	36.4	.011	198.1
10	72.7	.022	792.3
15	109.1	.033	1782.8
20	145.5	.044	3169.5
		Industry	
5	59.9	.009	260.4
10	119.8	.017	1041.5
15	179.7	.026	2343.2
20	239.6	.035	4166.0

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[a] Constant 1975 dollars

Source: Calculated from the assumptions in Table 2.1

These estimates of the cost of a capacity shortage assume that no actual outages occur--only reductions in consumption of 5 to 20 percent in response to price rationing. These estimates provide a lower bound on the cost of a capacity shortage, since an actual shortage would almost certainly be more expensive.

1. The model assumes a great deal of deterministic knowledge by the utility about its customers. Certainly in application a great deal of experimentation would have to take place before the correct ΔP could be found to implement the scheme effectively. Experimentation to find the correct ΔP would entail a higher cost. The administrative costs of informing customers of prices, collecting the revenue, and otherwise implementing such a system also would be significant.
2. Other schemes would be even more expensive. If the utility were to resort to rolling blackouts (the rationing of power to certain fractions of the customers on a rotating basis) or other selective curtailments, individual customers would face complete outages of electric power rather than percentage cutbacks. Complete outages would be more expensive and would pose safety hazards and possible spoilage problems.

APPLICATION OF THE CONSUMER'S SURPLUS APPROACH TO THE OUTAGES IN THE TENNESSEE VALLEY

The literature reviewed in the previous sections of this chapter described the use of the elasticity of demand for electric power consumption as a means of estimating the cost of electric power shortages. Assuming that the shortages are rationed by price increases and that only partial cutbacks and no outages occur, one can estimate the loss of consumer's surplus resulting from shortages.

The Cost of Long-Term Shortages in the Tennessee Valley

The TVA Annual Energy Model* provides estimates of the elasticity of demand for TVA customers defined in residential, commercial, and industrial categories. For the residential sector, the short-run (1-year) elasticity of demand for residential customers is estimated to be -.254.** Following the procedures presented in the last section, one would cut this elasticity by one-half to allow for the shorter time period dealt with by the outages.†

Table 2.4 summarizes the calculation of the lower-bound estimates for TVA residential electric consumers. The 1978 price of 2.68¢/kWh would have to be increased by 1.1 to 4.2¢/kWh to eliminate shortages of 5 to 20 percent. These shortages cost consumers at least 3.2 to 4.8 ¢/kWh (for energy not delivered), depending on the severity of the outage. If the shortages were to continue throughout the course of a year, they would cost $10.4 to $159.0 million, depending on their severity.

The Cost of Outages--Lower-Bound Estimates

Estimates for All Electric Uses Combined

These same calculations can be used to obtain the cost of a complete outage (as opposed to a shortage) if two assumptions are made:

1. The demand curve is linear, or a linear approximation to the log-linear curve estimated on the Annual Energy Model is suitable.

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*Operator Manual for Annual Energy Model (May 5, 1978). The July 1979 reestimation of the model is used.

**This is the elasticity of demand estimated from average prices: the elasticity based on marginal prices was virtually identical (-.238).

†See below for a more complete explanation of adjustments to elasticity coefficients.

Table 2.4. Summary of Calculations--Lower Bound on Estimates of Shortages to TVA Electric Customers

$$\frac{\Delta Q}{Q} \Big/ \frac{\Delta P}{P} = \frac{e}{2}$$

e = Short-run elasticity of demand
= $-.254$

Q = Quantity of electricity demanded
= 37.87 billion kWh

P = Price of electricity before the outage
= 2.68¢/kWh

ΔQ = Shortage of electricity

ΔP = Price change necessary to eliminate shortage

$\Delta Q/Q$	= Percent shortage =	5	10	15	20
ΔP	= Price change (¢/kWh) =	1.1	2.1	3.2	4.2
$P + \frac{\Delta P}{2}$	= Lower bound on shortage cost (¢/kWh)	3.2	3.7	4.3	4.8
$\frac{\Delta P \Delta Q}{2}$	= Total dollar value of shortage = if it continues 1 year ($ million)	2.1	4.0	6.1	8.0

2. The constant elasticity estimated in the Annual Energy Model holds at the mean on the linear demand curve.*

If Q is the quantity of electricity and P is the price, the demand curve is

$$Q = \alpha + \beta P$$

and

$$\Delta Q = \beta \Delta P$$

If e is the mean elasticity, it is defined as

$$\bar{e} = \frac{\bar{P}}{\beta \bar{Q}}, \ e < 0,$$

where $\bar{P}$ and $\bar{Q}$ are average price and quantity, respectively. Then for an outage ($\Delta Q = -\bar{Q}$) the marginal value of electric power ($\bar{P} + \Delta P$), the average value of electricity lost during the outage [$\bar{P} + (\Delta P/2)$], and the total value of losses as measured by consumer's surplus [$(\Delta P \Delta Q)/2$] are computed as follows:

$$\Delta P = -\frac{\bar{P}}{e} = \frac{2.68}{.127} = 21.10¢/\text{kWh}$$

$$\bar{P} + \Delta P = 2.68 + 21.10 = 23.78¢/\text{kWh}$$

$$\bar{P} + \frac{\Delta P}{2} = 2.68 + 1/2(21.10) = 13.2¢/\text{kWh}$$

$$\frac{\Delta P \Delta Q}{2} = \frac{\overline{PQ}}{2\bar{e}}$$

---

*A graphical comparison of the two curves reveals that for modest changes in kilowatt consumption (plus or minus 50 percent) the linear and log-linear form are close approximations. For changes that decrease electric consumption to near zero, the log-linear curve yields nonsensical results. Because it is asymptotic to the price axis, the cost of losing the last few increments of electricity is infinite. The switch to an alternate functional form (the linear form was chosen here) is necessary to prevent nonsensical results.

Table 2.5 summarizes the cost of an outage of 1 to 3 hours for a single household and for all households in the Tennessee Valley. The estimates assume that the households in the region consume the quantity of electricity shown in the top line of the table. The estimates are made by season and by time-of-day (on-peak/off-peak) for a typical day. The average cost of a 1-hour outage ranges from 21¢ to 50¢. The cost to all homes in the valley would be $0.5 to $1.2 million.

Lower-Bound Estimates Based Upon Contributions by Individual Appliances

In this section the cost of outages is calculated for individual appliances. The values are presented by season and time of day for specific appliances; the aggregation of values then yields another series of lower-bound estimates for the TVA region. The methodology used parallels that of the previous section; instead of average energy price elasticities and overall electrical usage, the elasticities used are appliance-specific, and electric usage is appliance-specific for the TVA area.

Appliance elasticities. In order to apply the consumer's surplus approach to an outage of 0 to 3 hours, the demand functions for individual appliances must be defined with respect to the very short run, a period in which neither changes in appliance stock nor purchases of mitigation effects can be made, and in which only instantaneous behavioral adaptation can occur. To obtain demand functions for the very short run, modification must be made to longer-run measures. As we are interested in own price elasticities for specific appliances, models based upon capital stock utilization rates are most readily adapted to the purpose. The difficulty is that of adjusting the coefficients to very-short-run values.

Although capital stock utilization models, such as those by Baughman and Joskow (1974) and Anderson (1973) focus upon demand for specific appliances in response to fuel prices, they are in essence modeling the long-run demand for energy (see also Edmonds, 1978). The reasoning was first set forth by Fisher and Kaysen (1962), in their argument that utilization rates

Table 2.5. The Value of an Outage of 1 to 3 Hours, by Season and by Time of Day, for Homes in the Tennessee Valley, 1978

	Winter		Summer		Spring		Fall	
Value	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
Household electric use (kW)	3.8	3.4	2.3	2.0	1.6	1.6	2.0	1.8
One home ($)								
Cost of 1-hour outage	.50	.45	.30	.36	.21	.21	.26	.24
Cost of 3-hour outage	1.50	1.34	.91	1.09	.63	.63	.79	.71
All homes ($ million)								
Cost of 1-hour outage	1.2	1.1	.72	.86	.50	.50	.62	.58
Cost of 3-hour outage	3.6	3.2	1.46	2.50	1.51	1.51	1.87	1.73

of specific appliances were constant, and the stock of appliances varied in response to energy prices. However, Hirst and Carney (1978) stated that this long-run approach includes some elements of purely behavioral response intermixed with capital-sensitive elements of appliance efficiency and market share. Hirst and Carney specified the behavioral or "usage" elasticities on a basis of engineering possibilities. That is, responsiveness to fuel price changes can be estimated in terms of purely behavioral changes, whereas equipment and structural capital stocks are held constant. Hirst and Carney refer to Anderson's econometric formulation which shows that 25 to 30 percent of the total long-run response is accounted for by purely behavioral change. Anderson subtracts indirectly computed elasticities from directly computed elasticities and attributes the residual to purely behavioral response. The indirectly computed elasticities assume the effects of price upon the efficiency of appliance use, whereas the direct elasticities are estimated from energy consumption equations. The difference reflects the effect of price upon the consumption per appliance installation. As Anderson's direct and indirect own price elasticity coefficients for electricity are, respectively, -1.12 and -.84, the residual of .28 represents a behavioral response of between 25 and 33 percent of the total long-run response, depending upon whether the direct or indirect elasticity coefficient is chosen as base (Anderson, 1973, pp. 51-57).

Although Anderson's formulation allows for the isolation of purely behavioral response, further adjustment is necessary prior to applying elasticities to an outage situation in which valuation is based upon instantaneous behavioral response, rather than upon behavioral response which may be learned over a prolonged period. Hirst and Carney (1978) and Shew (1977) agree upon a factor of 0.5 for the adjustment of elasticities from the behavioral to the instantaneous behavioral or very short run.

The elasticities shown in Table 2.6 are based primarily upon saturation elasticities selected from a study by Anderson (1973, p. 36) which have been adjusted to account for the very short run; that is, the long-run elasticities were multiplied by a factor of 0.25 to reflect the purely behavioral aspect and by a factor of 0.5 to account for the very short time

Table 2.6. Appliance-Specific Energy Price Elasticity Coefficients, Appropriate to the Very Short Run

Use	Coefficient	Use	Coefficient
Space heating	-.28	Dishwasher	-.11
Space cooling	-.12	Color TV	-.07
Hot water	-.33	Black-and-white TV	-.07
Freezer	-.10	Refrigerator	-.05
Range	-.13	Lights	-.05
Clothes washer	-.12	Other	-.05
Clothes dryer	-.20		

period. Application of these elasticities to determine outage costs is subject to the same assumptions discussed in the previous section; namely, that the demand curve can be linearly approximated.

Appliance use in the TVA region. Table 2.7 presents the average household usage and the percentage contribution to household load by season and time of day. Kilowatt contribution entries differ from those presented in Table 1.14 in that they include the space conditioning function, and they are adjusted to reflect the TVA area's appliance inventory rather than Knoxville's. Differences in the costs of outages because of an appliance mix different from the TVA norm are considered later in this chapter.

Outage values. The elasticities of Table 2.6, the kilowatt contributions of Table 2.7, and the 1978 residential average electricity price of 2.68¢ per kilowatthour were inputs into the calculation of consumer's surplus based upon the formulation

$$\text{consumer's surplus} = \frac{\Delta P \Delta Q}{2}$$

Table 2.7. Average Household Appliance Usage and Appliance Contribution to Load by Season and Time of Day, TVA Region, 1978

Use	Winter				Spring			
	On Peak		Off Peak		On Peak		Off Peak	
	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$
Space heating	1.832	.484	1.58	.466	.190	.118	.2047	.125
Air conditioning	-	-	-	-	-	-	-	-
Hot water	.492	.130	.53	.156	.451	.281	.451	.275
Freezer	.110	.029	.11	.032	.083	.052	.083	.051
Range	.249	.066	.25	.073	.208	.129	.166	.101
Clothes washer	.008	.002	.023	.007	.008	.005	.003	.001
Clothes dryer	.114	.030	.158	.047	.095	.059	.076	.046
Dish washer	.014	.003	.043	.0127	.014	.009	.014	.009
Color TV	.218	.058	.164	.048	.131	.082	.164	.100
Black-&-white TV	.084	.022	.042	.012	.042	.026	.042	.026
Refrigeration	.334	.088	.333	.098	.278	.173	.287	.175
Lights	.200	.053	.100	.029	.100	.062	.14	.085
Other	.130	.034	.060	.018	.010	.006	.01	.006
	$\Sigma\bar{Q}_i$ = 3.784		$\Sigma\bar{Q}_i$ = 3.393		$\Sigma\bar{Q}_i$ = 1.608		$\Sigma\bar{Q}_i$ = 1.639	

Use	Summer				Fall			
	On Peak		Off Peak		On Peak		Off Peak	
	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$	$\bar{Q}_i$ = TVA Electrical Use (kW)	Appliance % of $\Sigma\bar{Q}_i$
Space heating	-	-	-	-	.259	.130	.204	.112
Air conditioning	.621	.265	.214	.106	-	-	-	-
Hot water	.574	.245	.574	.287	.533	.267	.533	.295
Freezer	.165	.071	.138	.069	.110	.055	.083	.046
Range	.208	.089	.133	.066	.249	.125	.208	.115
Clothes washer	.008	.003	.016	.008	.008	.004	.008	.004
Clothes dryer	.076	.032	.113	.056	.095	.048	.095	.053
Dish washer	.014	.006	.029	.015	.014	.007	.014	.007
Color TV	.109	.047	.164	.082	.164	.082	.164	.091
Black-&-white TV	.042	.018	.042	.021	.042	.0210	.042	.023
Refrigeration	.444	.190	.389	.194	.333	.166	.278	.154
Lights	.050	.021	.150	.075	.150	.075	.12	.066
Other	.030	.013	.040	.020	.040	.020	.06	.033
	$\Sigma\bar{Q}_i$ = 2.340		$\Sigma\bar{Q}_i$ = 2.002		$\Sigma\bar{Q}_i$ = 1.997		$\Sigma\bar{Q}_i$ = 1.809	

The resulting estimates by appliance, season, and time of day for a 1-hour outage are presented in Table 2.8; those for a 3-hour outage comprise Table 2.9. The magnitude of the entries reflects both appliance contribution and elasticity; large values are associated with either a major contribution, such as space heating in winter, or with coefficients signifying a relatively inelastic demand function, such as for refrigeration.

Aggregated results. Table 2.10 presents the marginal and average cost of outage as well as the aggregate consumer's surplus losses associated with 1- and 3-hour outages. The entries were calculated from the values contained in Tables 2.6 through 2.9, and based upon the following formulations:

$$\text{average value of electricity lost} = \bar{P} + \frac{\Delta P}{2}$$

$$\text{marginal value of electricity lost} = \bar{P} + \Delta P$$

$$\text{loss in consumer's surplus} = \frac{\Delta P \Delta Q}{2}$$

As each of these values represents an aggregation of losses by appliances, they differ from the values in Table 2.5 which were derived from the TVA region overall averages of capacity, price, and elasticity. Yet the estimates shown in Table 2.10 manifest a strong similarity to those of Table 2.5. There are two reasons for this agreement. First, contributions to capacity are derived from the same totals. Second, individual appliance elasticity coefficients, when weighted, closely approximate the average coefficient used in the previous section.

Comparison of outage costs for some atypical households. The data presented thus far have dealt only with the average TVA household. Important differences exist within households, of course, and some differences can be illustrated.

Table 2.8. The Value of a 1-Hour Outage, by Appliance, Season, and Time of Day Based upon Loss of Consumer's Surplus to a Typical Household in the TVA Area (cents)

	Winter		Spring		Summer		Fall	
Appliance	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
Space heating	8.77	7.56	.91	.98	-	-	1.24	.98
Space cooling	-	-	-	-	6.93	2.39	-	-
Hot water	2.00	2.15	1.83	1.83	2.33	2.33	2.16	2.16
Freezer	1.47	1.47	1.11	1.11	2.21	1.85	1.47	1.11
Range	2.57	2.58	2.15	1.71	2.14	1.37	2.57	2.14
Clothes washer	.09	.26	.09	.09	.09	.18	.09	.09
Clothes dryer	.76	1.06	.64	.51	.51	.76	.64	.64
Dishwasher	.17	.52	.17	.17	.17	.11	.17	.17
Color TV	4.17	3.14	2.51	3.14	2.09	1.56	3.14	3.14
Black-and-white TV	1.61	.80	.80	.80	.80	1.61	.80	.80
Refrigerator	8.95	8.92	7.45	7.69	11.90	10.43	8.93	7.45
Lights	5.36	2.68	2.68	3.75	1.34	4.02	4.02	3.22
Other	3.48	1.61	.27	.27	.80	1.07	1.07	1.60
Total	39.40	32.75	20.61	22.05	31.31	27.68	26.30	23.50

Table 2.9. The Value of a 3-Hour Outage, by Appliance, Season, and Time of Day Based upon Loss of Consumer's Surplus to an Average Household in the TVA Area (cents)

	Winter		Spring		Summer		Fall	
Appliance	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
Space heating	26.31	22.68	2.73	2.94	-	-	3.72	2.94
Space cooling	-	-	-	-	20.79	7.17	-	-
Hot water	6.00	6.45	5.49	5.49	6.99	6.99	6.48	6.48
Freezer	4.41	4.41	3.33	3.33	6.63	5.55	4.41	3.33
Range	7.71	7.74	6.45	5.13	6.42	4.11	7.71	6.42
Clothes washer	.27	.78	.27	.27	.27	.54	.27	.27
Clothes dryer	2.28	3.18	1.92	1.53	1.53	2.28	1.92	1.92
Dishwasher	.51	1.56	.51	.51	.51	.33	.51	.51
Color TV	12.51	9.42	7.53	9.42	6.27	4.68	9.42	9.42
Black-and-white TV	4.83	2.40	2.40	2.40	2.40	4.83	2.40	2.40
Refrigerator	26.85	26.76	22.35	23.07	35.70	31.29	26.79	22.35
Lights	16.08	8.04	8.04	11.25	4.02	12.06	12.06	9.66
Other	10.44	4.83	.81	.81	2.40	3.21	3.21	4.80
Total	118.20	98.25	61.83	66.15	93.93	83.04	78.90	70.50

Table 2.10. The Value of an Outage for 1 and 3 Hours for One Household and for All Homes in the TVA Region Calculated from Aggregated Appliance Values, Lower Bound, 1978

Value	Winter		Spring		Summer		Fall	
	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
One Household								
1-Hour outage:								
Average value ($/kWh)	.131	.126	.155	.161	.161	.171	.158	.153
Marginal value ($/kWh)	.235	.225	.283	.295	.295	.315	.290	.280
Consumer's surplus lost ($)	.394	.322	.206	.221	.313	.287	.263	.235
3-Hour outage:								
Average value ($/kWh)	.393	.378	.465	.483	.483	.513	.474	.459
Marginal value ($/kWh)	.705	.675	.849	.885	.885	.945	.870	.840
Consumer's surplus lost ($)	1.118	.966	.618	.663	.939	.848	.789	.705
All Households								
1-Hour outage:								
Average value ($ million)	.314	.302	.372	.386	.386	.410	.379	.367
Marginal value ($ million)	.564	.540	.679	.708	.708	.756	.696	.672
Consumer's surplus lost ($ million)	.946	.773	.494	.530	.751	.682	.631	.564
3-Hour outage:								
Average value ($ million)	.943	.907	1.116	1.159	1.159	1.231	1.138	1.102
Marginal value ($ million)	1.692	1.620	2.04	2.120	2.120	2.268	2.088	2.016
Consumer's surplus lost ($ million)	2.84	2.318	1.483	1.591	2.254	2.056	1.894	1.692

Table 2.11 illustrates the differences that can exist geographically. Knoxville is one of the most highly electrified cities in the region; Memphis is one of the least electrified.* This table compares both cities with TVA averages during a typical winter day, the average value of lost electricity, and the cost of a 1-hour outage. The average load in Memphis is well below that in Knoxville and the TVA norm. The value of a kilowatt-hour lost in Memphis is higher than that for both TVA and Knoxville. The reason is that the value of electricity for large appliances is least valuable; in the very short run, that for commonly held appliances (TV, refrigeration) is highest. The high electric load carried in Knoxville is, however, more than enough to push the <u>total</u> cost of a 1-hour outage to the highest levels in the table.

Table 2.12 shows the cost of an outage to an all-electric home--one having at least one of all electric appliances considered in our calculations. These figures are the maximum inflicted on a household, reaching their peak at 51.8¢ on a winter day during peak periods.

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*See Tables 1.6 and 1.9.

Table 2.11. Comparison of Memphis and Knoxville with TVA Region: Average Load, Value of Lost Electricity, and Cost of 1-Hour Outage in Winter Months

Region	Average Load per Thousand (kWh)	Value of Electricity (¢/kWh)	Cost of 1-Hour Outage (¢)
TVA, on peak	3.78	13.1	39.40
TVA, off peak	3.39	12.6	32.23
Knoxville, on peak	4.99	11.8	45.54
Knoxville, off peak	4.44	11.5	39.22
Memphis, on peak	2.45	14.3	28.30
Memphis, off peak	2.15	13.9	24.10

Table 2.12. Comparison of Average Load, Value of Lost Electricity, and Cost of 1-Hour Outage for All-Electric Homes and the Typical TVA Home

Household	Average Load per Household (kWh)	Value of Electricity (¢/kWh)	Cost of 1-Hour Outage (¢)
All-Electric			
Summer, on peak	2.86	15.6	35.57
Summer, off peak	2.40	15.1	31.19
Winter, on peak	6.26	11.0	51.78
Winter, off peak	5.64	10.1	41.96
TVA Average			
Summer, on peak	2.34	16.1	31.32
Summer, off peak	2.00	16.8	28.27
Winter, on peak	3.78	13.1	39.40
Winter, off peak	3.39	12.6	32.23

CHAPTER 3. THE COST OF ELECTRIC POWER OUTAGES--UPPER-BOUND ESTIMATES BASED ON THE VALUE OF PRODUCTION IN THE HOME

In this chapter we apply the theory of household service valuation to develop a series of outage estimates for the residential sector. Estimates of the value of household services are based upon the time that individuals in various demographic categories allocate to these activities. Outage values for the TVA region are then constructed on the basis of the loss of household production during specified outages. In this chapter we describe the underlying methodology and apply this means of assessing outage costs to the United States as a whole and to the Tennessee Valley.

GENERAL METHODOLOGY

Household service valuation estimates were made as early as 1929 (see Hawrylyshyn, 1976). There are two primary methods of transforming time spent on household tasks into value estimates: the market cost approach and the opportunity cost approach (see Hawrylyshyn, 1976; Murphy, 1978). In the market costs or market alternatives approach, the wage rate of individuals performing the market counterpart of tasks performed in the home is used. In this method it is assumed that a replacement is hired for each separate function of household activities, such as cooking and washing clothes. The expression for the approach is

$$H = P \times \sum_{i=1}^{n} (QT_i W_i),$$

where H = daily value of housework

QT_i = hours per day devoted to household function i

W_i = hourly rate in the market for occupation corresponding to function i

n = number of household functions

P = number of household workers.

In the opportunity cost approach it is assumed that the individual has rationally allocated time to household work such that at the margin the value of this work is equal to the individual's market wage or opportunity cost. The marginal value of time is different for males and females and is adjusted for taxes. The formula is

$$H = QTWP,$$

where H = daily value of housework
QT = hours devoted to housework daily
W = opportunity cost wage of relevant individuals (adjusted for taxes)
P = number of household workers.

Despite differences in the method, national studies show considerable agreement between the results. Application of both methods to the TVA area resulted in the market cost approach giving an estimate that is 92 percent of the opportunity cost estimate.

APPLICATION TO THE UNITED STATES

Table 3.1, based upon national data, presents the average daily hours of household work, by task and by employment status, of men and women. Table 3.1 was multiplied by U.S. population factors for each category of employment status, sex, and family status to obtain Table 3.2, which presents total daily hours of household work in each category.

To obtain opportunity cost estimates, the row totals of Table 3.2 were multiplied by the opportunity cost wages shown in Table 3.3. These marginal wages are specific to gender, marital, and family status and have been adjusted to reflect marginal tax rates. Aggregating the value of hours by these classifications of individuals yields a total daily value of household production for the United States of $1,817,000,000. This number will be used below to develop outage evaluation estimates.

Table 3.1. Daily Hours of Household Work by Task, Employment Status, Marital Status, Family Status for Men and Women

Group	Food Preparation	House Upkeep	Clothing Maintenance	Family Care	Other[a]
Women employed/with children					
Married	1.8	1.4	1.1	0.9	0.8
Single	1.8	1.4	1.1	0.9	0.8
OMS[b]	1.8	1.4	1.1	0.9	0.8
Women employed/without children					
Married	1.3	0.9	0.6	0.1	0.8
Single	0.5	1.1	0.3	0.2	0.6
OMS	0.5	1.1	0.3	0.2	0.6
Women not employed/ with children					
Married	2.3	1.7	1.3	1.8	1.1
Single	2.3	1.7	1.3	1.8	1.1
OMS	2.3	1.7	1.3	1.8	1.1
Women not employed/ without children					
Married	2.0	1.5	1.1	0.1	0.9
Single	1.1	2.0	0.7	0.9	0.6
OMS	1.1	2.0	0.7	0.9	0.6
Men					
Married	0.1	0.5	0.0	0.1	0.4
Single	0.2	0.2	0.1	0.0	0.3
OMS	0.2	0.2	0.1	0.0	0.3

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[a] Other includes marketing, bookkeeping, household management.

[b] OMS = Other Marital Status: widowed, divorced.

Sources: Kathryn E. Walker, "Household Work Time: Its Implications for Family Decisions" *Journal of Home Economics* (1973), pp. 7-11.

Table 3.2. Daily Hours of Household Work by Task, Employment Status, Marital Status, Family Status for Total U.S. Population

Group	(1) Est. Pop. by Category (10^3)	Hours of Household Work (10^3)					
		(2) Food Preparation	(3) House Upkeep	(4) Clothing Maintenance	(5) Family Care	(6) Other	Totals, Rows 2 through 6
Women employed/with children							
Married	12,056	21,700	16,900	13,300	10,900	9,650	72,500
Single	391	704	547	430	352	313	2,350
OMS	2,962	5,332	4,150	3,260	2,670	2,370	17,800
Women employed/without children							
Married	10,564	13,700	9,510	6,340	1,060	8,450	39,100
Single	9,549	4,780	10,500	2,870	1,910	5,730	25,800
OMS	4,627	2,310	5,090	1,390	925	2,780	12,500
Women not employed/with children							
Married	12,709	29,200	21,600	16,500	22,900	14,000	104,000
Single	522	1,200	887	679	940	574	4,280
OMS	1,841	4,234	3,130	2,390	3,310	2,030	15,100
Women not employed/without children							
Married	12,910	25,800	19,400	14,200	1,290	11,600	72,300
Single	7,102	7,810	14,200	4,970	6,390	4,260	37,600
OMS	9,454	10,400	18,900	6,620	8,510	5,670	50,100
Men							
Married	48,255	4,830	24,100	0	4,830	19,300	53,100
Single	21,105	4,220	4,220	2,110	0	6,330	16,900
OMS	7,533	1,510	1,510	753	0	2,260	6,030
Totals		138,000	155,000	75,800	66,000	95,300	

Table 3.3. Calculation of Total Daily Value of Household Services for TVA Region, 1978, Opportunity Cost

Sex and Marital Status	Total Hours[a] (10^3)	Hourly Rate[b]	Total Value (10^3)
Married women (one income)	235,000	$3.29	$ 773,000
Married women (two incomes)	52,600	2.95	155,000
Single women (no children)	126,000	3.27	412,000
Single women (with children)	39,500	3.27	129,000
Married men (one income)	28,000	4.89	137,000
Married men (two incomes)	24,900	4.40	110,000
Single and OMS men	22,900	4.40	101,000
Total daily value			$1,817,000

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[a] Derived from Table 3.2; assumes .471 of married couples have two incomes.

[b] After adjustment for taxes.

To obtain market cost estimates, the hours spent on household tasks shown in Table 3.2 were summed vertically. These were in turn valued according to gender at prevailing market wages for persons performing similar tasks; Table 3.4 presents these average hourly wages by gender. The resulting value of $1,692,000,000 calculated in Table 3.5 represents the market approach value of all housework done in the United States on a typical day in 1978.

IMPLICATIONS FOR OUTAGE VALUATION IN THE UNITED STATES

The value of an electrical outage, considered in terms of the total daily value of lost household services, will vary substantially depending upon the assumptions about the outage. For the largest of the upper-bound estimates, assume that an outage interrupts all housework and that housework takes place within a daily 10-hour period. The 10-hour period represents an average of the 8 hours available for housework by employed individuals and the 12 hours available to those who are not in the labor force. Thus, a 1-hour outage will interrupt one tenth of the total daily housework valued at $1,817,000,000 or at $1,692,000,000 depending upon whether the opportunity cost or market cost approach is used. When the resulting total cost of a 1-hour interruption ($182,000,000 and $169,000,000) is divided by the 1978 hourly average electricity use of 230,342,470 kWh, the resulting upper-bound estimates are $0.79 and $0.73 per kWh.

However, more realistic scenarios can be drawn. First, assumptions can be made that will account for the marked difference in outage valuation depending upon time of day. This is particularly significant because 46 percent of the total household work hours are contributed by employed individuals. Their household activities are limited to an 8-hour period during the work week; therefore, an outage during the workday will have no effect upon their household production, and a 1-hour outage during the evening or early morning hours will represent proportionally more of their total

Table 3.4. Average Hourly Wages Year-round, Full-Time Civilian Workers, by Sex, 1978, Current Dollars

Bureau of Labor Statistics Classification	Average Hourly Wage Rate		Household Task
	Women	Men	
Cooks (not in private households)	$2.79	$3.43	Food preparation
Cleaning service workers	3.06	4.00	House upkeep
Laundry and dry cleaning operators	3.03	5.27	Clothing maintenance
Private household workers (living in)[a]	2.65	2.65	Family care
Housekeepers: not in private households	3.41	3.83	Women $3.71 Men $4.98 Other
Accounting clerk, Class B	4.01	6.12	

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[a] Inadequate sample size; minimum wage for 1978 assumed.

Source: Private correspondence with U.S. Bureau of Labor Statistics.

Table 3.6. Calculation of the Cost of 1-Hour Outage for the United States, 1978, by Time of Outage

Category	(1) Total Hours Household Activity(10^3)	(2) Oppor- tunity Cost	(3) Total Value of Household time ($\$10^3$) (Col. 1x2)	(4) % of Avail- able Household Hours Repre- sented by 1- Hour Outage 4 to 10 pm or 6 to 8 am	(5) Value ($\$10^3$) of 1- Hour Outage Occurring 4 to 10 pm or 6 to 8 pm (Col. 3x4)	(6) % of Available Household Hours Repre- sented by 1- Hour Outage Occurring 8 am to 4 pm	(7) Value ($\$10^3$) of 1- Hour Outage Occurring 8 am to 4 pm
Women employed with children							
Married	72,500	3.23	234,000	12.50	29,300	0	0
Single & OMS	20,200	3.27	65,100	12.50	8,140	0	0
Women employed without children							
Married	39,100	3.23	126,000	12.50	15,800	0	0
Single & OMS	38,300	3.27	125,000	12.50	15,600	0	0
Women not employed with children							
Married	104,000	3.23	336,000	8.33	28,000	8.33	28,000
Single & OMS	19,300	3.27	63,000	8.33	5,250	8.33	5,250
Women not employed without children							
Married	72,300	3.23	234,000	8.33	19,500	8.33	19,500
Single & OMS	87,700	3.27	287,000	8.33	23,900	8.33	23,900
Men Employed							
Married, one income	28,100	4.89	137,000	12.50	17,100	0	0
Married, two incomes	25,000	4.40	110,000	12.50	13,800	0	0
Single & OMS	28,600	4.40	126,000	12.50	15,800	0	0
Total					192,000		76,700

Table 3.7. Calculation of Total Value of 1-Hour Outage, Relaxing Total Activity Cessation Assumption

Activity	(1) % of Activities Lost During a 1-Hour Outage	(2) Total Value ($$10^3$) of Daily Activity		Value Lost to 1-Hour Outage ($$10^3$) (1) x (2) x 1/10	
		Female	Male	Female	Male
Food preparation	70	354,000	36,400	24,800	2,550
Household upkeep	66.6	383,000	119,000	25,500	7,930
Clothing maintenance	90	221,000	15,100	19,900	1,360
Family care	40	162,000	12,800	6,480	512
Other	90	250,000	139,000	22,500	12,500
Total		$1,370,000	322,000	99,200	24,900
				$124,100	

lower bounds. Table 3.8 summarizes the estimates of the cost of an outage per kilowatthour calculated on the basis of household service valuation.

APPLICATION TO THE TENNESSEE VALLEY

The methods used to estimate outage values for the Tennessee Valley are paralleled to those used in the previous section for outage valuation in the United States. Table 3.1, based upon national data, was multiplied by TVA area population estimates in each category of employment status,

Table 3.8. Summary of Residential Upper-Bound Estimates for the United States

Values for 1-Hour Outage	Method	Key Assumptions
$.79/kWh	Opportunity cost	All activities cease with outage; 10-hour availability; no differentiation among hours of day
.73/kWh	Market cost	All activities cease with outage; 10-hour availability; no differentiation among hours of day
.83/kWh	Opportunity cost	Outage occurs during nonworking hours; all activities cease with outage; 8-hour availability for employed; 12-hour availability for unemployed
.33/kWh	Opportunity cost	Outage occurs during working hours; all activities cease with outage; 8-hour availability for employed; 12-hour availability for unemployed
.54/kWh	Market cost	Some activities continue in part during outage. No differentiation into working/nonworking hours
.38/kWh	Eclectic average	Outage occurs during working hours; some activities continue

sex, and family status to obtain Table 3.9, which presents total daily hours of household work in each category. To obtain opportunity cost estimates, the row totals of Table 3.9 were multiplied by the TVA region opportunity cost wages shown in Table 3.10. Again, these marginal wages are specific to gender, marital, and family status and have been adjusted to reflect marginal tax rates. Aggregating the value of hours by types of individuals yields a total daily value of household production for the region of $56,000,000.

To obtain the market cost estimates, the hours spent on market tasks shown in Table 3.9 were summed vertically. These were in turn valued by gender at prevailing market wages for persons performing similar tasks. Because market wage data for the TVA district are inadequate, the national wage averages shown in Table 3.4 were used. As the wages for these occupations on the national level are quite close to the minimum wage for 1978, it is felt that the wages closely reflect the wage rates for the TVA region. Table 3.4 presents these average hourly wages by gender. The resulting value of $57,800,000 represents the market approach value of all housework done in a typical day in 1978 in the TVA region. As in the calculations for the United States, it is assumed that an outage interrupts all housework and that housework takes place within a daily 10-hour period. Thus, a 1-hour outage will interrupt one-tenth of the total daily housework valued at $56,000,000 or at $57,800,000, depending upon whether the opportunity cost or market cost approach is used. When the resulting total cost of a 1-hour interruption ($5,600,000 and $5,780,000) is divided by the 1978 hourly average electricity use of 4,323,516 kWh, the resulting upper-bound estimates are $1.30 and $1.34 per kWh.

As in the national case, assumptions can be made that will account for the marked difference in outage valuation depending upon time of day. Table 3.11 shows the calculations based on the opportunity cost approach, supporting a total outage valuation for a 1-hour outage during two time intervals. Column 4 lists the percentage of available household hours represented by a 1-hour outage occurring during nonworking hours: for the

Table 3.9. Daily Hours of Household Work by Task, Employment Status, Marital Status, Family Status for Total TVA Area Population

		Hours of Household Work					
Group	(1) Est. TVA[a] Population by Category	(2) Food Preparation	(3) House Upkeep	(4) Clothing Maintenance	(5) Family Care	(6) Other	(7) Totals, Rows 2 through 6
Women employed/with children							
Married	411,396	741,000	576,000	453,000	370,000	329,000	2,470,000
Single	13,235	23,800	19,000	14,600	11,900	10,600	79,900
OMS	100,919	182,000	141,000	111,000	90,800	80,700	605,000
Women employed/without children							
Married	360,661	469,000	325,000	216,000	36,000	289,000	1,340,000
Single	325,918	163,000	359,000	97,800	65,200	196,000	881,000
OMS	157,729	79,000	173,000	47,300	31,500	94,600	425,000
Women not employed/ with children							
Married	434,006	998,000	738,000	564,000	781,000	477,000	3,560,000
Single	17,647	40,600	30,000	22,900	31,800	19,000	144,000
OMS	62,868	145,000	107,000	81,700	113,000	69,200	516,000
Women not employed/ without children							
Married	440,624	881,000	661,000	485,000	44,100	397,000	2,470,000
Single	242,647	267,000	485,000	170,000	218,000	146,000	1,290,000
OMS	322,610	355,000	645,000	226,000	290,000	194,000	1,710,000
Men							
Married	1,646,998	165,000	823,000	0	165,000	659,000	1,812,000
Single	720,334	144,000	144,000	72,000	0	216,000	576,000
OMS	257,110	51,000	51,000	25,700	0	77,100	205,000
Total							18,100,000

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[a] Categorized from national ratios.

Table 3.10. Calculation of Total Daily Value of Household Services for TVA Region, 1978, Opportunity Cost

Sex and Marital Status	Total Hours[a]	Hourly Rate[b]	Total Value
Married women (one income)	8,050,000	$3.03	$24,400,000
Married women (two incomes)	1,790,000	2.67	4,780,000
Single women (no children)	4,302,000	2.89	12,430,000
Single women (with children)	1,346,000	2.89	3,890,000
Married men (one income)	959,000	4.31	4,130,000
Married men (two incomes)	853,000	3.89	3,320,000
Single men	781,000	3.89	3,040,000
Total daily value			$56,000,000

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[a] Derived from Table 3.9; assumes .471 of married couples have two incomes.

[b] After adjustment for taxes.

Table 3.11. Calculation of the Cost of 1-Hour Outage for TVA Region, 1978, by Time of Outage

Category	Total Hours Household Activity	Opportunity Cost	Total Value of Household Time (Col. 1x2)	% of Available Household Hours Represented by 1-Hour Outage 4 to 10 pm or 6 to 8 am	Value of 1-Hour Outage Occurring 4 to 10 pm or 6 to 8 am (Col. 3x4)	% of Available Household Hours Represented by 1-Hour Outage Occurring 8 am to 4 pm	Value of 1-Hour Outage Occurring 8 am to 4 pm
Women employed with children							
Married	2,470,000	2.86	7,060,000	12.50	$ 883,000	0	0
Single & OMS	686,000	2.89	1,980,000	12.50	248,000	0	0
Women employed without children							
Married	1,340,000	2.86	3,830,000	12.50	479,000	0	0
Single & OMS	1,310,000	2.89	3,790,000	12.50	474,000	0	0
Women not employed with children							
Married	3,560,000	3.03	10,800,000	8.33	900,000	8.33	$ 900,000
Single & OMS	660,000	2.89	1,910,000	8.33	159,000	8.33	159,000
Women not employed without children							
Married	2,470,000	3.03	7,480,000	8.33	623,000		623,000
Single & OMS	3,000,000	2.89	8,670,000	8.33	722,000		722,000
Men Employed							
Married, one income	958,000	4.31	4,130,000	12.50	516,000	0	0
Married, two incomes	853,000	3.89	3,320,000	12.50	415,000	0	0
Single & OMS	781,000	3.89	3,040,000	12.50	380,000	0	0
Total					$5,800,000		$2,400,000

employed it represents one-eighth or 12.5 percent; for the nonemployed it is one-twelfth or 8.3 percent. As in the case for the United States, these percentages are multiplied by the total value of housework time (column 3) and summed vertically to obtain the \$5,800,000 total value of a 1-hour outage during that time interval. When divided by daily electrical use, this value averages \$1.34 per kWh. Similarly, column 7 shows the percentage of the available household hours of an outage occurring during working hours; after multiplying these percentages by the total value of housework time in column 3, the resulting value, \$2,400,000, is the total value of a 1-hour outage. This averages \$0.56/kWh.

As in the national calculations, further refinement of the market cost method can be made by adjusting for the effect of an outage upon individual activities. Table 3.12 shows the proportions of activities that cannot be carried out during an outage. The resulting valuation is \$3,080,000 or \$0.71 per kWh.

The cost of outage per kilowatthour is further reduced when the hour-of-day adjustment is coupled with a relaxation of the assumption that all activity ceases. An outage during working hours under the cessation assumptions of Table 3.12 would have a cost of approximately \$1,700,000 or \$0.39 per kWh, further closing the gap between upper and lower bounds. Table 3.13 summarizes the estimates of cost of outage per kilowatthour which were calculated on the basis of household service valuation for the Tennessee Valley.

Table 3.12. Calculation of Total Value of 1-Hour Outage, Relaxing Total Activity Cessation Assumption, TVA Region

Activity	(1) % of Activities Lost During a 1-Hour Outage	(2) Total Value of Daily Activity		(3) Value Lost to 1-Hour Outage[a] (1) x (2) x 1/10	
		Female	Male	Female	Male
Food preparation	70	$12,100,000	$1,240,000	$ 847,000	$ 86,800
Household upkeep	66.6	13,000,000	4,080,000	866,000	272,000
Clothing Maintenance	90	2,490,000	515,000	224,000	46,400
Family care	40	2,080,000	436,000	83,200	17,400
Other	90	2,300,000	4,740,000	207,000	427,000
Total				2,230,000	850,000
				$3,080,000	

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[a] Assumes 10 hours available for housework.

Table 3.13. Summary of Residential Upper-Bound Estimates, TVA Region

Values for 1-Hour Outage	Method	Key Assumptions
$1.30/kWh	Opportunity cost	All activities cease with outage; 10-hour availability; no differentiation among hours of day.
1.34/kWh	Market cost	All activities cease with outage; 10-hour availability; no differentiation among hours of day.
1.34/kWh	Opportunity cost	Outage occurs during nonworking hours. All activities cease with outage; 8-hour availability for employed; 12-hour availability for unemployed.
.56/kWh	Opportunity cost	Outage occurs during working hours. All activities cease with outage; 8-hour availability for employed; 12-hour availability for unemployed.
.71/kWh	Market cost	Some activities continue in part during outage. No differentiation into working/nonworking hours.
.39/kWh	Eclectic average	Outage occurs during working hours; some activities continue.

CHAPTER 4. FURTHER CONSIDERATIONS: MITIGATION ACTIVITIES AND THE OUTAGE FREQUENCY-DURATION TRADEOFF

When the range of inquiry is broadened beyond the immediate valuation of outages, several aspects of behavior and preference become important to outage-related planning. This chapter deals with two of those considerations: first, the incorporation of backup energy supplies and other activities to mitigate the effects of electricity shortages into the assessment; and second, the development of a framework to analyze the tradeoff between the frequency of outages and their duration.

A FRAMEWORK FOR THE INCORPORATION OF MITIGATION ACTIVITIES IN THE LONG-RUN EVALUATION OF OUTAGES

In the long run, the potential responses of the household to an electrical outage widen in scope because the longer time frame allows, for example, changes in appliance stock and other equipment to mitigate outages. This and other factors interact to make outage evaluation in the long run difficult. First, an accounting of costs must treat the effect of outage mitigation upon the costs of outages. Second, the method must allow for behavioral response as well as for shifts in capital stock. Third, the examination must consider the effects of these preparations on the outage event as well as the differing nature and amount of damages associated with the long-run framework.

Two categories of costs comprise of total long-run outage costs. The first is the economic loss or damage of the outage, and the second is the cost of damage mitigation, i.e., the cost of alternatives to incurring the full cost of the outage. In the extreme, one measure precludes the other, as in the cases of maximum damage with zero mitigation or maximum mitigation with zero damage. However, discrete levels of substitution can take place between these two extremes, yielding an optimal balance between mitigation costs and damage costs. This mitigation framework can be used to yield minimum total outage cost after consideration of long-run responses to outages. Mitigation, such as the purchase of generating capacity, is obviously a long-run measure that reduces damage. However, because of the nature of outages, the damage that remains after partial mitigation must be evaluated as if additional changes to capital or appliance stock were impossible. This framework is therefore a conceptual mixture of the long and short run.

Figure 4.1(a) depicts a hypothetical outage damage function which relates outages to the degree of mitigation selected. The horizontal axis measures the percent of peak use supplied by alternative means during an outage. The relationship shows maximum damage at 0 percent mitigation and zero damage at 100 percent mitigation; in this hypothetical case a continuous substitution characterizes the relationship between extremes. Similarly, the cost of the mitigation function is the annualized purchase and operating costs of alternatives to outages at various levels of mitigation. The third curve, the total cost of the outage, is a vertical summation of the cost of damages and the cost of mitigation. Movement along this curve from left to right reflects the substitution of mitigating alternatives for the costs of damage. The optimal mix can be found at the minimum point of the total cost of the outage curve. At optimum, OQ_2 percent mitigation will be purchased, allowing Q_2Q_3 percent to be unmitigated and accordingly to incur damages. In this optimal arrangement, the total cost of the outage is OC_3, comprised of OC_1 of mitigation costs and C_1C_2 of damage costs.

The optimal mix can also be found by determining the marginal cost of damage and the marginal cost of mitigation and solving for the level of mitigation at which these two marginal functions are equal, as in Figure 4.1(b). To the left of the point of optimization, the marginal cost of mitigation is less than the marginal cost of damage; to the right of this point, mitigation is more costly at the margin than the acceptance of the remaining damages. In this case also, the optimal level of mitigation would entail the purchase of equipment to provide OQ_2 percent mitigation.

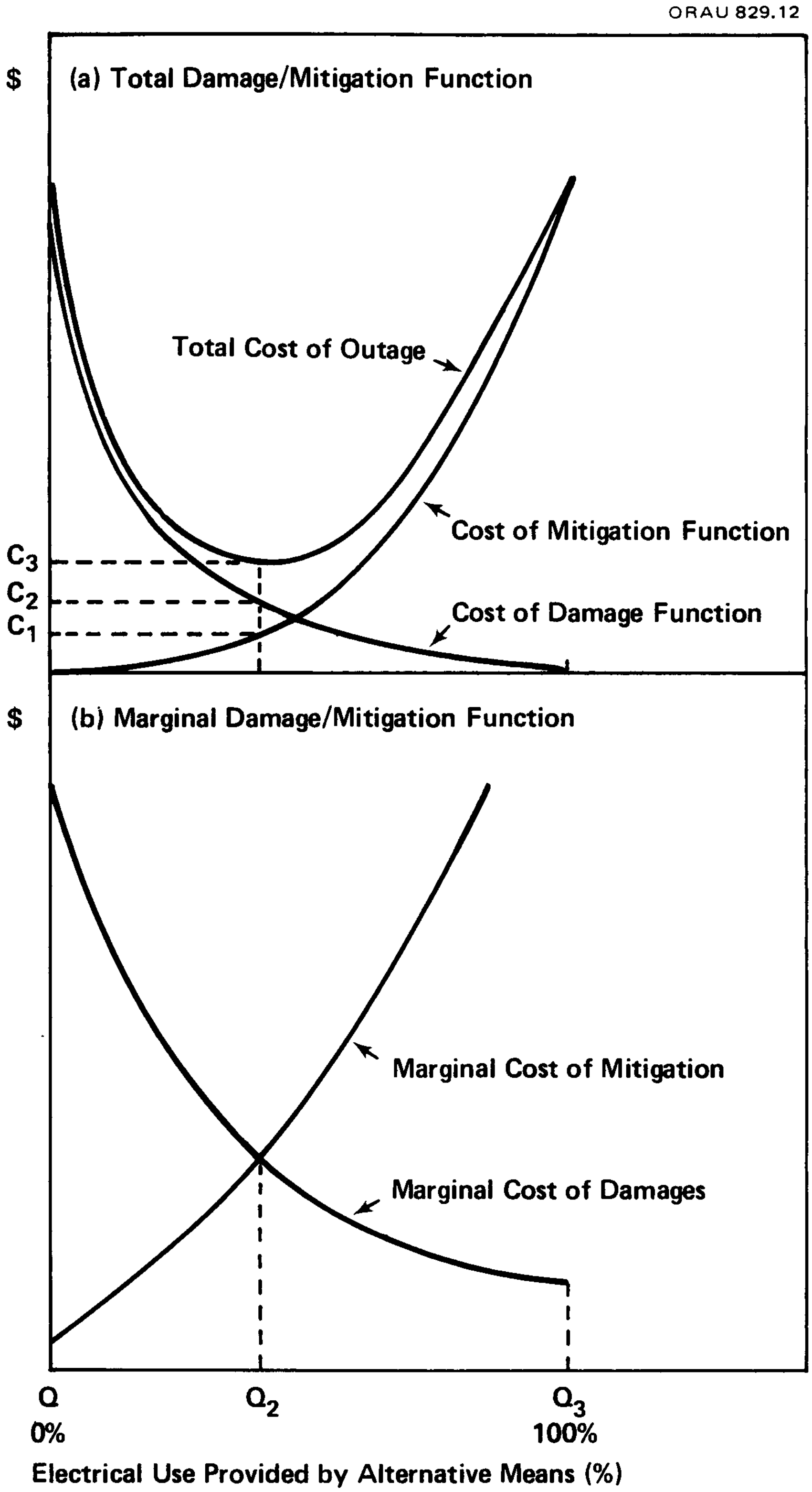

Figure 4.1. Percent of Electrical Use Provided by Alternative Means

If the duration of outages is limited to less than 8 hours, the application of consumer surplus data to the mitigation framework is appropriate. For durations of greater length, physical damage in addition to discomfort sets in, so that the sole use of consumer's surplus measures is not appropriate in those cases.

To approximate the mitigation cost function, it is assumed that alternative generation of electricity is the most perfect substitute for on-line electrical service. Table 4.1 presents costs for backup electricity based upon the fuel and capital costs of residential-sized electricity-generating units of three manufacturers; these costs are arrayed according to the total annual hours of outage. If capital costs are prorated over the hours of use, costs per kilowatthour decline significantly with more hours of outage. Similarly, costs per kilowatthour fall as the generator capacity increases, manifesting economies of scale in generation.

As for the cost of the damage function, a marginal approach entails the ordering of appliances by loss of consumer's surplus for an outage of specified length. This measure incorporates both elements of elasticity and of contribution to load. Those appliances that have relatively elastic demand curves would be at the right end of the horizontal scale of Figure 4.1(b), and those with inelastic demand curves would be ordered at the left, where they would be likely to receive the first few kilowatthours from a household backup generator.

Using the consumer's surplus formulation of Chapter 2, we designate the marginal contribution to outage value by appliance by the measure of $\bar{P} + \Delta P$, where $\bar{P}$ is the average price of electricity and $\Delta P = \bar{P}/\bar{e}$, where $\bar{e}$ is the elasticity of demand for electricity associated with that appliance. These calculations show that the categories with the highest marginal cost of outage are lights, refrigeration, and other, all with a marginal value ($\bar{P} + \Delta P$) of \$0.56. The highest marginal value would therefore be the decision criterion for the purchase of the first unit of alternative generation. In view of the generation costs shown in Table 4.1, the \$0.56 measure precludes any purchase of alternative generation, regardless

Table 4.1. Fuel and Capital Costs of Backup Electricity Generation for Specified Annual Hours of Outage[a]

($/kWh)

General Manufacturer	kW Rating	Hours of Outage 3	12	24	48	100
Honda	0.4	56.05	14.31	7.34	3.86	2.06
	1.0	28.20	7.28	3.78	2.04	1.13
	1.5	25.61	6.76	3.32	2.05	1.23
	2.5	20.04	5.19	2.72	1.47	.83
	3.5	16.69	4.35	2.28	1.25	.67
	4.5	16.12	4.22	2.23	1.23	.71
Kohler	1.75	15.52	4.09	2.19	1.24	.74
	2.25	13.32	3.55	1.92	1.10	.68
	3.5	11.34	3.02	1.63	.94	.58
	5.0	11.29	3.02	1.64	.95	.59
Onan	1.75	18.91	4.94	2.62	1.45	.85
	2.25	16.26	4.28	2.29	1.29	.77
	3.00	15.80	4.18	2.24	1.27	.77
	3.75	15.77	4.14	2.19	1.23	.73
	5.00	13.74	3.62	1.93	1.09	.65

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[a] Assumptions:

1. Capital costs assume: 15-year life, straight-line depreciation, zero value, all cash transaction, 12% capital charge/year. Fixed charge rate = .186
2. Gasoline price @ $1.20/gallon
3. Capital cost and fuel consumption from: "Emergency Electricity," <u>Mother Earth News</u>, September/October 1979.

of the annual hours of outage shown in Table 4.1. In graphical terms, the point portraying the first unit of mitigation is vertically higher than the associated first unit of damage. The rational long-run solution is to avoid the purchase of mitigation equipment and accept the damage caused by outages. This solution holds in all cases with less than 100 annual hours of outage. Beyond that level, mitigation might be purchased; however, that level of outages greatly differs from the parameters of reliability assumed in this study.* The solution is appropriate for outages lasting less than 8 hours. The reasoning behind this specification is explained in the next section.

IMPLICATIONS OF THE HOME PRODUCTION THEORY TO THE FREQUENCY-DURATION TRADEOFF

The theory of home production is based on the viewpoint that household management entails the production of intermediate goods and services, which in turn yield utility or satisfaction (Hill, 1978). Accordingly, electricity is viewed not as a consumer product but rather as an input into intermediate goods, such as "stocks" of clean dishes or clean clothing. This section describes the home production theory and examines the implications for the evaluation of outage duration.

Methodology

The home production process incorporates elements of transformation and of inventory maintenance. Transformation refers to the use of electricity as an input to produce a desired service or commodity. The inventory adjustment process entails storing the transformed product until it is used; accordingly, the household production model traces the fluctuation of

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*This conclusion of no widespread installation of backup electricity generation in response to continued blackouts does not preclude other, less expensive adjustments--candles, flashlight, a camp stove, or a good book to substitute for the TV set.

inventories between the maximum stock of the processed commodity and the minimum level at which reordering is signaled. Optimization of inventory policy is based on the interaction of the size of the inventory, storage costs, shortage costs, and reprocessing costs.

Time preferences are incorporated into the home production framework. Demand for a household commodity is postponable up to the point of minimum inventory; at minimum inventory, either the reorder process must commence or the costs of commodity shortage will be suffered. Accordingly, there are several elements of decision criteria: size of inventory, minimum level, storage costs, reorder costs, and the resultant shortage costs. Interaction of these elements results in a reorder interval, a measure of implied postponability. Postponability is a key element in the outage valuation process, in that activities that have long reorder intervals are easily postponed and are therefore unlikely to be a major basis of damage during an outage of less than 3 hours. Thus, short-term loss of clothes washing is less likely to be damaging than loss of a less easily "storable" activity such as TV viewing.

Table 4.2 explains the cost components and resulting inventories and reorder intervals. The term "shortage costs" refers to the ordering of damages from the postponement of the activities listed in the left-hand column. "Storage costs" refers to the costs of maintaining an inventory of the goods produced by the activity sufficient to postpone the activity. These costs range from small for those products in which an inventory can be easily maintained to high for products such as lighting. Reorder or fabrication costs have a fixed and a variable component; the fixed component is a function of the capital intensity of the production method. The size of the inventory, a function of these factors, determines the length of the reorder interval, a period of time in which an outage will not affect the household utility function.

The mitigation approach is consistent with the household production framework. The length of the reorder interval is implicit in the damage function; in outages of short duration those activites characterized by

Table 4.2. Inventory Cost Components and Implied Reorder Intervals

Activity	Shortage Cost	Storage Costs	Reorder Costs	Implied Inventory	Implied Reorder Interval
Clothes washing	Moderate & increasing	Small	Large fixed component	Large	Long
Dishwashing	Moderate & increasing	Small	Large fixed component depending on mode	Moderate	Moderate to long
Housecleaning	Small	Very small	Moderate fixed component	Moderate	Moderate
Air-conditioning	Moderate & increasing	Moderate & increasing	Small fixed component	Small	Short
Heating	Moderate & increasing	Moderate & increasing	Small fixed component	Small	Short
Refrigeration	Very large	Small	Small fixed component	Small	Short
Lighting	Moderate	Very high	Zero fixed component	Zero	Zero
Cooking	Large	Moderate & increasing	Large fixed component	Moderate	Moderate

Source: D. W. Hill, "Home Production and the Residential Electric Load Curve," Resources and Energy, North Holland Publishing Co. (1978), pp. 339-358.

long and moderate reorder intervals are of less importance to the damage function than activities of zero or short reorder intervals. Similarly, the mitigation cost function would encompass mitigating actions such as the increase in inventories of those activities for which storage costs are low.

Outage Duration and Damages

Within the context of the home production model, it is unlikely that those activities characterized by moderate and long reorder intervals will be major components of the damage function. Those activities characterized by a zero or a short reorder cycle require measures of inconvenience suffered, as opposed to estimates of permanent damage. Table 4.3 summarizes how time affects various activities in the home. Clothes washing, dish washing, and housecleaning need not be performed too frequently because of large "inventories"; space conditioning, refrigeration, and cooking have slight initial significance but grow steadily; TV and lighting cannot be stored and have the same (modest?) significance throughout.

The relationship between damage and the duration of the outage depends upon both technical characteristics of use as well as the consumer's per-

Table 4.3. Comparison of Cost Components of an Electric Power Outage of Increasing Duration, Effect on Cost as Outage Lengthens

Activity	Duration (hours) 0 to 3	3 to 8	8 to 24
Clothes washing	Slight	Slight	Slight
Dishwashing	Slight	Slight	Slight
House cleaning	Slight	Slight	Slight
Space conditioning	Slight	Increasing	Potentially large
Refrigeration	Slight	Increasing	Potentially large
Lighting	Modest	Modest	Modest
TV	Modest	Modest	Modest
Cooking	Modest	Increasing	Potentially large

sonal sense of discomfort. On this basis there are three ranges of duration that are appropriate classifications: 0 to 3 hours, 3 to 8 hours, and more than 8 hours. The first two ranges are distinguished by the number of functions affected and are quantified by measures of discomfort based upon loss of consumer's surplus; the third category of duration reflects the length of time required for the initiation of property damage and can be quantified by summing damages such as food spoilage and frozen plumbing.

Because of the physical aspects of electrical use, outages of 0 to 3 hours' duration are characterized by relatively low damage. Refrigerators and freezers adequately maintain cold temperatures over this period; heat inertia in structures minimizes changes in temperature, which often go unnoticed over this duration. As an example, Figure 4.2 shows a heat loss of 1.5° to 5.5°F from structures under the extreme winter conditions of outdoor temperatures which range from 5° to -4°F. Figure 4.3 relates awareness and discomfort to resulting indoor-temperature decreases. Note that 50 percent of the residents did not notice a 3° drop in temperature; 50

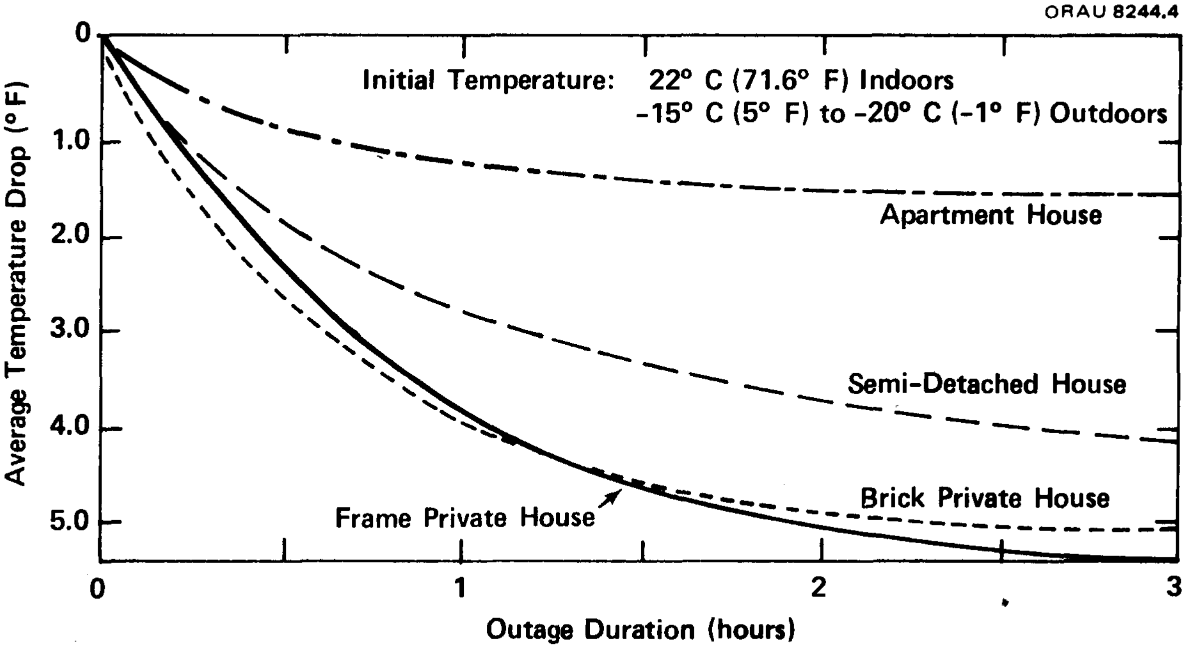

Figure 4.2. Temperature Decrease in Dwellings After Loss of Electricity for Heating

Source: Roger Brown et al., "The Worth of Electricity to Consumers: A Model Structure," Stanford Research Institute, Menlo Park, Calif., September 1979, p. 55.

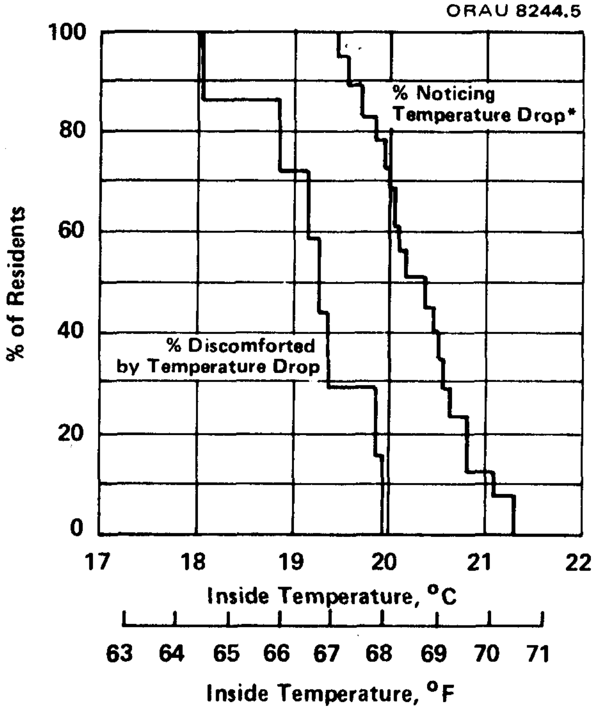

Figure 4.3. Effect on Resident Comfort in Buildings from Loss of Electric Energy for Heating

percent of the residents did not sense discomfort from a 5°F drop. Similar inertia applies to the air-conditioning of structures and to heating water. Under these circumstances, losses of five household functions are presumed to be negligible for an outage of 0 to 3 hours: space heating, space cooling, water heating, food freezing, and food cooling. In evaluating the outage of 0 to 3 hours, these functions are deleted from consideration as sources of potential loss of consumer's surplus. The remaining activities (of those that were listed in Table 2.9) are viewed as contributors to the loss of consumer's surplus. Accordingly, only activities of short and zero reorder interval would be aggregated in the evaluation of outage costs.

The same logic of the home production model can be used in selecting activities for the valuation of 3- to 8-hour outages. In this category of duration the reorder interval is exceeded for all activities. In this case also, as loss of activities requires measures of inconvenience rather than of permanent physical damage, the consumer's surplus by appliance would then be summed for all activities, with the measures contained in Table 2.9 adjusted for duration.

In evaluating outages of greater duration than 8 hours, quantification should be based upon the cost of physical damage plus lost consumer's surplus. If the mitigation approach were to be used, changes would also occur in the types of alternatives that are available over this long duration.

CHAPTER 5. SUMMARY OF FINDINGS AND IMPLICATIONS FOR FURTHER INQUIRY

FINDINGS

Table 5.1 summarizes the residential outage values generated as a result of this study. The values obtained look quite realistic on the basis of the available data. Costs are shown for homes in the TVA region differentiated on the basis of season, time of day, working versus non-working hours, and household functions interrupted by the outage. By changing parameters and assumptions, differences in appliance holdings could be illustrated, e.g., geographical differences and outage costs to all-electric homes. These findings can be summarized as follows:

1. Regardless of method or measure, the most costly outages occurred in the winter because of the space heating contribution. Summer outages were the second most costly because of air-conditioning. Fall and spring (when demand for heating is modest) were least costly. This finding holds for outages of both long and short duration.
2. Outages during peak periods were most costly in all seasons. This result depends on the definition of peak and off-peak periods as defined in the Knoxville time-of-day study. Use of the household production method demonstrated significantly lower outage costs during working hours when people were out of the home.
3. Shorter outages have lower costs per hour in the home. A number of short outages would be preferable to a lesser number of long outages. Because electric energy and its services cannot be stored, higher costs occur beyond a 3-hour duration; beyond 8 hours there is a significant potential for physical damage.
4. Within the TVA area, outages have greater impact on some locations than on others. For example, a winter outage is 61 percent more expensive in Knoxville than Memphis. The difference is due to the

Table 5.1. Summary of Residential Findings: Cost of 1-Hour Outage, TVA Region (cents)

Category	Winter		Spring		Summer		Fall	
	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak	On Peak	Off Peak
Seasonal Measures								
TVA area aggregate	50.00	45.00	21.00	21.00	30.00	36.00	26.00	24.00
Summation by appliance	39.40	32.23	20.60	22.06	31.32	28.27	26.30	23.45
All-electric home	51.78	41.96	-	-	35.57	31.19	-	-
Geographical measures (winter)								
TVA average	39.40	32.23						
Knoxville	45.54	39.22						
Memphis	28.30	24.10						

Upper bound measures by household production

130.00	All activities cease with outage; 11-hour availability; no differentiation among hours of day; opportunity cost method.
120.00	All activities cease with outage; 11-hour availability; no differentiation among hours of day; market cost method.
139.00	Outage occurs during nonworking hours. All activities cease with outage; 8-hour availability for employed; 14-hour availability for unemployed; opportunity cost method.
53.00	Outage occurs during working hours. All activities cease with outage; 8-hour availability for employed; 14-hour availability for unemployed; opportunity cost method.
65.00	Some activities continue in part during outage; no differentiation into working/nonworking hours; market cost method.
24.00	Outage occurs during working hours; some activities continue; electric average method.

greater electrification of Knoxville, especially in its use of electricity for space heat, water heating, and cooking.

5. The appliance inventory causes significant differences in outage costs among individual homes. Outage costs to all-electric homes in winter are 30 percent higher than outage costs in a typical TVA home. Space heating and water heating are large energy users and are responsible for at least part of the cost difference on the basis of their volume; smaller energy-consuming appliances adding significantly to the cost of an outage are the refrigerator and TV set.
6. The individual household showed no need to install backup electric generators on the basis of short, repeated outages. Up to 100 hours of such outages per year might not induce the consumer to install a generator. Other, less expensive steps will be taken (flashlight, candles, etc.) to offset the effects of the outage, and generators might be installed in anticipation of long, weather-related distribution outages. Short, frequent outages such as rotating blackouts are unlikely to induce a response.
7. Future changes in the cost of outages per household are likely to be tied to the penetration of electricity for space conditioning, water heating, and cooking.

AREAS OF FURTHER INQUIRY

The methodologies applied here can be developed and extended further if data are included that are or will soon be available to TVA. The Chattanooga Load Study is being extended to Knoxville, Nashville, Memphis, and Huntsville. This will provide data on household and commercial energy consumption by hour. It can be used to further confirm the results of this study that household schedules were too diverse to permit predictions of household appliance use by hour. The data can also be aggregated across hours and used much as the Knoxville data were used in this study. These data would be more flexible in application, however, as the on-peak and off-peak hours can be determined by the investigator. A second source of data is the Westat Survey, recently completed for households. It is a one-time study of 8000 homes throughout the TVA region. Some of the survey data have been cited in this report. These survey data can be used in much the same way as the Knoxville data if survey characteristics are matched with monthly billing data. No distinctions can be drawn on the basis of time of day; they can be drawn on the basis of season. Most importantly, the Westat Survey is a stratified sample drawn to be representative of the entire TVA region.

With new data the valuation of electric outages might be extended in other useful directions. Several possibilities are listed below.

Time-of-Day Studies

A good study of peak pricing by time of day could yield very useful results for outage valuations as well. Rationing electrical capacity by price is not the same as rationing by queuing with rotating blackouts, but such a study would yield insights if (unlike the Knoxville study) it were properly designed.

> — If several price levels were specified, it would be possible to compute elasticities of demand specific to each appliance by comparing appliance use in on-peak and off-peak periods. Because of the experimental and short-run nature of these studies, the responses would be largely behavioral rather than based on shifts in appliance stock.
>
> -- The elasticities by appliance can be used (as in this study) to compute outage costs.
>
> — A time-of-day pricing experiment might also be used to learn more about how behavioral adjustments over time improve the household's ability to manage electrical load. Since much of the response to price is behavioral, a study of the learning process (comparing first winter to second, first spring to second, etc.) might suggest how a household would manage load in the face of frequent blackouts. The ability to shift load from on-peak to off-peak requires an ability to "store" electricity--the same requirements as for weathering an outage.

Estimation of the Effects of Prior Notification

Surveys by Ontario Hydro and the Consumers Power Company of Jackson, Michigan, have pointed to a market preference on the part of consumers for prenotification of a potential outage (Samsa et al., 1978, pp. 37-41). Although the survey results showed a perception of reduced damages associated with various levels of notification, there was no attempt to place dollar values on damage thus avoided. Since notification allows for the maximization of household inventories and permits the planning of alternative activities, this option has the potential to significantly lower the damage function. It would be appropriate to attempt the evaluation of damage in a with/without notification format.

Inquiry into Institutional Aspects of the Long-Duration Damage Function

In the residential sector, outages of more than 8 hours may result in property damage. It is appropriate to inquire into the legal status of the power producer and distributor in such situations, as legal responsibility by either party would markedly shift the residential consumer's perceived damage function, possibly resulting in a different level of mitigation. Inquiry into the degree of insurance coverage for such property damage is appropriate for similar reasons; insurance premiums based upon such contingencies should be included in the quantification of the mitigation cost function.

More Complete Mitigation Function

Although residential power generation is the most perfect substitute, incorporation of nonelectric substitutes is appropriate to the accurate definition of the cost of the mitigation function, particularly in the cases of durations of 3 hours or more. Investigation into such nonelectric substitutes would include evaluation of alternative space-conditioning fuels, as well as consideration of the home production approach whereby increases in the inventories of household products (for example, more clean dishes) may reduce outage costs. These options can be used to place alternative upper bounds on the cost of continued outages in the long run.

Variation in Peak Definition

In this study, outage measures dealing with on-peak/off-peak periods were wedded to the definitions of the Knoxville study. Because of the importance of these definitions to the cost of outages, more careful consideration should be given to these definitions. As suggested above, the Chattanooga Load Survey (and surveys of the cities to which this study is being extended) might provide the basis for such an investigation.

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