Analytical Framework for Evaluating Energy and Capacity Shortages

EA-1215, Volume 2
Research Project 1104-1

Final Report, April 1980

Prepared by

JACK FAUCETT ASSOCIATES
5454 Wisconsin Avenue
Chevy Chase, Maryland 20015

Principal Investigator
E. J. Mosbaek

Prepared for

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
A. N. Halter

Supply Program
Energy Analysis and Environment Division

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NOTICE

Prepared by
Jack Faucett Associates
Chevy Chase, Maryland

ABSTRACT

This paper provides:

1. A methodology for estimating shortage costs.

2. Two examples of shortage costs:

   a. The 1976-77 winter shortfall in natural gas supply, and

   b. A 1978 spot shortage in electric power.

The methodology shows how to develop a comprehensive estimate of willingness-to-pay to avoid shortages -- a total comprised of the willingness-to-pay of producers, employees, consumers, and the general public.

The 1976-77 natural gas experience indicates that total costs per million Btu's of shortage (i.e., the cost for every Mcf of curtailment to non-residential users who are not normally curtailed) are $54 and $5 for capacity and energy shortages respectively. The electric power shortage indicates that total costs per million Btu's of shortage are $670 (i.e., a cost of $2.30 for every kWh of shortage to non-residential users).

EPRI PERSPECTIVE

PROJECT DESCRIPTION

Capacity and energy shortages can occur with both natural gas and electric power. A natural gas capacity shortage occurs when the pipes are too small to meet peak day demand. This is analogous to limited electrical generating capacity. A natural gas energy shortage occurs when winter weather creates a November-through-March demand that exceeds production and storage capabilities. An analogous situation for electricity would be when a coal strike limits electric power production, or when electric power plants are curtailed by a referendum or by another means.

Research Project (RP) 1104 investigated ways of assessing the economic and social costs of capacity and energy shortages. The research consisted of the following four parts: (1) a natural gas-shortage case study, (2) an electricity-shortage case study, (3) the development of the theoretical economic basis for valuing reliability to the consumer, and (4) the design of survey methods to obtain data before shortages occur.

Work from items 3 and 4 will be presented in forthcoming EPRI publications. Continuing work under RP1104 will include other case studies of energy shortages and the development of tools for using the impact cost estimates in utility planning.

PROJECT OBJECTIVE

The objective of this project was to develop general methodologies for assessing the economic and social costs of capacity and energy shortages. These assessment methods were applied to two energy-shortage case studies. One case study reviewed the natural gas shortage that occurred during the winter of 1976-77. The second studied the 1978 summer electricity shortage that occurred in Key West, Florida. (The factual results from these two case studies have been published as EPRI Report EA-1215, Volume 1; and EPRI Report EA-1241, respectively.) This report, Volume 2 of EPRI Report EA-1215, presents the details of the assessment methods as modified and improved after the experience of the two case studies. It also presents a summary of the factual information from the case studies.

PROJECT RESULTS

The methods developed in this project are a significant advance over previous work. No previous shortage impact study was found that incorporates the breadth of impacts and the care in avoiding double counting and overestimating. In this project, theoretical development went hand-in-hand with the conduct of the case studies. No formal, single, comprehensive model could be developed to include all shortage cost estimations. Submodels for cost estimations were developed to describe the complexity of the energy-user coping processes and of the diverse types, levels, and coverage of energy shortages.

Comparisons were made of shortage impacts between natural gas and electricity. A major distinction between shortages in natural gas and electric power is the difference in the ability of the user to select his highest priority use for each fuel. The natural gas user can allocate a share of his continuing supply to his highest priority, while the electric power user has no way to concentrate an interrupted supply. However, the electricity supplier may be able to arrange for allocation among users and thus offset the impacts of this lack of user options.

In the case study of the 1976-77 winter natural gas shortage, it was found that the total cost was $54 per million British thermal units (Btus) for capacity and $5 per million Btus for energy shortages. This was the cost of gas curtailment to nonresidential users who were not normally curtailed. In the Key West, Florida electricity shortage case study, it was found that the total cost for the comparable category of users was $670 per million Btus for shortages. This translates into a cost of $2.30 for every kilowatt hour of shortage to nonresidential users.

It is recommended that the improved methods developed in this project be utilized by government agencies as well as by private suppliers to quantify shortage impacts. Future capacity and energy shortages are likely to increase in number and severity. Unavoidable events (such as adverse weather and oil embargoes) are likely to cause short-run shortages. Also, efforts to curb costs and delay construction of electricity-generating plants and other energy plants are likely to cause short-run shortages. Because of the opportunities for reducing or eliminating shortage impact through governmental and private-sector coping mechanisms, it is vital to have available a shortage evaluation methodology to guide investment in the coping process.

A. N. Halter, Project Manager
Supply Program
Energy Analysis and Environment Division

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EXECUTIVE SUMMARY

Just as gross national product (GNP) is a careful accounting of value added by all sectors, shortage evaluation must be a careful accounting of value lost by all sectors including employees and consumers. But shortage evaluation must even go beyond GNP accounting -- it must account for consumers' and employees' loss in utility from disrupted production and it must account for the increase in producer costs for the same disruptions.

This methodology report is designed to delineate the careful accounting that is necessary and the special models that are desirable when estimating energy shortage impacts.

Observed Shortage Costs

The widespread natural gas shortage during the cold 1976-77 winter and the Key West electric power shortage during a one-month equipment breakdown were developed as case-studies. Shortage costs per unit of energy varied greatly, but the following costs of shortages provide an introduction to available estimates. (Note a kWh of electricity is 3412 Btu's, and an Mcf of natural gas is 1,000,000 Btu's.)

	Gas Shortage[a/]			
	Capacity	Energy	Gas Shortage Coping Costs[a/]	Power Shortage Impact Costs b/
1. Producers (Direct plus indirect gas users)	$49.95/Mcf	$5.28/Mcf	$0.96/Mcf	$ 2.00
2. Employees	4.50/Mcf	.03/Mcf	Not Applicable	.10
3. Consumers	Negligible	Negligible	Not Applicable	.20
4. Macro-effects	Negligible	Negligible	Not Applicable	Negligible
TOTAL	$54.45/Mcf	$5.31/Mcf		$2.30/Kwh

[a/] These estimates are for costs stemming from curtailment of users who are not normally curtailed -- e.g., large boiler users who are normally curtailed 100% every year between November 1 and March 31 are not included in this estimate.

[b/] These estimates are an average for all non-residential users. These users are somewhat accustomed to shortages up to a few hours' duration because of frequent storm-caused interruptions in Key West.

$54.45 is approximately 30 times the $2.00/Mcf market price for natural gas. The $2.30 is approximately 50 times the 5¢/kWh market price of electric power.

The 1976-77 natural gas situation was an energy shortage in that users were curtailed to a percentage of what was normally their allocation for November 1st through March 31st. It was also a capacity shortage during the approximately ten days when selected users were cut nearly 100% because the gas pipes were not large enough to meet the daily total demand. This distinction -- between energy shortages and capacity shortages -- has important implications for coping processes and shortage accounting, as will be apparent throughout this report.

Most shortages are complex situations with varying levels of shortages and varying durations of shortage among users. In fact, this large variation is a major reason why shortage cost estimates should be developed in detail. The large variation provides many opportunities for a spot market that would allow efficient and equitable energy transfers among users.

The methodology and estimates in this report show how shortage costs can be estimated much more accurately than has been done to date. These estimates, in turn, can guide decisions that will save billions of dollars of loss annually.

Major Perspectives

Energy shortage costs extend beyond the familiar impacts such as increased unemployment and reduced GNP. The intricate coping mechanisms of industrial and commerical users substantially reduces these impacts, but also generates significant costs in the process. Therefore, shortage cost estimation must be approached from three perspectives:

1. Consumer loss in utility from disrupted production (and availability of products) during a shortage.

2. Increased cost of production when and if the producer installs coping mechanisms because of the possibility of shortages.

3. Increased cost of production when and if an actual shortage occurs.

Any energy shortage methodology must include a detailed examination of the coping process itself from two perspectives:

1. Coping costs are a form of shortage costs; but they must be amortized over all shortages to be evaluated properly.

2. Each coping cost changes the shortage impact cost model; there is less unemployment and GNP reduction because of the effectiveness of the coping process during future shortages.

Extensive coal transportation, the electric power transfers, and users' purchase of portable generators during the 1977-78 coal strike illustrate the coping actions that can (1) cause higher coping process costs just because of the shortage probability that existed and (2) greatly reduce shortage impacts if the shortage occurs.

Shortage cost estimation is meaningful only if shortage evaluations start with the objective of estimating willingness-to-pay for avoiding shortages. No other objective will lead to the many types of impacts that must be considered. The willingness-to-pay concept also gives proper warning to avoid double counting and otherwise overestimate shortage impacts.

Whereas shortage coping costs are largely confined to direct users, shortage impact costs can be significant with four different groups, each with a unique perspective:

- Producer who idles capacity and boosts costs when production is curtailed or production is continued with more costly substitutions;

- Employee who loses income when producer curtails production;

- Consumer (user) of products who must wait or switch to more expensive products when production is curtailed; and

- Macroeconomic effects resulting from adverse economic conditions triggered by shortages and increased through the multiplier effect.

Evaluating losses in each group separately eliminates duplication and facilitates the comprehensive assessment of impacts.

Capacity and energy shortages must be evaluated differently. In an energy shortage, flexibility allows substantially more coping, which, in turn, decreases shortage impact cost per unit. Unlike energy shortages, capacity shortages occur in specific time periods. Further, they are imposed with little warning and generally affect high-priority users as well as the low-priority users who usually absorb all energy shortages. For example, during the January-February 1977 natural gas shortage, greater impacts resulted from the few days of capacity shortage among high-priority users than in the winter-long energy shortage for low-priority users, despite the latter's much larger shortfall.

Models in Estimating Methodology

An all-encompassing formal mathematical model for shortage impact estimation is of limited use. A set of flexible submodels is better; in fact, a flexible set of submodels is essential if shortage evaluations are to be both meaningful and accurate. The need for these models derives from: (1) the complexity in energy user coping processes and (2) diverse types and levels and coverage of energy shortages.

In a sense, the best shortage evaluation framework is an accounting system plus coefficients and equations for measuring different impacts in the shortage accounts for producers, consumers, employees and the general public. Just as GNP is a careful accounting of value added by resources in diverse economic sectors, impact assessment is a careful accounting of value lost by resources (producers, employees, and consumers) in numerous sectors where energy shortage impacts occur.

Although the Federal Government and certain states have endeavored to predict shortage impacts, their effort and approach have seldom met the need for good energy shortage evaluation. Each government effort is essentially focused on the immediate situation and is designed to help review the need for emergency government action. A major consequence is that the private sector coping process is not understood, and the costs of the private process are not included with impact estimates.

Industry and both Federal and State Governments have every incentive to identify impacts in terms of willingness-to-pay to avoid the situation. However, their methodology seldom includes the comprehensive evaluation necessary for influencing both short-run and long-run government and industry decisions.

The models readily available for Government agency and energy supplier use have been grossly inadequate, regardless of the professional help that accompany them. No one has even established the accounts that these estimation models should estimate, and, therefore, they have at best produced accounting impacts limited to GNP effects.

Recommendations

Typical shortage evaluations of the past should be expanded. The scope of both private- and government-sponsored shortage evaluation should include the following:

1. Identification of all shortage impacts, including shortage coping costs that are caused by the mere possibility of shortages.

2. A clear distinction between temporary and permanent losses in economic activity.

3. A summary of impacts in terms of best estimates of willingness-to-pay to avoid the totality of temporary and permanent losses.

The clear distinction between the private and public perspective becomes available with a breakdown in losses among groups. Therefore, each shortage evaluation should identify losses to each of the following groups (or specify that the losses were not considered):

1. Producers
   - direct energy users such as steel mills
   - indirect energy users such as auto manufacturers

2. Employees
   - of direct energy users (e.g., steel mill workers)
   - of indirect energy users

3. Consumers
   - (e.g., the purchaser of a new automobile)

4. General Public

- the persons affected by inflation, by recession caused by the economic multiplier, or by other factors initiated through shortage impacts.

By isolating each group separately, the inequities of impacts as well as possible incompleteness in impact assessment are more readily apparent.

Since employer surveys are likely to be desirable in each short-run energy shortage, the shortage impact analyst should take advantage of two factors. First, experience in interviews for this study can help develop the indepth and critical interviewing that is necessary [60, Appendix B; 65, Appendix C]. Second, the Bureau of Labor Statistics' current effort in designating a sub-sample of employers who regularly report employee layoffs can be extremely helpful [28]. The BLS effort means that a sample for collecting opinion on pending and actual impacts will be readily available.

Future capacity and energy shortages are likely to be sufficiently numerous to justify improved estimation and evaluation. On the one hand, unavoidable events (adverse weather and oil embargoes) are likely to cause short-run shortages because tighter energy supplies result in reduced short-run supply flexibility. On the other hand, efforts to curb costs and delay construction of electric generating and other energy plants are likely to cause short-run shortages as the marginal capacity (reliability) for satisfying peak demand is reduced. Therefore, Government agencies as well as private suppliers should have good shortage evaluation capability.

Because of opportunities to ameliorate shortage impacts through government and private sector coping mechanisms, shortage evaluation methodology should be substantially improved to guide investment in the coping process. Most importantly, it must include the willingness-to-pay estimates that should guide short-run and long-run decisions.

Chapter 1

EMPIRICAL ESTIMATES AND THEORETICAL CONCEPTS

This chapter is an overview of two sets of results: First, empirical estimates for both a gas shortage and an electric power shortage are presented. Second, the theoretical concepts for good shortage analysis are outlined.

The 1976-77 Natural Gas Shortage

Both the percentage cutback and the duration of cutback during this shortage varied greatly across the nation. Weather patterns caused higher demand peaks in some places; inventories prior to the 1976-77 winter season varied among companies; and supplier rules on when to deplete inventories varied among companies.

The case studies reported in this document cover the January-February peak demand period for four states:

Ohio - a major gas use area and a 1976-77 weather pattern that appears to have a probability of 1-in-100 years or less of happening again.

Kentucky - a small state where some suppliers were better prepared then most for winters such as that which occurred.

Tennessee - an area served by pipelines affected by adverse weather elsewhere on the pipeline.

Alabama - an area with severely restricted pipeline capacity.

The curtailment levels are described in Appendix A, but Figure 1 illustrates a typical set of cutbacks; namely, a 20 to 40% curtailment of total monthly supply for January and February combined with ten days of nearly 100% curtailment.

The respective curtailments are referred to as energy and capacity shortages, as shown in Figure 1. The significance for shortage impacts is that capacity shortages run close to 100% cutback and occur on precise days. An energy shortage forces the user to curtail sometime during the month.

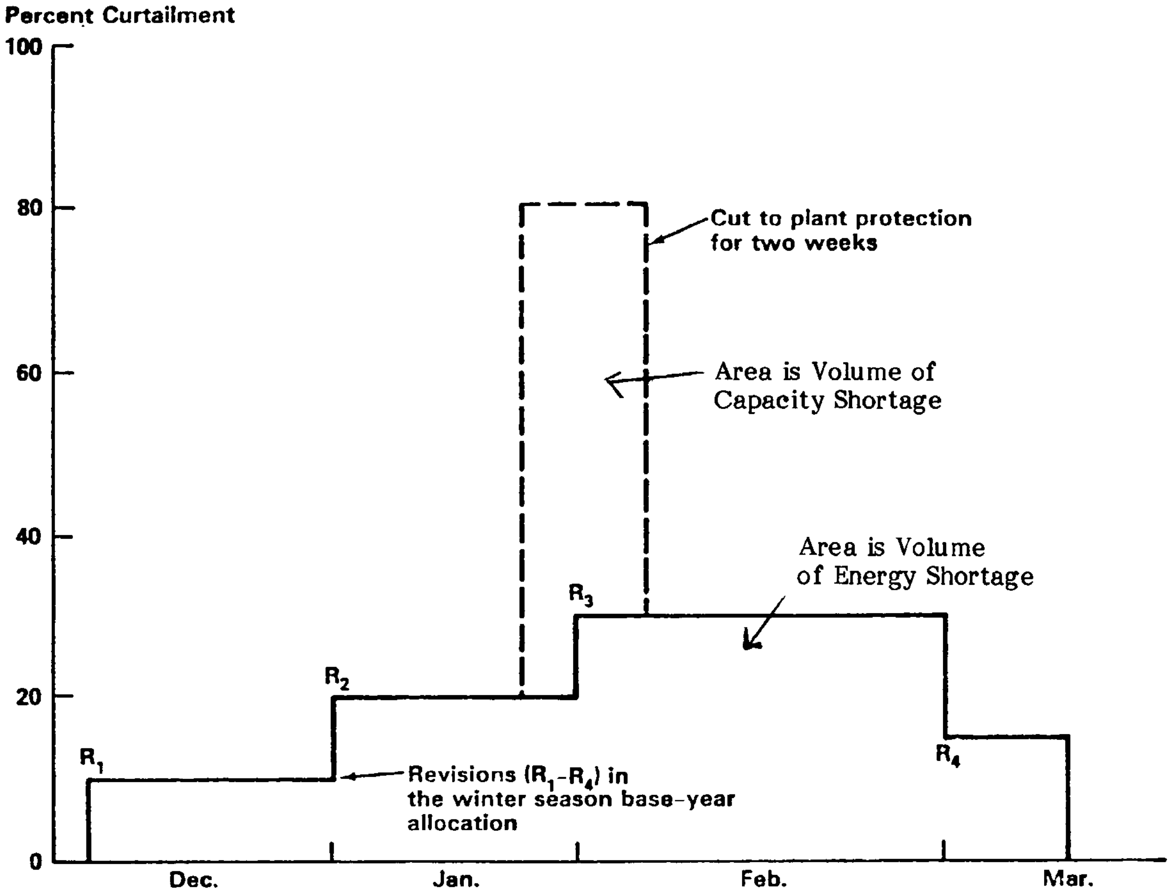


Figure 1: Energy and Capacity Curtailment

The empirical research on the 1976-77 natural gas shortage produced some startling realizations, as illustrated below:

- Approximately 20% of the shortage volume caused over 70% of the shortage impact costs; i.e., capacity shortages which cause curtailment to plant protection involved only 1/5 of the 1976-77 shortfall, but caused 70% of shortage impact costs.

- Shortage impact costs per million Btu's (or per Mcf) varied by more than a factor of 10 among states[1/] because of difference in shortage severity and types of consumers curtailed. The $54 average shortage cost per Mcf in a capacity shortage is about 30 times the market value of the gas.

- Shortage coping adds a signficiant cost to shortage impacts -- a cost that could be avoided if shortages were eliminated; coping cost cannot be estimated accurately from a single shortage, but there are indications that shortage coping costs can equal shortage impact costs in the present types of shortages.

- Eighty percent of shortage impact and shortage coping costs directly attributable to the 1976-77 shortage could very likely have been avoided; i.e., shortages could have been absorbed by selected users who can cope best. The justifiable compensation to these selected users would have been less than 20% of the actual 1976-77 shortage costs.

- Differences among industry sectors are not nearly as large as differences between users who had been curtailed previously (and prepared themselves), and users for whom the 1976-77 shortage was a new experience.

The above estimates are typical of a certain type of shortage; however, there are many types of shortages, as will be illustrated throughout this report. The proposed estimation methodology incorporates the background conditions that determine the type of shortage.

The 1976-77 case study gives the most information for the upper left in the useful classification of shortage types shown in Figure 2.

[1/] Variation among distribution companies in the four states was even greater because of difference in curtailment level; see Glossary for definitions of terms.

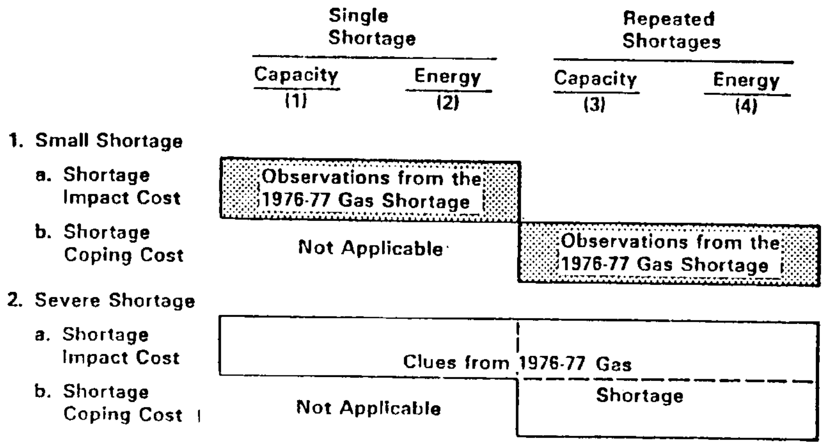


Figure 2: Shortage Classification

The methodology presented in Chapter 5 focuses on the upper left, Chapter 6 focuses on the lower left, and Chapter 7 focuses on the right. The important difference between small and severe shortages is that all costs in the former can be estimated at the direct-user facility. The important difference between a single shortage and a distribution of shortages is the probability function associated with the latter.

There are four groups affected by shortages and each has a willingness-to-pay to avoid shortages. Their losses include:

Producers -- extra costs in order to maintain production in spite of the energy shortage, or unrecovered costs if they lose potential sales.

Employees -- a loss in utility of income that is not included in the producers' willingness-to-pay.

Consumers -- a loss in satisfaction from delays and from forgoing consumption; the loss caused by unavailable products is not measured by employee or producer willingness-to-pay.

General Public -- the general public suffers inflation and economic multiplier impacts that are over and above the losses in the first three groups.

A comprehensive estimate of shortage must include all four groups without double counting -- i.e., it must include, but only include willingness-to-pay measures.

The following estimates of shortage costs among the four groups are probably typical for small shortages (i.e., the upper half of the above classification)[a/]:

	Shortage Impact Cost [a/]	Shortage Coping Cost [a/]
1. Producers (Direct plus indirect gas users)	$12.94/Mcf	Not Estimated
2. Employees	.74/Mcf	Not Applicable
3. Consumers	Negligible	Not Applicable
4. Macro-effects	Negligible	Not Applicable

The empirical study for this report involved lengthy interviews with approximately 100 natural gas users in each of four sample states - Ohio, Kentucky, Tennessee, and Alabama. Important state differences and economic sector variations are given in subsequent chapters.

The 1978 Electric Power Shortage

This case study describes a spot shortage in Key West, Florida. The local situation provided a unique opportunity to study shortage impacts because there was an approximately 25% curtailment in the peak 10 hours for each of 25 consecutive days. Because of its geographical location, the Key West utility has no interconnections with other utilities.

There are many measures that can be used, such as cost per user, cost per event, cost per capacity unit, and cost per energy unit. The best single measure and best summary is cost per kWh, because it can easily be translated into other measures. For example, an estimate of cost/kWh allows easier comparison between energy and capacity shortage, comparison among shortage events within electric power, and comparison among electric power and other energy shortages.

There are many significant details available only from the separate Key West shortage report [65], but Table 1 provides a useful summary.

[a/] These estimates are for costs stemming from curtailment of users who are not normally curtailed -- e.g., large boiler users who are normally curtailed 100% every year between November 1st and March 31st are not included in this estimate.

Table 1

ELECTRIC POWER SHORTAGE

(Key West, Florida - 1978)

	Cost/KWH	Cost For Total Shortage (1000)	Market Value[a/] Of Electricity (1000)	Shortage[b/] Level
• Goods and Service Production				4.8% for 26 days
Producers, (e.g., auto repair, stores, schools)	$2.00	$16,000	$1,042	
Employees				
Wage loss	.10	800		
Comfort	Insignificant			
Consumers	.20	1,600		
Macro-effects	Insignificant			
TOTAL	$2.30			
• End Use of Power			588	7% for 26 days
Residential comfort and convenience	.05	500		
Fires, freezing, etc. in home	Insignificant			
• Special				
Crime, looting, etc.	Insignificant			
Traffic flow and other disrupted patterns	Insignificant			
TOTAL		$18,900	$1,630	6% for 26 days

a/ The market value of sales if there were no shortage during July 28 - August 22.

b/ The percentage of hours that users were disconnected and the total days they were subject to periodic disconnect.

One summary of demand, supply, and shortage is the energy units (kWh) shown in Table 2. The 29,160 MWh is projected demand for the 624 hour period with no shortages.

The total amount of lost sales was 185 MWh from the Navy self-generation plus 1,438.7 MWh lost from disconnecting feeders, plus 4,915.2 MWh conservation minus 7% line losses -- making a sales loss total of 6,801 MWh. At $.0519 per kWh, this reduced system income by $315,514 during the brownouts.

There were other expenses during the brownouts such as additional overtime contract labor, equipment repair over and above that planned for, and purchase of new equipment. These expenses do not show in this report.

It is interesting to note that the customers conserved 16.9% of the energy they would normally have used. It was only necessary to disconnect feeders so as to reduce the MWh by 4.9%.

The generation from the old Navy Diesel Plant only supplied .53% of the City Electric System (CES) total, but this generation eliminated the dropping of additional feeders. The special efforts to get this plant on line in a minimal time is a credit to the CES staff. A second Navy Generation Plant also helped relieve the generation problem by supplying the Navy directly rather than from CES. There were some firms that would have leased other emergency units to CES, but the transportation plus other costs were too high and installation time too long.

Shortages occur from a large increase in demand that exceeds the safety margin, or from a large decrease in supply that exceeds the safety margin. The Key West shortage was an example of the latter.

The total shortage cost for each kWh of shortage to non-residential users breaks down as follows:

Producers	$2.00
Employees	.10
Consumers	.20
TOTAL	$2.30

This $2.30 is approximately 50 times the 5¢/kWh market price for electricity.

Table 2

THE JULY 28 - AUGUST 22 SHORTAGE PERIOD

• Level of Demand	MWH	%	Capacity
Estimated Demand	29,160	100.0	64 MW Max.
CES Facility Supply	22,467	77.0	51-58 MW
Navy Facility Supply	339	1.2	
User Conservation	4,915	16.9	
Disconnected Feeders	1,439	4.9	0-11 MW

• Hours of Outage	Hours
Total hours during equipment failure	624.
Hours of shortage (approx. 15 hrs/day)	390.
Maximum feeder outage during period	59.34
Total feeder hours of outage	898.
Average outage per disconnect	1.13
Longest continuous feeder disconnect	2.92
Maximum feeder disconnections in 24 hrs	5.33

The cost per kWh of shortage in residential use is only 5¢. Stated otherwise, the average residential user stated that he would have been willing-to-pay approximately twice the market value of electricity to have avoided this specific shortage.

The system peak demand for the shortage period and the typical day demands are shown in Figure 3. The peak demand was expected to be approximately 64 MW in the 1978 summer. Therefore the 51 MW that was generated during several days was 20% below a 64 MW peak, and 11% below a 58 MW typical demand.

Concepts for Applying Estimates

The theoretical framework for developing good shortage cost estimates is very complex. However, the concept of applying available estimates can be simplified as follows:

1. Develop and apply estimates as willingness-to-pay to avoid shortages.

2. Distinguish between impact and coping costs.

    - Shortage impact cost -- any loss than can be attributed to a specific shortage.

    - Shortage coping cost -- any loss (such as cost of increased fuel substitution capability) that will be amortized over more than one shortage.

3. Adjust estimates before use to account for differences from the case studies which generated these estimates.

The concepts are discussed throughout this report.

Estimates in this report are objective evaluations of willingness-to-pay to avoid the shortage which occurred. Unlike estimates of wage loss and GNP reduction, these estimates can be interpreted as dollar estimates. Stated otherwise, the affected groups would be indifferent between spending a dollar to avoid shortages and absorbing the shortage impacts reflected in each estimated dollar of shortage cost.

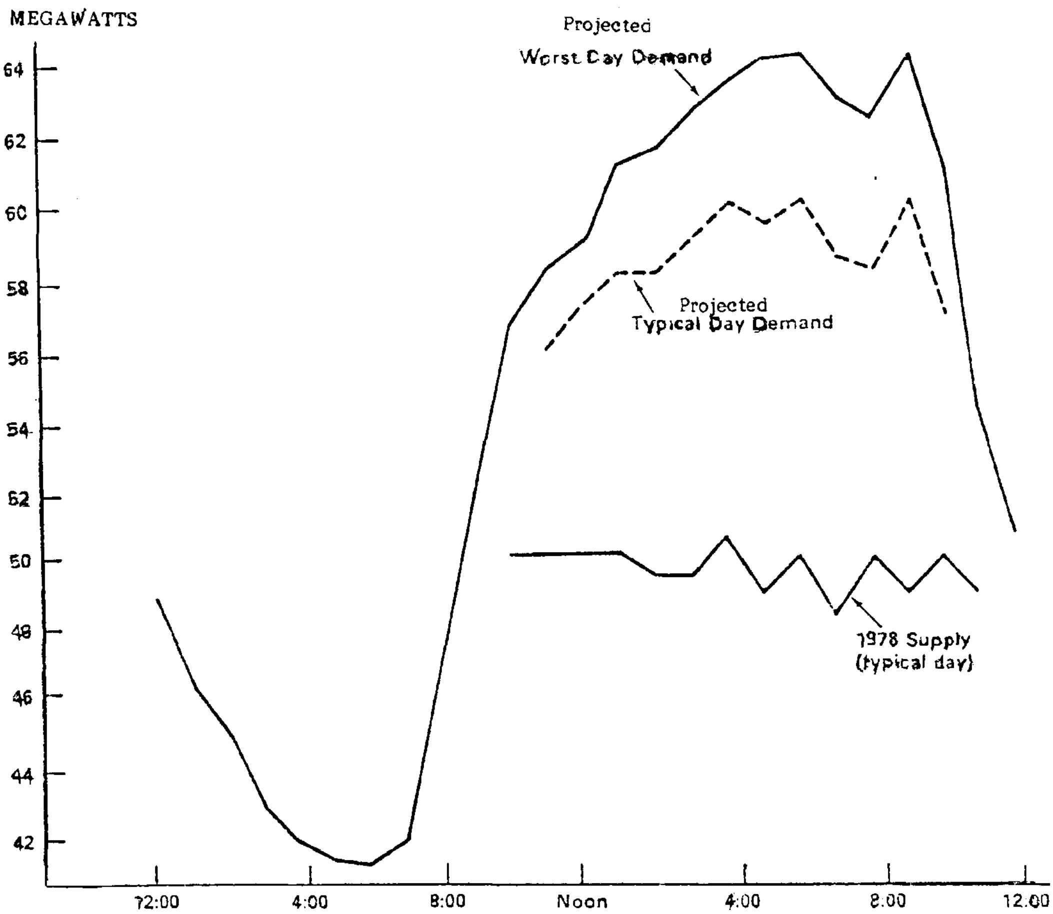


Figure 3. Daily Load Load Curve: Key West 1978 Shortage

The concept in developing estimates was that the final results should be directly applicable for cost-benefit analysis of efforts to reduce shortages. As the study progressed it also became clear that willingness-to-pay was both the easiest and the most useful definition of shortage cost. The reason is that the different impacts on many groups became confusing without a common denominator; the amount the affected group is willing-to-pay to avoid shortages serves as that denominator.

Since shortage costs per unit of shortfall vary with shortage severity and since user fuel substitution can reduce shortage impact, estimates in this report must be adjusted. First, however, the differences between impact and coping costs must be understood.

Many costs caused by shortages involve investments and other efforts by users to reduce impact costs if and when a shortage occurs. For example, a user who switches from natural gas to propane to avoid gas interruption incurs a cost that should be attributed to potential gas shortages.

The best concept for distinguishing coping and impacts is to define coping cost as any cost that must be amortized over more than one shortage. For example, the investment to allow use of propane as standby fuel is a coping cost because it helps in all possible future shortages. On the other hand, the extra cost per unit of fuel during a shortage is a cost attributable to that specific shortage.

Following a clear separation of coping and impact costs, the concept of adjusting available estimates can be developed. Estimates for both the case studies reported in this document are associated with one specific point on the conceptual shortage cost curve shown in Figure 4. This curve shows that there is a threshold level of curtailment before costs increase, and that the costs probably increase at an increasing rate as curtailment increases. The figure also shows that different values for the six parameters associated with a shortage event will shift the curve. Three parameter values will shift the curve upward: (1) greater geographical coverage of shortage, (2) longer duration of shortage, and (3) greater underestimation of shortage probability by users. Three parameter values will shift the curve downward: (1) greater warning time, (2) larger excess capacity and or available inventories, and (3) increased focusing of curtailments on users who are best prepared to cope with the shortage.

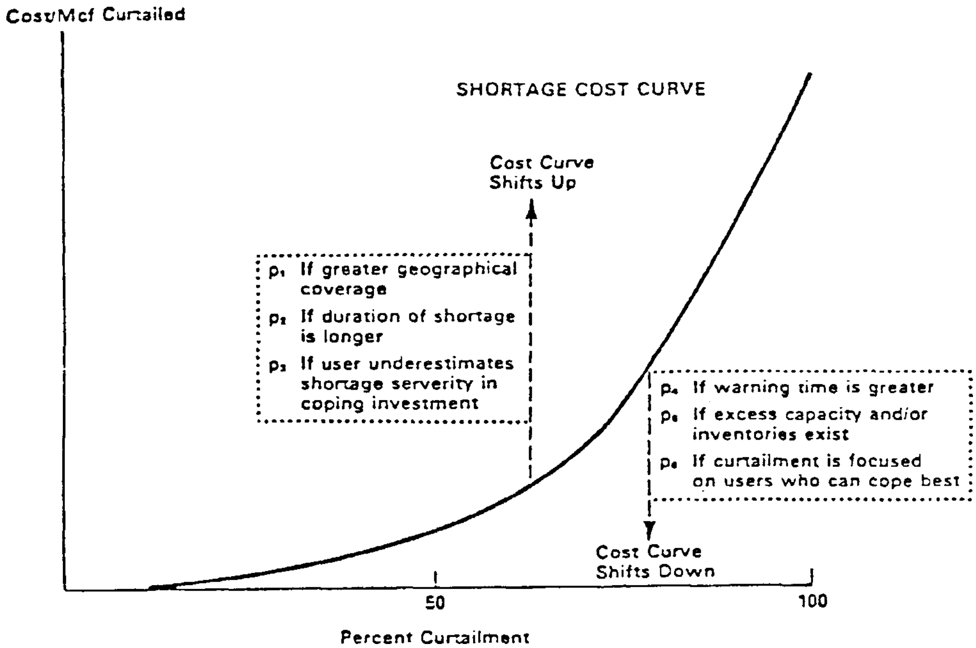


Figure 4: Shortage Cost Curve and Shift Parameters

In a sense, shortage impact costs per unit of shortage can vary easily. On the one hand, a shortage scenario can be quite different from the reported case studies and generate different shortage impacts. On the other hand, continued shortages cause users to improve coping and, thus, reduce shortage impacts for given levels of shortages.

One important application of shortage costs is for determining optimum reliability of energy supply. Some concepts are provided in Figure 5.

Optimum reliability designated by Point "a" in Figure 5 requires prior optimization in order to minimize total societal cost -- it requires planning to cope with a shortage once it is unavoidable.[a/] Just as operating efficiency shifts the cost curve "A" down as far as possible, supplier planning for shortage situations shifts the shortage cost curve "B" downward as far as possible. To determine the R% optimum safety and to obtain the C* minimum cost designated by Point "a" requires an understanding of shortage costs as much as it requires understanding of reliability costs -- an understanding that permits us to determine the level at which the true incremental reliability cost equals the true incremental shortage cost; anything else creates higher than necessary societal costs.

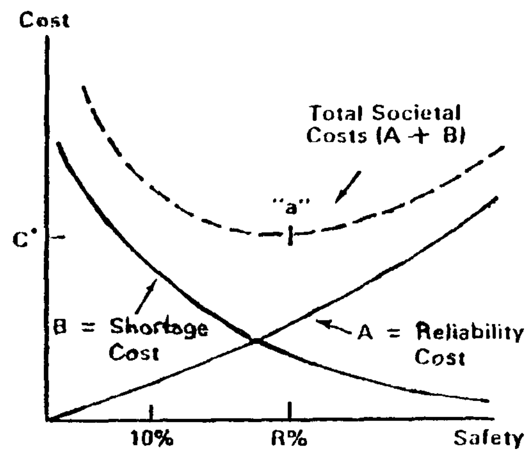


Figure 5: Cost Tradeoff

The shortage cost estimation methodology in this study contributes toward reducing total societal costs in both of the two categories discussed above.

A. Minimizing shortage impact when a shortage occurs:

1. The value of preplanning identified in this study may assist other utilities.

[a/] Curve A in Figure 5 is the total cost of providing a specified safety margin; Curve B is the expected total shortage cost for various levels of safety.

2. The utility's emergency plans reviewed in this study can be used by other suppliers.

3. The users' reflections presented in this study can help suppliers inform users and prepare plans.

4. The potential for government assistance and supplier pooling outlined in this report can reduce shortage costs and improve safety margins.

B. Optimizing reliability to minimize total user cost:

1. The ratio of shortage cost to production cost in study results can be used to determine optimum (user justified) level of reliability.

2. The sacrifice from voluntary cutback provides a clue on the degree to which conservation should be used to complement reliability.

There are many applications of shortage cost estimates, but the above illustrates a particularly useful application.

Chapter 2
DIVERSE COSTS AND COMPLEX CHAIN REACTIONS

Total costs ascribed to energy shortages are multifaceted, as shown in Figures 6 and 7. One reason is that direct-user costs and other production consequences are passed on to scores of producers, employees, and consumers. Another reason is that shortage costs include both shortage coping effects and shortage impact effects in the short-run. Coping costs include increased investments to allow more fuel substitution during a future shortage, but this necessarily increases average operating costs.

Shortage impact costs are potentially large because an energy shortage can halt production of items worth many times the market value of energy used in their production. For example, an energy shortage at an auto parts plant can close both that plant and the plants of auto manufacturers who are dependent upon purchasing the part.

Figure 6 illustrates the complex chain reactions that can accompany an energy shortage. First, the shortage impacts are initiated by the energy shortage, with delayed production shown as the initial factor in the upper left of Figure 6; this causes lost production by direct-energy users (A or B, as shown). Second, delayed production can cause (1) delays by indirect users as shown by G, (2) employee sacrifice shown as K, and, possibly, (3) lost production by indirect users shown as H.

If delay and extra cost of production are excessive, the energy shortage will cause lost production (B) which, in turn, sets up another chain reaction. In Figure 6, the initial impacts are shown in capital letters A thru Z, and the effect of each impact on other impacts is shown by a lower case letter.

The chain reaction in coping costs is less complex than that for impact costs because most coping mechanisms are limited to direct-energy users. However, to the extent that direct-energy users do not cope well, indirect users will invest in coping to prevent impacts passed on from direct users (See Impact J).

The initial effects which generate chain reactions are shown along the left of Figure 6, but they are more easily discussed in the Figure 7 schematic. Furthermore, the four groups shown across the top of Figure 6 are shown with more detail in Figure 7.

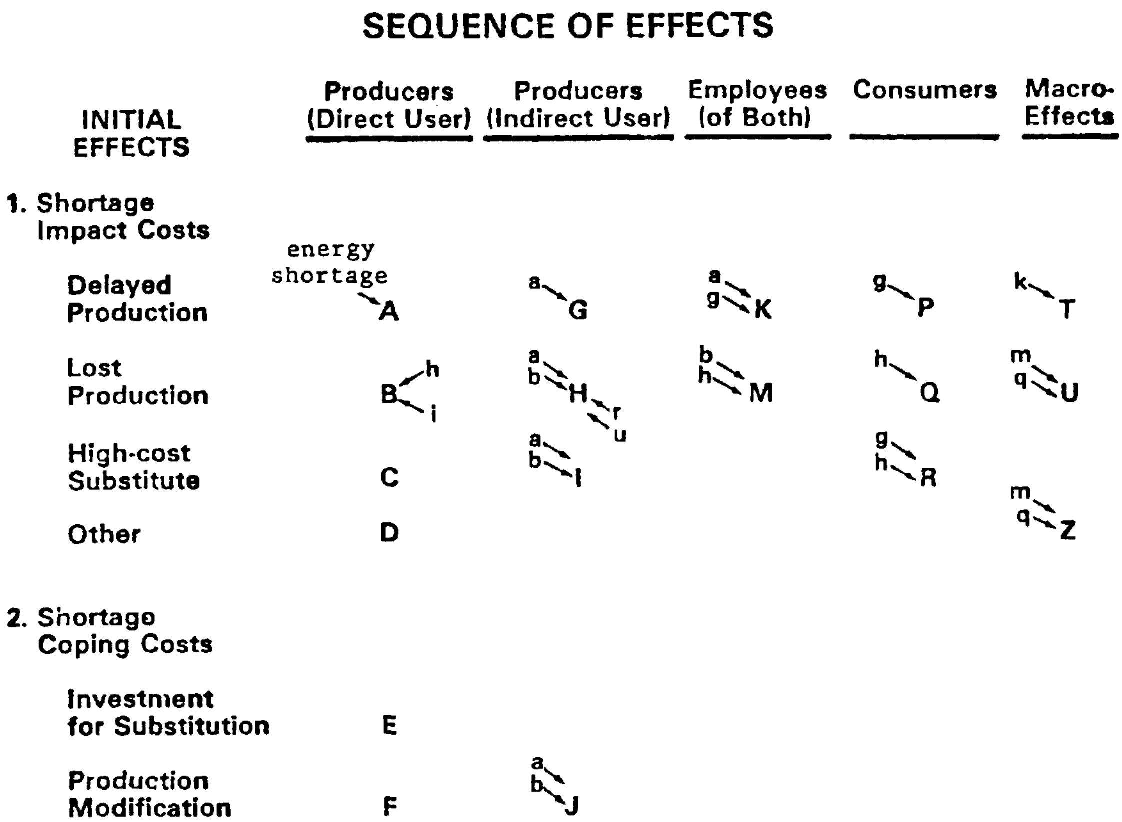


Figure 6: Shortage Costs A-Z and Their Causes

INITIAL EFFECTS \ SEQUENCE IN EFFECTS	Line No.	PRODUCERS: Direct Energy Users (1)	PRODUCERS: Indirect Energy Users (2)	EMPLOYEES: Layoffs (3)	EMPLOYEES: Working Cndtns. (4)	CONSUMER: Final[a] Demand (5)	MACRO EFFECTS: Multiplier Weak Economy (6)
	1						
A. Permanent Fuel Substitution	2		Major impacts can all be measured by direct user production costs				
1. Cost of capability	3						
2. Cost of fuel	4						
B. Temporary Fuel Substitution	5						
1. Cost of capability	6						
2. Cost of fuel	7						
C. Delayed Production	8						
1. Makeup cost	9	This can create costs in Columns 1 through 5					
2. More inventory cost	10		These can be measured by direct user production costs				
D. Changed Production	11						
1. Modification for coping	12						
2. Lost sales	13	All 6 columns are important					

[a] Includes residential demand for energy.

Figure 7: Initial Impacts and Ripple Effects

The Figure 7 matrix is the best introduction to diverse types of shortage costs. At this point, it is important to review the items. First, each of the six columns represents initial and ripple effects showing up at various points in the production-consumption cycle, as indicated below:

1. Direct user -- costs that originate at the direct user point in the production-consumption cycle regardless of direct-user pass-ons.

2. Indirect user -- similar to direct user costs, but exceed direct user pass-on costs.

3. Employee wage loss -- costs (hardships) accruing to employees but unreflected in employer's cost -- e.g., a worker losing a month's wages because his employer loses sales to a competitor suffers a loss beyond the employer's cost (identified in Columns 1 and 2, Figure 7).

4. Employee working conditions -- conditions that can include abnormally low temperatures, such as below 50 degrees.

5. Final demand -- loss by the final consumer who must switch to an inferior product because the production of his first-choice product is interrupted by an energy shortage. Again, this cost is beyond the producer's loss from the forgone sale.

6. Macro-economic effects -- typically, these start with an employee buying less because of lost wages. His reduced purchases lower production, which depresses other wages, thereby introducing the multiplier effect. If the economy is particularly weak, the multiplier effect is even worse.

The above is a brief review of stages in the "ripple effect" from shortages. Shortage impacts that trigger the ripple effect are discussed next.

The two initial impacts on the direct user -- coping and impact costs -- that can generate ripple effects are subdivided into the categories shown on the left-hand side of Figure 7. These are discussed below.

Figure 7 (center boxes) indicates whether the ripple effects can be measured by added costs at the direct-user stage. For example, fuel substitution costs in Lines 1-7 might be passed on to, say, final consumers in Column 5. But the full cost can be fairly accurately measured at the direct user stage in Column 1.

Initial Effects

Initial effects caused by a shortage can be easily discussed in four divisible parts:

1. Continuing production and absorbing impacts of specific energy shortage
   - Makeup cost with delayed production
   - Extra cost of substitute fuel and inefficient production
   - Inventory drawdown
2. Losses from production cutback beyond coping capacity
   - Layoffs reducing employee income
   - Sales losses creating unrecoverable cost to business-as-usual producers
   - Extra cost to product users who substitute for the lost product
3. Sacrifice in comfort and convenience
   - Residential cutback in temperature setting
   - Worker conditions within industrial and commercial establishments
4. Investment to cope with future shortages
   - Greater fuel substitution capability
   - Larger fuel and product inventories or modifications of the production process

The above effects entail a significant willingness-to-pay to avoid them. Those effects which reflect a coping process to reduce impact should not be overlooked. Some of the largest costs (willingness-to-pay) are in the coping process. Even energy conservation has a coping cost that must be justified before conservation can be promoted rationally. Expenditures for coping capability must be amortized over all shortages. For example, fuel substitution in a specific shortage utilizes equipment and capacity serving many shortages. Likewise, new capacity added after a shortage (i.e., after a shortage which led to increased expectation of future shortages) is a cost that should be amortized over multiple shortages.

Some natural gas users, for example, have permanently shifted to electricity to avoid shortages. Any gas shortage after a permanent fuel switch will not reduce their level of activity, but their increased fuel costs due to the fuel shift are a shortage cost and should be attributed to shortages.

While the above categories are useful for discussing impact types, they should be rearranged (shown in Rows 1-13 and Columns 4 and 5 in Figure 7) when developing estimates. In other words, sacrifices in comfort and convenience are in Columns 4 and 5, and the producer effects at the direct user level are rearranged as shown in Lines 1-13. This rearrangement helps in various ways, including better understanding of the ripple effects.

<u>Impact Categories and Stages of Impacts</u>

Impact categories 1-13 in Figure 7 can also be characterized as to the measurable degree at various stages within the ripple effect. The following is an outline of Stages among costs in Columns 1-6:

<u>Stage I -- Costs Show Up at the Direct User Level</u>

1. Permanent fuel substitution

    - Cost of capability (Line 3)
    - Cost of fuel (Line 4)

2. Temporary fuel substitution

- Cost of capability (Line 6)
- Cost of fuel (Line 7)

3. Changed production

- Modification for coping (Line 12)
- Lost sales (Line 13)

Stage II -- Reduced Economic Activity by Indirect Users (i.e., the Users of Products from, or Suppliers of Products to, the Direct Energy User)

1. Use of inventories (buildup in inventories) (Line 10)

2. Delayed production (because of direct user supply interruption) made up later at extra cost (Line 9)

3. Lost production for same reason as 2b (Line 9)

Stage III -- Impacts on Consumers (i.e., Final Demand that Cannot be Satisfied)

1. Delayed consumption (stemming from Line 8)

2. Substitute products (stemming from Line 13)

3. Permanent consumption reduction (Line 13)

Stage IV -- Impacts that Result from the Multiplier Effects

1. Income multiplier (initiated at Line 13)

2. Multiplier because of a weak economy (initiated at Line 13)

Note that employee impacts can be calculated from the producer impact of Stages I and II.

The four stages have significant implications for developing a framework for evaluating shortages. For example, the direct-energy user can be queried on the impact from an expected shortage confined to Stage I. However, the indirect users and final demand sectors cannot be easily questioned about shortages that will reach Stages II-IV.

While shortage impacts (costs of effects that occur in spite of coping process) can be identified with a specific shortage, coping costs must be amortized over all shortages in order to understand them. In Figure 7, parts A-1, B-1, and D-1 are coping costs that must be amortized over all shortages. Proper amortization for estimating impacts from a specific shortage is discussed later, but a few general comments are given below:

- Investments to help cope with possible future energy shortages create a significant impact. These investments must be amortized over all shortages that they protect against. They represent a significant effect on almost every shortage. These investments include changes in the production process and the move toward larger inventories (Lines 10 and 12). Coping investments are overlooked in most shortage evaluations because they are either in place before the shortage or they occur after the shortage.

- Production cutbacks are the most widely recognized shortage impact costs. However, these are seldom evaluated from the perspective of reduced employee income, greater employer costs, and losses to users of products that are, in turn, cut back. While production effects can be temporary or permanent, the cost can be significant in both cases.

While voluntary energy cutback in a shortage might prevent substantially gerater costs, they still constitute an important effect. Evaluation of actions to reduce shortages should include all effects for which there is a willingness-to-pay to avoid. For example, employers in the survey of the 1976-77 natural gas shortage [14] reported that workers sacrified considerable comfort.

Four Affected Groups and Costs Passed-On

Shortage costs accruing to the four groups -- producers, employees, consumers, and the general public -- cannot be fully understood until the "pass-through" of added cost is delineated carefully. An example and counterexample of ripple effects that are mere pass-through of impacts will be helpful.

Assume the following plausible scenario as an example of significant additional costs at each stage in ripple effects:

- $10 Initial Cost. Energy user A stops production in the shortage period but makes it up later by overtime with $10 extra cost.

- $5 Additional Cost. Indirect user B waits for the makeup items, but he incurs $5 of extra cost in subsequent overtime.

- $3 Additional Cost. Employee C would be willing-to-pay $3 to avoid the income loss from user A (assume that employer A uses employee D at overtime wages to make up what employee C would normally produce).

- $2 Additional Cost. Final consumer would pay $2 to avoid waiting for the delayed production on indirect user B.

- $1 Additional Cost. The overall economy loses $1 in production because employee C reduces normal purchases (more than employee D increases purchases) when he loses wages and this reverberates throughout the economy, generating a $1 net loss.

The $21 total willingness-to-pay (= 10 + 5 + 3 + 2 + 1) cannot be estimated without considering all four groups; that is regardless of whether costs, from any stage, are or are not passed-on. "Passed-on" is a separate equity issue.

Now assume the following plausible scenario as a counterexample in considering four different groups in estimating willingness-to-pay to avoid an enegy shortage:

- $11 Initial Cost. Energy user A incurs $6 of extra cost for substitute fuel plus $4 extra cost for overtime and passes all $10 on to his customer (indirect user B). In addition, employees of direct user A have a net loss of $1 between interrupted wages and overtime pay.

- $0 Additional Cost. Indirect user B does not incur any extra cost beyond the $10 passed-on by A, but he passes on all $10 to final consumer C.

- $0 Additional Cost. Final consumer C does not incur any loss beyond the $10 extra cost he pays for goods and services.

- $0 Additional Cost. There is no multiplier effect on the $11 extra cost for user A in Stage I, on the $10 passed-on to indirect user B, or on the $10 extra cost paid by consumer C.

The counterexample illustrates that it is not always necessary to consider all four stages and all four groups in achieving a complete impact accounting.

Chapter 3
WILLINGNESS-TO-PAY: ESTIMATES RELEVANT FOR DECISIONS

In energy shortage assessment, willingness-to-pay represents the benefits from reduced shortages. The concept of willingness-to-pay places emphasis on carefully determining which benefits of shortage reduction the public is willing-to-pay for.

Benefits can emanate from reducing the shortage (its severity, frequency, or geographical coverage), or from forcing the shortage to be absorbed by users having less impact per unit of shortages. The equity impact should be identified even though equity is not a major focus in this report. Willingness-to-pay that includes equity can be defined as follows:

- Efficiency. Economic surplus is the loss that could be avoided if the shortages (or distribution of shortages) were eliminated or, at least, reduced a specified amount.

- Equity. Willingness-to-pay is the societal value in avoiding the inequity that occurs in the distribution of energy shortage impacts.

Contrary to popular opinion, we can quantify the gains and losses in equity. It is not a question of whether the analyst wants to quantify equity changes. Rather, it is a question of whether he wants to facilitate the best decisions regarding both equity and efficiency.

Since this methodology focuses on estimating shortage impact without policy recommendations, discussion of benefits (willingness-to-pay) is confined to their relevance for estimating efficiency impacts per shortage unit.

With the above definitions, we can proceed to more technical discussions on willingness-to-pay to avoid losses accruing from energy shortages.

A Balance Sheet on Shortage Costs

A balance sheet accents the bottom line (willingness-to-pay) and summarizes various items. The concept is useful in shortage evaluation to characterize what happens and where the effects finally rest.

A balance sheet must go beyond both the initial effects on the energy user and the ripple effects on other producers, employees, and consumers. Specifically, it must include user decision effects in coping with future shortages. One of the most important empirical insights from this project is that shortage coping costs (often, unnecessary ones) are frequently larger than the unemployment and other shortage impact costs. Again, the balance sheet must be employed to portray shortage impacts correctly.

Figure 8 is an expanded version of the Figure 7 schematic. It is designed to differentiate single shortages from the distribution of possible future shortages over the years. It also gives hints on the magnitude of effects (of willingness-to-pay).

The symbols C and I on the left of Figure 8 describe the impacts as follows:

C A coping cost -- a cost that may be amortized over the distribution of shortages (e.g., the investment cost of fuel substitution capability in Line 6)

I An impact cost -- a cost that can be associated with a specific (single) shortage such as the added cost of fuel in Line 7

The above distinction does not change the concept of willingness-to-pay (to avoid shortages), but it does highlight the necessary differences in the empirical measurements approach.

Lines 14-16 in Figure 8 identify a factor similar to equity: namely, an imbalance, among geographic regions, of the impacts on economic sectors. That imbalance can itself generate a willingness-to-pay beyond the total loss in efficiency. In other words, a $10 million total shortage cost generally is worse if concentrated in a small region or a single sector because it is an inequitable distribution of impacts.

The concepts of an "accounting format" for identifying all shortage impacts and a "balance sheet" for displaying shortage costs can be extended. The concept of "certified public accounting" of shortage costs connotes that shortage cost estimates should have three important characteristics:

1. <u>Objectivity</u> because they represent the total net amount that the public is willing-to-pay to avoid shortage (i.e., if the consequences are understood), but do not represent merely the analyst's personal taste.

	Line No. and Type of Impact	PRODUCERS: Direct Gas Users (1)	PRODUCERS: Indirect Gas Users (2)	EMPLOYEES: Layoffs (3)	EMPLOYEES: Working Cndtns. (4)	CONSUMERS: Final Demand (5)	MACRO EFFECTS: Multiplier: Weak Economy (6)
• NATIONWIDE	1						
A. Permanent Fuel Substitution	2 C	• Yes	• N.A.	• Insig.		• Count in Column 1	• Insig.
1. Cost of capability	3						
2. Cost of fuel	4						
B. Temporary Fuel Substitution	5	• Yes	• N.S.	• Insig.		• Count in Column 1	• Insig.
1. Cost of capability	6 ,C						
2. Cost of fuel	7 ,I						
C. Delayed Production	8	• Yes		• Temporary Income Loss		• Possible Delay	• Possible Multiplier
1. Makeup cost	9 I		• Yes				
2. More inventory cost	10 I		• Insig.				
D. Changed Production	11					• Cost counted in Column 1, 2	
1. Modification for coping	12 C	• Yes		• Uncertain		• Extra cost counted in Columns 1, 2	
2. Lost sales	13 I	• Under-util.	• Sub Trans. • Sub Prod. • Under-util.	• Lost Income		• Sub Product • Do without	• Likely Multiplier
• SPECIAL SUB PARTS	14						
E. Most effected geographical area	15						
F. Most effected energy sector	16						

CODE: N.A. = Not applicable; Insig. = Insignificant; Under-util. = Extra Cost from under-utilized capacity; I = Impact cost; D = Distribution of shortages; S = Single shortage.

Figure 8: Measures of Shortage Impacts

2. Completeness because nothing is left out -- e.g., comfort and conveniences are not left out merely because they are "subjective" items that are difficult to quantify.

3. Usefulness because private companies and government agencies can use them in making decisions to cope with or avoid shortages. The accounts can guide decisions because they account for the total value to the public of reducing shortage impacts.

Although the name certified public accounting does not itself provide a methodology, it provides an important perspective.

The above discussion illustrates the need for a concept like a "balance sheet" for shortage impacts. The examples cited illustrate but do not exhaust the concept. The following sections add essential detail.

Complete Accounting for Willingness-To-Pay

Energy shortage is a household word. Yet no one has defined a good and usable measure of shortage. At the same time, few have estimated impacts with any accuracy. Most shortage impact estimates, moreover, do not even estimate quantities that have a direct implication for public policy or industry decisions.

Deficiences in energy shortage evaluations focus attention on the federal and state governments, who do most of the analyses -- i.e., most analyses are not done by the individual energy user. Some analytical deficiencies exist because of the limited governmental role and constraints on government involvement. However, these are not as important as deficiencies caused by shortage evaluation difficulties -- i.e., poor data availability and evaluation methodology. The study of the 1976-77 natural gas shortage [14] was easier in some ways and more difficult in other ways because it did not involve government sponsorship.

No reason exists why the government should be less interested than private suppliers in objective and complete measures of willingness-to-pay to avoid shortages. The deficiencies should not stem from lack of scope in government responsibility. Regardless of basic reasons for the deficiency, each major weakness in previous energy shortage evaluations is identified and reviewed for implications.

Possible deficiencies in accounting for all shortage impacts can be outlined as follows:

1. Cost of coping is excluded from impact assessement (i.e., the coping that reduces the impact on future economic activity and involves cost). Increased unemployment and decreased GNP that the coping process cannot avoid will dominate only for large shortages. Investment for fuel substitution capability and extra costs for substitute fuel are significant coping costs in moderate energy shortages.

2. Impact estimates focus on unemployment and GNP only. There are significant costs in reduced productivity, shifts in work schedules, and inferior performance of substitute fuel that are unreflected when the sole foci are unemployment or GNP changes.

3. Temporary and permanent impacts are not distinguished. GNP and unemployment impacts can be temporary because production is made up within weeks or months. An extra cost occurs in making up production, but a temporary reduction is less costly to the nation than a permanent production loss.

4. Impacts are not evaluated in terms of willingness-to-pay. Estimates of unemployment and GNP changes are not easily related to social cost in the form of willingness-to-pay to avoid the impacts.

5. Impacts are not summarized in ways that help future impact estimation and evaluation. The development of a long-run capability for shortage evaluation is hampered because estimates are developed for immediate government action. Little effort, therefore, is spent on improving evaluation methodology.

6. Post-shortage analyses are not conducted. Valuable information for reviewing accuracy of impact estimates and for determining increased capability to cope with future shortages is not generally obtained.

Deficiencies vary from one shortage situation to another, but the above list is relevant for the three major energy shortages: (1) the 1973-74 oil embargo, [15;4, p.367] (2) the 1976-77 natural gas shortage, [13; 17] and (3) the 1977-78 coal strike (reports have been developed but were not available as of this publication).

Several federal efforts are underway, and more could be undertaken to remove deficiencies. These are discussed below:

1. Predesigned sample and questionnaire -- the 160,000 "establishment sample" for routine data collection has been subdivided, with a sample of 4000 employers (those with more than 1000 employees) designated for special data collection. This was done after the 1977-78 coal strike and should prove helpful. However, there is a need to collect data from small establishments as well, in the event that coping mechanisms create different impacts by size of firm. The questionnaire cannot be designed in detail ahead of the energy shortage, but a basic design which can be modified is worth developing. A design's major value is preventing the oversight of important information.

2. Data collection for post-analysis -- data on energy allocation, shortages, and layoffs should be collected while readily available but should include a focus on a post-analysis when impacts are better known. Also, estimates before and during a shortage should be recorded for later accuracy review. The relationship between estimated and actual impacts is particularly helpful in assessing future estimates.

3. Specification of a base condition or reference scenario -- the energy shortage impact should be measured as the difference with and without the shortages under prevailing conditions. The base condition -- the economic scenario without the energy shortage -- should be delineated with sufficient detail to enable accurate impact assessment.

4. Development of a uniform format and basic methodology for impact estimates -- a uniform format would insure consistency in impact evaluation and prevent oversight of important evaluations. A precise methodology is not feasible because of the special circumstances which prevail in most energy shortages.

Industry has incentives to conduct energy shortage evaluations, but these cannot be expected to contain the comprehensive accounting of public willingness-to-pay. However, trade associations sometimes sponsor studies that supplement government efforts [18].

As the threat of more energy shortages looms, current government actions to improve shortage evaluations appear to be deficient. Accordingly, the six major deficiencies listed above are likely to persist unless greater effort is made to improve data and methodology.

A good trend in shortage evaluation is the government task force effort in the 1977-78 coal shortage. A larger team capable of following the diverse shortage aspects to detect key impact areas is highly useful. Needless to say, if the task force continued into a post-shortage analysis and reviewed the possible methodology improvements, the efforts would be of more value.

An accounting system cannot ignore any cost item on the grounds of measurement difficulty. Specifically, voluntary energy cutbacks to help ease a shortage cause losses in comfort and convenience and should be specified. Although it might be desirable to discount an initial estimate like comfort, it should be assigned some numerical measure. For example, the value of overdue accounts in a business might be discounted in computing net worth. Some number greater than zero for a discounted estimate of reduced comfort and convenience is surely an appropriate entry in certified public accounting of energy shortage impacts.

Decision Focus: With and Without a Specified Shortage

The difficulty in a comprehensive accounting of impacts (notably, willingness-to-pay to avoid impacts) is matched by the difficulty in avoiding three causes of overestimates:

1. Double counting -- e.g., counting the added cost of substitute fuel to the producer and the subsequent price increase to the consumer.

2. Spurious correlation -- e.g., severe winter weather creating an energy shortage also generates plant closings simultaneous with energy-caused plant closings.

3. Opinions that include exaggerated first impressions -- e.g., first impressions that invariably overlook the intricate coping devices that can greatly mitigate shortage impacts.

Overestimates are more easily avoided if shortage evaluation is given a decision focus -- the difference with and without a specified shortage (s).

It appears obvious that shortage level and shortage impact estimations serve two functions:

1. Estimating forthcoming effects that should be anticipated -- to help decision makers plan for the effects, even though they cannot be avoided in the short-run.

2. Estimating the cost (what society would be willing-to-pay to avoid the impacts) to help identify effective actions for reducing shortages and mitigating impacts over the long-run.

Because estimates of pending impact have been so inaccurate, they hardly help decision makers plan for events. A good case in point: coal shortage impacts in 1978 consistently focused on unemployment that never materialized and predicted the depletion of coal stocks much earlier than they actually occurred. The following impact estimates were published in February, 1978 [1].

	Estimated Unemployment (%)		
	February 25	March 7	March 17
Ohio	30	50	50
Tennessee	20	30	50
Maryland	10	20	50
Virginia	0	0	10

Another forecast, at the same time, indicated a .05 percent national unemployment increment, or about a five percent average for states heavily impacted like those listed above [10]. The actual unemployment is still unknown. Yet all indications are that it was negligible during the entire period. BLS reported 22,900 peak unemployment, or about four percent of the labor force in affected regions.* Selected layoffs in railroads carrying coal and certain other industries were less than the number of striking coal miners in many states. Nationwide, 160,000 coal miners were on strike and 20,000 railroad workers were idled.

*The FPC designated ECAR region (East-Central Area Reliability Group); see Reference 28, March 30, 1978, page 3.

Most energy shortage impacts focus on news items. These attract attention but afford little input for decisions. To be sure, they certainly fail to provide insight on whether more should be done to avoid shortages and mitigate impacts. A few examples illustrate this.

The strategic petroleum reserve is a one-billion-barrel capacity, $20 billion investment designed to mitigate oil shortage effects. Congressional deliberations and executive branch energy planning arrived at a billion-barrel safety reserve without benefit of reliable estimates of the shortage cost that this reserve is supposed to preempt.

The electric utility industry must establish a supply reliability for meeting peak loads without benefit of facts on the actual cost of shortages that greater reliability would avoid. The gas utility industry has established pipeline size and storage capacity, also without facts on the cost or shortage that can be preempted with greater capacity.

Nuclear generating plants in California and elsewhere are being vetoed without information on increased chances of energy shortage and similar impacts [19]. No reliable estimate exists for the cost-benefit ratio in actions changing energy shortage potential.

Electric utility industry and potential industrial uses must decide on coal conversion without benefit or reliable estimates of future coal shortages (like the 1977-78 experience) or their impacts. The federal government is urging coal conversion without knowledge of impacts from coal shortages or shortages of energy forms to be used if coal is not utilized.

A compelling need exists for understanding the energy shortage coping mechanism and estimating costs accompanying optimum coping. There are three indisputable guidelines for energy shortage studies:

1. Impacts must be estimated in terms of willingness-to-pay to avoid them (and to mitigate selected impacts) in order to provide relevant inputs for decisions and to force analysts to use relevant measures.

2. Coping mechanisms are so different from "business as usual" that on-the-shelf models of the normally functioning economy will not produce good shortage impact estimates.

3. Obtaining reliable estimates from special surveys requires so great an effort and errors in predictions from using on-the-shelf models are so large that a

combination of special surveys and specially designed partial models is essential.

To date, these indisputable guidelines have not been recognized. On the one hand, urgency for estimates during a shortage is so great that any estimate form is acceptable during the crisis. On the other hand, interest in a shortage impact vanishes so rapidly after the shortage that post-analysis is seldom carried out.

The U.S. economy is an intricate mechanism capable of developing multifaceted ways to cope with disruptions of normal business activity. Each energy shortage reflects the relationship between shortage and impacts; each shortage provides another observation on events that are triggered by shortages and the impacts emanating from these events. An analytical framework for evaluating shortages should normally produce good estimates for the specified shortages and also contribute to our understanding of the impact-shortage relationship for diverse energy shortages.

Chapter 4

DIMENSIONS IN SHORTAGE INTENSITY: IMPLICATIONS FOR METHODOLOGY

No model of reasonable size (methodology) can incorporate all conditions. Shortage assessment is no exception. If we can establish a methodology for a shortage of typical or average intensity, we can then specify modifications for handling other levels of shortages.

The major dimension in shortage impact cost (the impact beyond the coping capability) is the percentage of energy cutoff, as shown by the solid line in the upper part of Figure 9. Factors causing the impact-severity relationship to shift will be discussed later. The major dimension in coping cost is users expectation of pending shortages, as shown by the solid line in the lower part of Figure 9. There are several factors which shift this curve, particularly when the vertical axis reflects actual rather than potential shortages. These factors will be discussed later.

The empirical work for this report has shown the importance of the following two-step methodology:

1. Establish a base methodology for a typical situation (average values for shortage parameters) such as the shortage cost curve in the upper part of Figure 9.

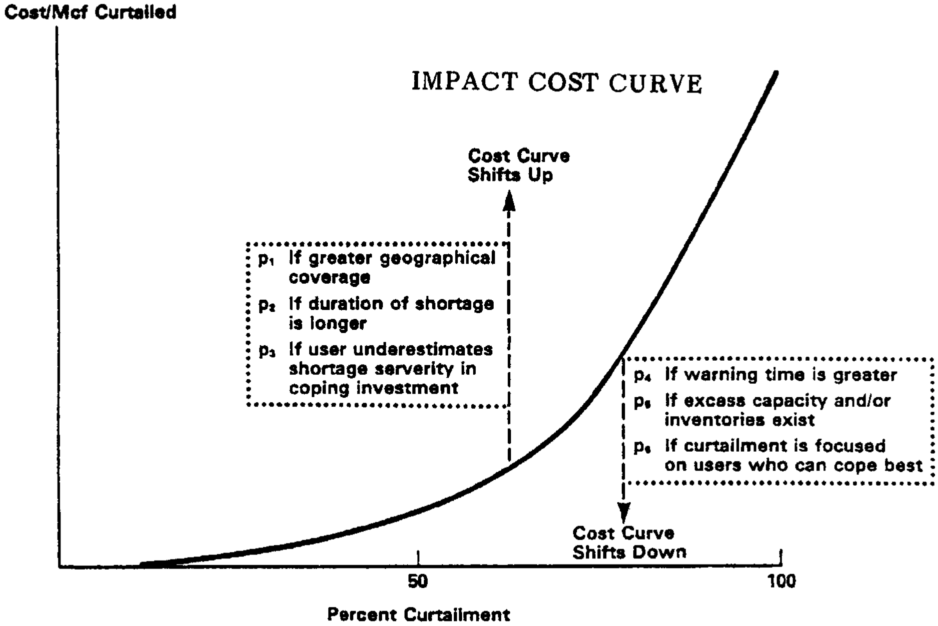
2. Modify the base methodology to meet special conditions.

In essence, a comprehensive methodology encompassing coping costs and impact costs for all levels of shortage severity will inevitably be too cumbersome for practical use.

Utilizing the extensive insights from several shortage evaluations and established economic theory, it has been possible to develop and present a practical methodology based on the solid-line relationships shown in Figure 9, namely:

1. shortage impact costs as a function of shortage level

2. shortage coping costs as a function of shortage level



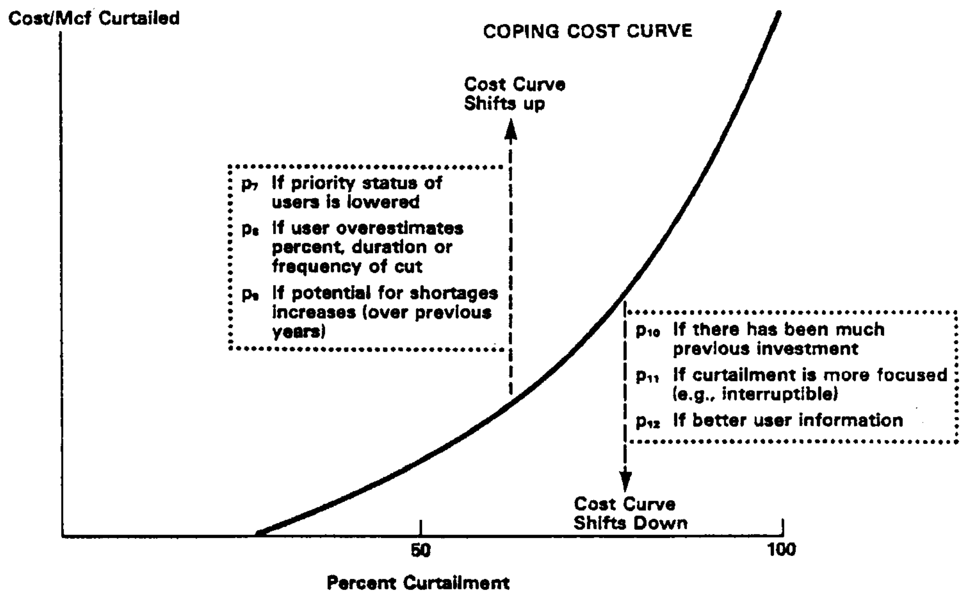


Figure 9: Parameters That Affect Shortage Costs

Until now, there has been no relevant theory or empirical insight for developing a sound shortage evaluation methodology. However, this report establishes a base and a path for achieving the sophisticated shortage evaluation required for evaluating potential shortages in the U.S.

Each shortage evaluation gives us a potential point (or calibration) on the Figure 9 shortage cost curves and their shifts. Each furnishes a valid decision input if the methodology in this report is followed. Examples include:

1. measures in terms of willingness-to-pay,
2. comprehensiveness in the accounting of impacts, and
3. certification in terms of reliable assessment of public welfare impacts.

Factors in the Relationship Between Coping Costs and Shortages

Like shortage cost, coping cost should be expressed as a function of shortage severity as shown in Figure 9. However, there are important differences that make it impossible to combine the curves for shortage coping and shortage impact costs, as noted below.

Each coping investment cost is a single expenditure. By contrast, shortage impacts occur with each shortage (shortage beyond coping capacity). As noted later, coping investment increases with each shortage because some firms increase their expectations of potential damage. Therefore, nationwide investment for better future coping occurs yearly.

The Figure 9 horizontal axis for the coping cost curve is complex. On the one hand, it must reflect "actual shortage" to be a useful prediction tool. On the other hand, it must show each gas user's expectation to represent the true relationship. A detailed analysis in the next section will facilitate a clearer understanding of this concept.

Six major factors can shift the above-noted curve in Figure 9. Given the basic relationship between coping cost and shortage severity, the most obvious factor that can shift the curve is users' overestimation of shortage severity. If the user installs optimum coping for severe shortages (high probability, large cutback, and long deviation), the costs per unit of shortage will be higher if the true shortage situation is less severe (low probability, small cutback, and short deviation). This shifts the cost curve as shown in the lower part of Figure 9; in addition, it highlights the ambiguity in defining the horizontal axis. Two other factors that shift the curve upward are: (1) changing priority classification, from high-priority to lower, and (2) increasing potential for shortages. Each of these changes in status encourages users to increase their substitution capacity.

The last three factors produce a downward shift of the coping cost curve. They are as follows:

1. If shortage threats have been constant and continuous for several years, investment will already be near optimum and new (annual) costs will be lower, regardless of probability of shortages.

2. If curtailment is focused on a few users and those are most able to cope, the costs will shift downward.

3. If there is enough information that users can form accurate expectations of probability/cutback/duration, lower coping costs will result.

Factors in the Relationship Between Shortage Costs and Shortages

Empirical data clearly indicates that the basic shortage impact cost function should be expressed in terms of percentage cutback, as shown in Figure 9. However, there are six more factors apropos of shifts in the basic relationship between shortage costs and percent cutback.

The first major factor in an upward shift of the shortage impact cost curve is the lack of fuel substitution capability (that is, a lack of capability relative to the optimum level of capability). Inadequate substitution occurs if users underestimate the shortage potential. On the one hand, shortages might not have occurred to unaware users. On the other hand, users might simply underestimate probability/intensity/duration, even though they have suffered current shortages.

Two other major factors in the curve's upward shift are: (1) greater geographical coverage, preventing indirect users from using alternative suppliers in the same area and (2) above average shortage duration which depletes substitute fuel and product inventories.

Three remaining major factors occur in the downward shift of the shortage cost curve:

1. With increased warning time on a pending shortage, users can stockpile and hedge to reduce shortage impacts; peak-day shortages are particularly costly due to the absence of warning time.

2. If users have excess production capacity and large inventories, shortage impacts are lower than otherwise.

3. If curtailment is focused on users who can best cope, the shortage impact is less than under a pro rata curtailment.

Actual shifts in the shortage impact and coping costs curves are discussed further in the next section. Nevertheless, the concepts and perspectives in this section are a helpful guide before absorbing additional detail and more intricate mathematical relationships.

Review of Problem Elements and Data Availability

In one sense, the elements of a shortage evaluation are a complete model of the company. Such a model would be useful for obtaining impacts from many exogenous factors: energy shortages, weather conditions, embargoes, labor strikes, etc. However, such a model must be developed from business-as-usual data, and it is completely unrealistic to assume that such data can be used to predict the effects of rare events.

Elements of the shortage evaluation problem can be variously categorized. However, the following four components are basic in explaining past estimating errors and describing insights gained from developing previous estimates:

1. Coping mechanisms for shortages. The nationwide coping mechanism is highly intricate. Ingenuity for minimizing impact is extensive, but its actual use depends upon the state of the economy and other scenarios.

    a. Coal was stockpiled prior to the coal miners' strike in 1977-78, and western coal was shipped to shortage areas during the strike; natural gas users switched to oil in 1977; and critical items are stockpiled and alternative suppliers are utilized in all shortages.

    b. Therefore, relationships and models for business-as-usual are not applicable to most energy shortage situations.

2. Relevant information. Relevant and complete impact measures have not been defined, and data collection is often unrelated to important attributes.

   a. Unemployment in the 1977 gas shortage was extremely temporary and reduced GNP in the 1978 coal strike was completely averted, but there were coping process costs that could have been reduced.

   b. Therefore, routinely collected data, such as unemployment and reduced production levels, are not sufficient to reveal the complete impact accounting of many shortages.

3. Shortage definition and estimated level. The reference level for measuring a shortage is critical, but hard to establish clearly.

   a. In the 1977 natural gas situation the reference level could be total demand at market price, base annual allocation, the actual allocation with given winter conditions, or the users' expectations.

   b. Therefore, the specific definition of shortage must be developed for each shortage evaluation.

4. Accurate and detailed data. Data are often not focused on the relevant area and do not have sufficient accuracy or detail.

   a. The most severe natural gas shortage, late January and early February 1977, was between the BLS information-gathering dates in the third week of each month; the confounding of weather and gas shortages in 1977 prevented easy identification of energy shortage impacts.

   b. Therefore, impacts that are often small, even in target areas, must be estimated separately from those in specified typical areas or states; otherwise they will be confused with other impacts and become difficult to identify accurately.

All this suggests that there is tremendous complexity and ingenuity utilized in the coping mechanism. The history of the 1977-78 coal strike affords a good illustration of the multidimensional ingenuity of a coping mechanism [2].

Such routine statistics as GNP, employment, and productivity pose great limitations for monitoring changes in business-as-usual and are unacceptable for selected and specific impact analyses [3, p.21]. A major element in shortage evaluation is developing a measure of willingness-to-pay. It is the relevant measure for warnings on pending impacts and for decisions that can reduce impacts. A major part of this report is devoted to this topic.

The data problem is the well-recognized tradeoff between reliable and low-cost data routinely collected, and less reliable and more costly data from special surveys. Since a shortage is a special event often focused on specific areas, a critical review of data collection options is necessary.

A shortage can be easily defined in general terms—e.g., the coal not produced in the 1977-78 coal miners' strike, or the oil not imported in the 1973-74 embargo. Such a definition, however, is not useful for capturing a relationship between shortage and impact. The coal stockpile and nonunion western coal relieved the shortage, while fuel substitutions trimmed oil embargo impacts. Since stockpiling and use of nonunion coal are highly variable, a more stable coal shortage-impact relationship can be developed only with a more specific coal shortage definition.

Numerous data and subsequent shortage cost estimates are worse than no estimate because the true and final impact is much closer to zero than to the estimates. Very misleading estimates of 50 percent unemployment in several states during the coal strike are a good example [1]. In Kentucky, estimates of 15 percent unemployment during the 1977 natural gas shortage [13, p. 10] were also far from the present evidence of less than five percent [14]. Numerous preliminary estimates developed by Jack Faucett Associates have been revised substantially downward [11, 12] after further investigation. The analysts' experience in estimating shortage impacts during past energy shortages is especially valuable in delineating the elements for developing reliable estimates.

There are two reasons for poor estimates. First, impacts indicated by clues and initial responses of sample respondents are inflated. Thus, the true shortage level is exaggerated, and the given shortage impact is overestimated. Second, coping mechanisms which substantially reduce impact do not start immediately; and most people misunderstand the coping mechanism's real power to curtail impacts. Thus, respondents' immediate response to potential impacts is to identify those that would arise without the coping mechanism.

The next chapter presents a complete methodology for comprehensive accounting of all impacts. The following data discussions, meanwhile, identify data sources and possible misinterpretations of GNP and unemployment statistics. A good example is the frequent misuse of unemployment statistics in shortage impact assessment.

Net output losses from reduction in GNP are only the differences between the market value of lost production and the value of inputs to this production that may have short-run alternative uses (i.e., opportunity costs). Value added in production is a good approximate measure of net output because it represents the contributions of labor, fixed capital, and entrepreneurial effort to the product value. These inputs cannot effectively be applied to other short-term users or stored for later use. Other inputs—raw materials, fuels, supplies, and components—can be stored for later use in the same or other production processes. Thus, reduction in value added is a first approximation in accounting for production opportunities lost in an energy emergency.

While most labor input reduction should be evaluated as employee income rather than as producer costs, it is correctly included in reduced value added. The separation of employee income and producer costs, particularly producer loss resulting from employees finding other work during layoffs, is discussed elsewhere.

The value-added measure is only an approximate measure of social losses, since opportunity costs of capital, labor, and entrepreneurial effort are not always zero. In tight labor markets idle labor may find temporary jobs in other plants, with probable lower productivity and rehiring loss to the original employer (see loss CC_L in Figure 10 and the discussion in Chapter 6). Also, net output lost currently may be recouped to some extent by overtime production later, if product demand is postponable and backlogged. To the extent these conditions exist, measures of value added lost during a shortage must be adjusted downward, as discussed in the next section.

Measures of value added for manufacturing industries are available in four-digit SIC detail annually with a two- to three-year lag [26]. This measure is available yearly for broader industries with a one- to two-year lag [25]. Thus, these measures are never current and lack sufficient detail by sector or time period to be of much use in shortage impact measures. They do, however, provide statistical relationship observations which can be useful in estimating value-added losses from more current data.

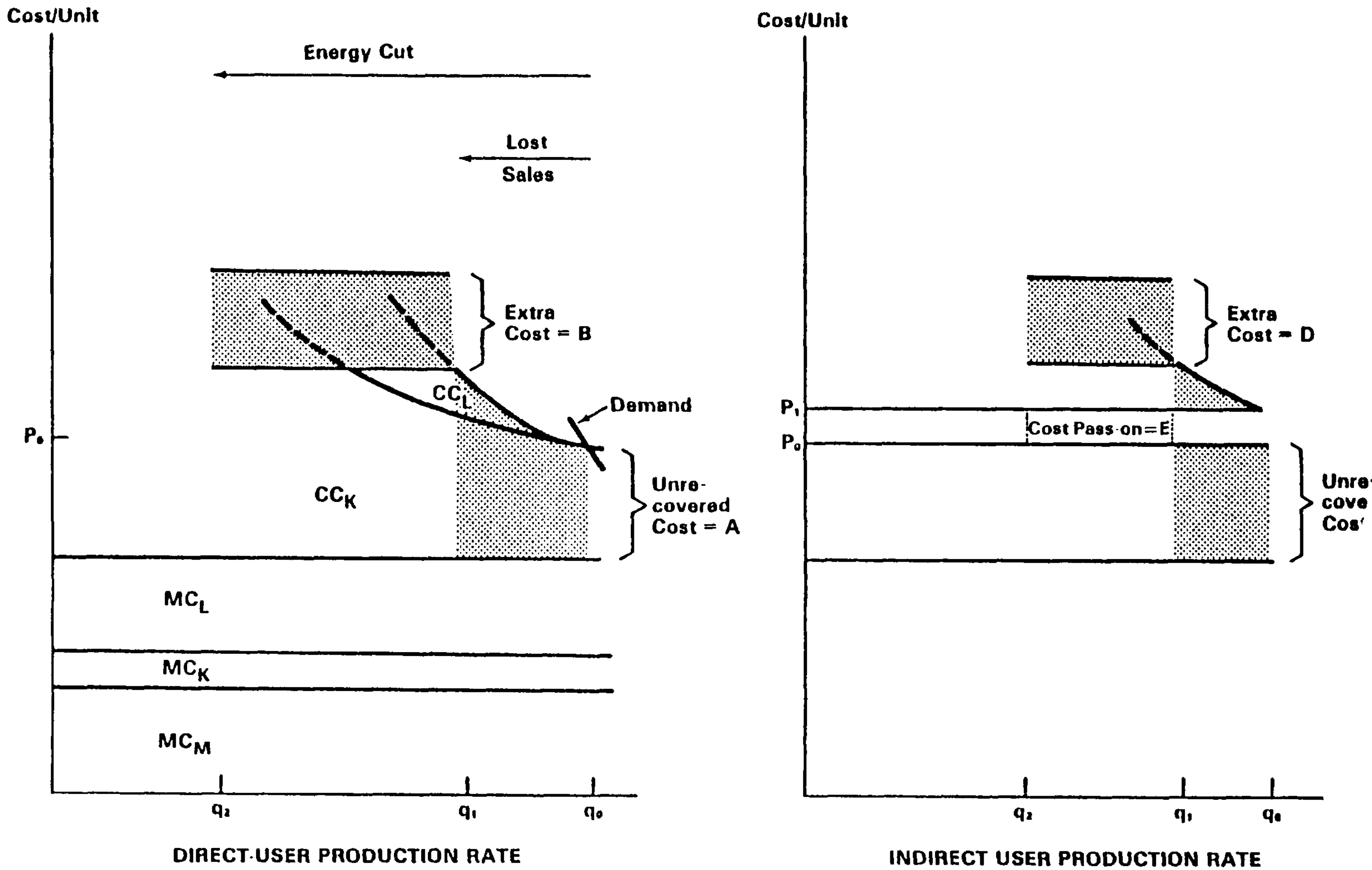


Figure 10: Direct and Indirect User Costs

Employment data may be used to estimate value-added losses with a fair degree of accuracy, based upon relationships from historical data. Industry employment data and geographic detail are available monthly with a one- to two-month lag. Published data include three- to four-digit SIC detail nationwide and broad industry detail (e.g., two-digit SIC in manufacturing) for states and large cities [27] by the Bureau of Labor Statistics, Department of Labor.

Apart from the monthly publication, Employment and Earnings [27], the Department of Labor has a household sample for estimating the annual labor force. The sample size was expanded in January 1978. Estimates of employment status from this sample do not give industry or regional details, but can give monthly unemployment changes nationwide. The only detail in these data is type of labor. Therefore, the utility of these data is limited to estimating nationwide unemployment effects of a shortage. BLS also monitors unemployment due to monthly energy shortages. These data have two major gaps: (1) nonshortage unemployment is also included and (2) short-duration unemployment beginning and ending between monthly sample dates is not picked up.

The regular labor force survey of the Department of Labor is supplemented by additional inquiries. The latter are coordinated with monthly enumerations and are designed to provide more detailed statistics on special aspects of economic activity. Results of these studies are usually published by the Department of Labor in a series of Special Labor Force Reports appearing as articles in the Monthly Labor Review [30]. These articles include data on total employment, highlighting layoffs from special events such as energy shortages. Once again, however, the data do not provide the industry and regional detail necessary for detailed analysis of energy shortage impacts.

Unpublished data with greater detail may be obtained by special arrangements through state employment security offices. However, these are subject to disclosure rules with the result that detail is sometimes withheld. Also, unemployment is usually not attributed to a specific cause such as an energy shortage.

One major problem in using routinely collected data to measure shortage employment effects is the lack of a base to calculate the difference in employment due to the shortage effect. What would the employment have been without the shortage? Employment data are subject to seasonal, cyclical, and random fluctuations and long-term trends. Data may be adjusted for seasonal fluctuations, but available methods are subject to significant error. Cyclical movements may be estimated; long-term trend, by contrast, is not a significant factor in short-term movements. However, the error in the employment estimate without the shortage effect is likely to be larger than the actual effect of the shortage, except for major shortage conditions. Therefore, the reliability of routinely collected data is extremely low for most shortages.

Since the difficulty and reliability of isolating the effect of shortages in the employment measure varies inversely with the size of the effect, the most reliable estimates can be obtained for industries directly affected by the shortage—namely, those industries using fuel in short supply in their production processes. Industries that feel the effect indirectly due to a resulting shortage in some product input may mitigate the effect by using substitute inputs or, more likely, by drawing down input inventories. Thus, the effects experienced are generally smaller and, accordingly, the reliability of the measures decrease.

During previous energy shortages several federal agencies, some state governments, and some private organizations have made assessments of shortage effects on the nation's economy. To illustrate, in 1974 the U.S. Department of Energy conducted a study of the impacts of the 1973-74 oil embargo [15]. This study examined the embargo impacts on GNP, unemployment, and other economic activity. In a study of the recent coal strike the DOE Coal Task Force also estimated the impacts of a protracted strike (reports unavailable).

Surveying several four-digit industries, the U.S. Department of Commerce recently conducted studies on the "Assessment of the January-February, 1977 Severe Winter Weather and Fuel Curtailment on Selected Industries in Manufacturing" (13; 17). Results of the telephone surveys included employment effects, plant closings, and production cutbacks. In the meantime, the Bureau of Labor Statistics also collected data on actual unemployment [28].

In addition, several other federal agencies have launched studies on estimating energy shortage impacts. The Department of Transportation, in particular, conducted a number of postembargo studies on measuring the economic impacts of the oil embargo [12].

At the regional level, various regional commissions—New England Regional Commission, the Ozark Regional Commission, etc.—are developing capabilities to assess impacts from future energy shortages. In the past these and other regional commissions were primarily involved in monitoring shortages.

State energy agencies devote a significant amount of time to monitoring fuel distribution and consumption. In general, states do not have funds to support major activities involving microeconomic models and data systems necessary for projecting shortage impacts. Notable exceptions include: California, Minnesota, Wisconsin, New York, and Massachusetts. States are in a better position, however, to survey and collect reasonably accurate local data. During the 1976-77 winter gas shortage and the 1977-78 coal strike several states monitored the energy supply daily.

Gas and electric utilities, as a matter of business practice, prepare supply/demand profiles but are generally dependent upon prime suppliers and major pipelines for their supply. Utilities generally keep emergency plans for use during sudden supply interruptions, but they do not engage in economic impact forecasting and analysis.

Industry associations conduct special analyses in which a large number of data sources are available. These analyses provide both future planning and advice inputs to various clients [18] . The following organizations are frequent sources of limited data: American Gas Association, American Petroleum Institute, National Coal Association, American Automobile Association, Retail Gasoline Owners' Association, National Oil Jobbers Council, National Congress of Petroleum Retailers, and Society of Independent Gasoline Marketers of America. Basic model relationships can be quantified from past data. Current data, however, is needed for model input.

Current inventory information can be obtained partly through data collected regularly by the Department of Energy, the Department of Commerce, and other federal agencies. State energy offices can provide further information on fuel inventories and electric energy supply. Further information can be collected by telephone calls to large energy suppliers, producers, and distributors. Alternate fuel price information can also be obtained from the same sources. Transport availability information for alternate fuels can be obtained from data regularly collected by the American Gas Association, the National Coal Association, the American Petroleum Institute, other associations and industry sources, and state energy offices.

In addition to these data needed for input to the model, it is imperative that data be collected on a real-time basis on emerging impacts so that the model results can be checked and calibrated as necessary to correct for model structure bias. Data sought will include information on:

1. plant closings or plans to close,

2. availability, use, and cost of alternative fuels by plant, and

3. alternate fuels transport and bottlenecks.

Recent changes in substitution and other means of coping are perhaps the most important information that can be collected during this period. This information is difficult to collect beforehand because plant managers may be unaware of coping possibilities until faced with a dire need.

The bulk of information can be gathered from the same agencies, associations, and industry sources mentioned earlier. In addition, state employment security offices and other state agencies can supply information on plant layoffs. Emergency monitoring offices in federal and state agencies also collect such information continuously during an emergency.

The problem with using data collected from these sources is its low reliability in special applications. An improved but costly approach would involve the predesign of samples from which the data would be collected, either through existing state agencies or by the research organization involved.

Chapter 5

METHODOLOGY: SINGLE SHORTAGE AND SMALL CUTBACK

The simplest methodology is that for a single small shortage. It can be expanded as follows:

1. from a single shortage (such as one winter season) to a distribution of shortages (the probability distribution each year in a planning horizon)

2. from a small cutback (where all impacts originate and possibly are confined to the direct users) to a large cutback when impacts pervade the economy

Definitions of single shortage and small cutback are important for reasons described below.

A single shortage is a quantity of shortfall over a specified time; the definition is designed to allow the following basic shortage cost calculation:

$$\text{(Shortage cost)} = K_i \text{ (Shortage Quantity)} \qquad (5\text{-}1)$$

where "K_i" is cost per unit shortfall for the i^{th} cost component in the Table 3 classification.

The single shortage can be a peak-day capacity shortage or a winter season energy shortage; but it is the quantity of shortfall over a winter season as described below.

Peak-day capacity shortages can occur several times during the winter instead of only one "t_1 - t_2" continuous interval period as shown in Figure 11. In any case, the peak-day shortage volume is the accumulated shortfall during plant protection days, as shown and it is computed as follows:

$$\text{peak-day shortage} = q_5 - q_3, \qquad (5\text{-}2)$$

where quantity "q_5 - q_3" is the quantity "d - c" in Figure 11. This represents the accumulated difference between the consumption rate and the delivery rate, as shown.

Table 3: Shortage Cost Estimation For Small Curtailment

	Substitutable Direct Users (total) (1)	Non-Substitutable Direct Users: Direct User (2)	Indirect User (3)	Employee (4)	Total Impacts (5)
A. Peak-day Capacity Curtailment (impact Costs Only[a])					
Lost Sales	Insig.	$L_1=K_1$ (ΔSales) $=K_1^*$ (ΔMcf)	$L_2=K_2$ (ΔSales) $=K_2^*$ (ΔMcf)	$L_3=K_3$ (ΔSales) $=K_3^*$ (ΔMcf)	
Makeup b/ Costs	$L_4=K_4$ (Δprod) $=K_4^*$ (ΔMcf)	$L_5=K_5$ (Δprod) $=K_5^*$ (ΔMcf)	$L_6=K_6$ (Δprod) $=K_6^*$ (ΔMcf)		
Inefficiency b/	Insig	$L_7=K_7$ (Δprod) $=K_7^*$ (ΔMcf)	Insig.		
Fuel Costs	$L_{10}=K_{10}^*$ (ΔMcf)	$L_{11}=K_{11}^*$ (ΔMcf)			
Damage	Insig	$L_{12}=K_{12}^*$ (ΔMcf)			
TOTAL					$54/Mcf
B. Winter-season Energy Curtailment (Impact Cost Only[a])					
Lost Sales	Insig.	$L_{13}=K_{13}$ (ΔSales) $=K_{13}^*$ (ΔMcf)	$L_{14}=K_{14}$ (ΔSales) $=K_{14}^*$ (ΔMcf)	$L_{15}=K_{15}$ (ΔSales) $=K_{15}^*$ (ΔMcf)	
Makeup b/	$L_{16}=K_{16}$ (Δprod) $=K_{16}^*$ (Δprod)	$L_{17}=K_{17}$ (Δprod) $=K_{17}^*$ (ΔMcf)	$L_{18}=K_{18}$ (Δprod) $=K_{18}^*$ (ΔMcf)		
Inefficiency b/		$L_{19}=K_{19}$ (Δprod) $=K_{19}^*$ (ΔMcf)	Insig.		
Fuel Cost	$L_{21}=K_{21}^*$ (ΔMcf)	$L_{22}=K_{22}^*$ (ΔMcf)			
Damage	Insig.	$L_2=K_{23}^*$ (ΔMcf)			
TOTAL					$ 5/Mcf

C. Numerical Estimates from 1976-77 Gas Shortage (in dollars)

K_1=.50	K_1^*= 22.00	K_9=	K_9^*=	K_{17}=	K_{17}^*=See K_{19}^*
K_2=0.0	K_2^*= 0.0		K_{10}^*=.71	K_{18}=.00	K_{18}^*=.00
K_3= .50	K_3^*= 4.50		K_{11}^*=.90	K_{19}=.28	K_{19}^*=2.40
K_4= .28	K_4^*= .60		K_{12}^*=.45		K_{21}^*=.66
K_5=See K_7	K_5^*=See K_7	K_{13}=.50	K_{13}^*=1.93		K_{22}^*=.95
K_6=.28	K_6^*= 3.70	K_{14}=.00	K_{14}^*=.00		K_{23}^*=.00
K_7=.28	K_7^*= 23.00	K_{15}=.50	K_{15}^*=.03		
K_8=	K_8^*=	K_{16}=	K_{16}^*=.88		

Note: Δ signifies reduction; i.e., reduction in available Mcfs of energy, sales, and production (prod).

[a] Coping costs are not included in this table.

[b] Makeup and efficiency are combined.

Source: Reference 19

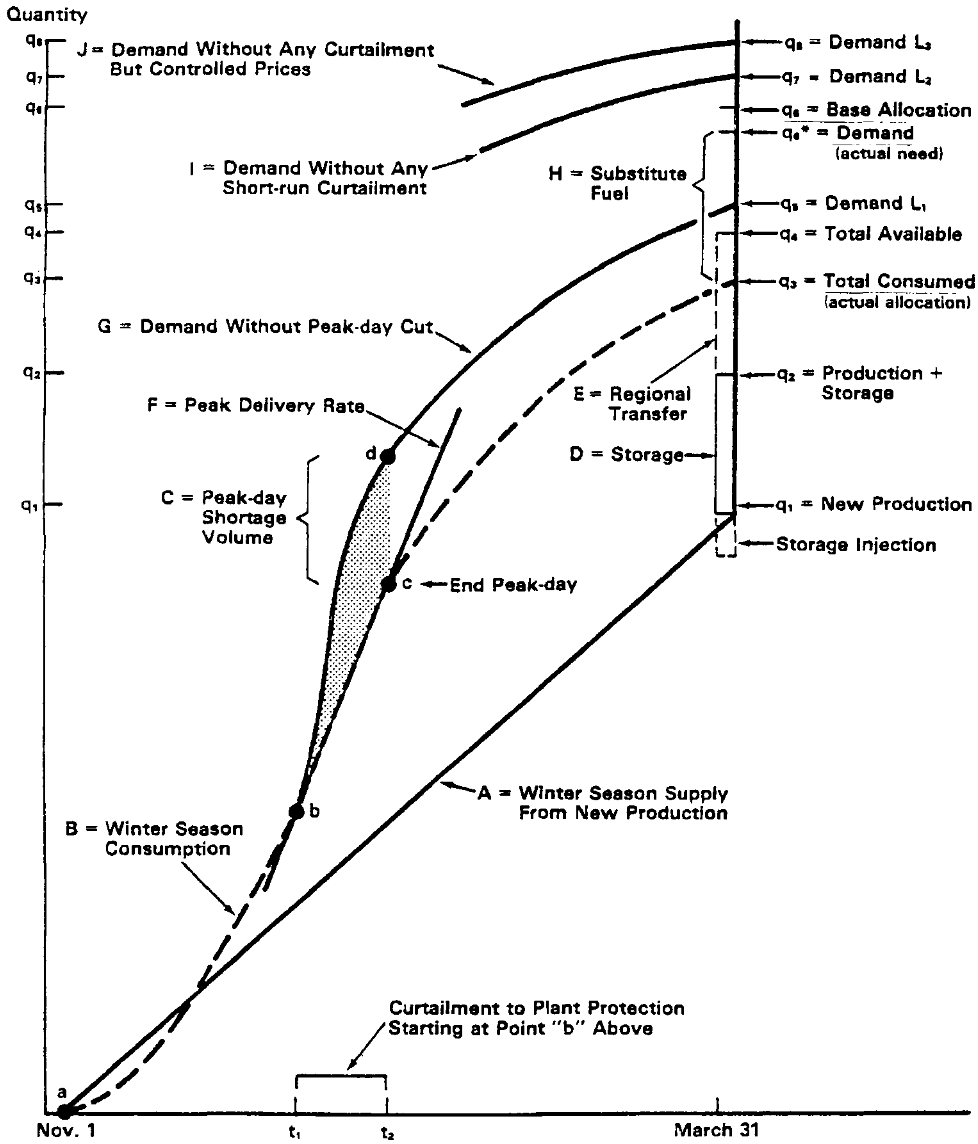


Figure 11: Winter Season Capacity & Energy Shortage: Region X

Winter season energy shortages can occur in any of the five months, and the total shortage is defined in Figure 11 as:

$$\text{actual winter shortage} = q_6^* - q_3 \qquad (5\text{-}3)$$

but must be measured as

$$\text{winter observable shortage} = q_6 - q_3 \qquad (5\text{-}4)$$

where demand "q_6^*" can be above or below the base allocation. In other words, supply can exceed base allocation if, say, weather permits and requires considerable gas transfer as designated by Item E in Figure 11.

For practical reasons, winter season shortages must be defined in base allocation terms rather than the q_6^* demand (i.e., demand under a system of base allocations). Stated otherwise, the q_6 base allocation is a known quantity and permits calculation of shortages. Demand q_6^* is unobservable, although it is the desired base from which to calculate shortages.

Quantities and definitions in the Figure 11 schematic of winter season (short-run) shortages are complex; nevertheless, they represent the real world. It is essential to understand energy shortage conditions of Figure 11 before reviewing the methodologies for estimating shortage impact and coping costs in the next sections.

Given the above definition and discussion of "single shortages," we can now define "small cutback" (the level of cutback for which the methodology in this section is applicable).

A small shortage is a winter season in which (1) virtually all shortage impact costs are generated at, and possibly confined to, the first stage in the four-part ripple effect depicted in Figure 7 and (2) shortage coping costs are not increased because user expectations do not increase. The change in user expectations and his subsequent investment in greater coping capacity are better discussed in the next section.

Among other things, a small cutback is a situation where shortage impact costs can be estimated from information at the direct users' level—Stage 1. It is obvious that such small cutbacks are easier to evaluate than large cutbacks.

Estimating Shortage Impact Costs

The methodology must include: (1) the means for determining if the energy cutback is small enough to use the simplified estimation and (2) the parameters and equations for estimating actual shortage costs in a "small shortage."

Figure 12 is drawn to show small costs beyond the direct user. Generally this energy shortage is not intense (i.e., it is a small percentage cut or of a short duration). Thus, costs to the direct user and the reasons for small indirect user costs are discussed first.

If sales are lost, direct user costs are the "unrecovered cost" shown as Area A in Figure 12. These could be capital costs or labor costs to retain employees in order to avoid losing them. Unrecovered costs could easily be 50 percent of the market value of lost sales, as indicated in Figure 12.

If the indirect user can obtain the same product from another supplier with little extra transportation or can use a substitute product with little sacrifice, his loss, even when the direct user loses sales, will be small, as indicated by shaded areas C and D in Figure 12. For example, if the energy shortage is local, indirect users can quickly obtain an alternative supplier or product.

If the direct user maintains production, his "extra costs" are one or more of the following:

1. Cost of substitute fuel
2. Cost of overtime to make up production loss during the shortage
3. Efficiency loss if substitute fuel is inferior or production is continued with below optimum energy resources
4. Cost of damage to plant or in-process products

These impact costs pertain only to a part of production, as indicated by shaded area B in Figure 12. For example, a 50 percent energy cut would generally affect 50 percent or less of production.

There are reasons why no significant additional impacts exist beyond direct-user impacts (when the direct user maintains sales, there are only small effects on indirect users, as

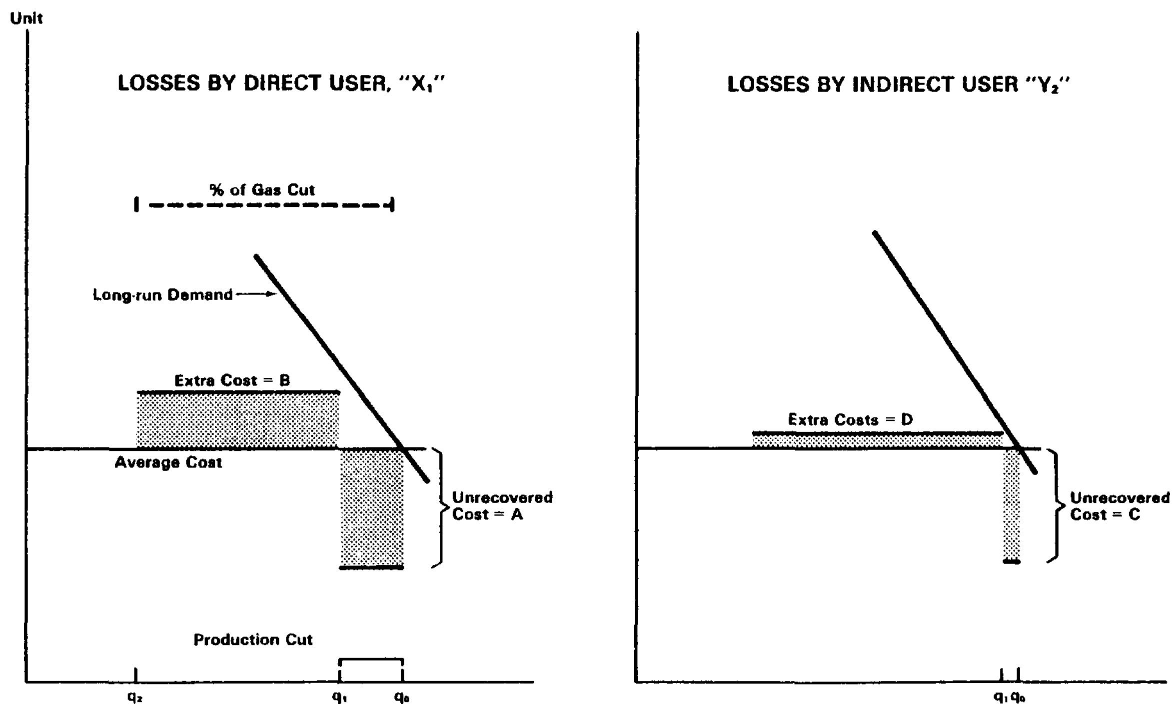


Figure 12: Losses By Direct And Indirect Gas Users

indicated by shaded area D in Figure 12). First, either the supplier inventory of product X or the user inventory allows uninterrupted production, despite direct user interruptions. Second, extra costs of fuel, overtime, and inefficiency are not passed on.

Verification of negligible shortage costs beyond the direct user involves considering the same costs shown for the direct user in the left-hand side of Figure 12, namely:

1. Area C. The cost if the indirect user loses sales. The production delay by direct user causes both output delay and lost sales by indirect user Y_2; this, in turn, causes greater sales loss by direct user X_1.
2. Area D. Indirect user's cost to maintain production include:
   a. Waiting on products from the direct user,
   b. Substituting an inferior product, or
   c. Buying the same product elsewhere and paying higher transportation costs.

   The latter two reasons, in turn, augment sales losses by direct user X_1.

The Table 3 matrix summarizes the estimation of shortage costs for "small curtailments." It is necessary to estimate costs from peak-day curtailments (essentially 100% cutback under plant protection) apart from winter season energy curtailment because of widely different losses/Mcf.

Numerical estimates from the 1976-77 natural gas shortages are given in the bottom of Table 3. They are representative of typical values for the six parameters shown in the upper part of Figure 9. Appendix A gives more detail on the parameter values.

As shown in Table 3, the model allows better estimation if direct user information is available on (1) sales loss, (2) amount of production delayed, and (3) volume under less efficient production. The K_I^* coefficients are provided in case direct-user information in unavailable and measures of energy curtailed must be used.

Estimation of Coping Costs

Coping costs can increase during and after a specific shortage, but the cost should not be allocated to a specific shortage. Coping costs increase whenever the occurrence of a specific shortage increases users' expectations of future shortages as shown in Figure 13.

Fuel substitution during a specific shortage should be analyzed carefully. In the following outline, only Item 2a is significant in response to a small shortage:

1. Investment to increase future coping capability
   a. Higher percentage of fuel substitution
   b. Greater inventories
   c. Rearranged production schedule

2. Fuel substitution
   a. Higher cost/Btu
   b. Storage and carrying cost of substitute fuel

Investment in Items 1 and 2b are insignificant because the incidence of a "small shortage" does not cause the user to increase preparedness; the explanation is given in Figure 13.

A single shortage (or notice of a pending shortage) will create significant investment costs only if the user expectation of benefits shifts upward from MV to MV' as shown in Figure 13. The MV' marginal value of substitution capacity is:

$$MV'_Q = P_Q \left[\text{Shortage Impact Cost}\right]_Q \qquad (5\text{-}5)$$

where MV' is the incremental value of having substitution capacity of "Q + Q", P_Q is the probability of shortages greater than Q, and "shortage impact cost" for level Q is the V_4 value shown at the top of Figure 13.

After each shortage, the marginal value curve can shift upward for two reasons: first, the estimated probability can increase and second, the loss when a shortage occurs can be greater than expected, as shown by the estimates V_3 and V_4 in Figure 13. Conversely, there are two reasons why a small shortage does not shift the curve: (1) shortage impact costs per unit of shortage are generally small and (2) small shortages have little effect on user expectations; they might lower expectations, but the user cannot disinvest in the short-run.

In the next chapter, the important investment decisions perspective in Figure 13 will be utilized and explained further in discussing severe shortages.

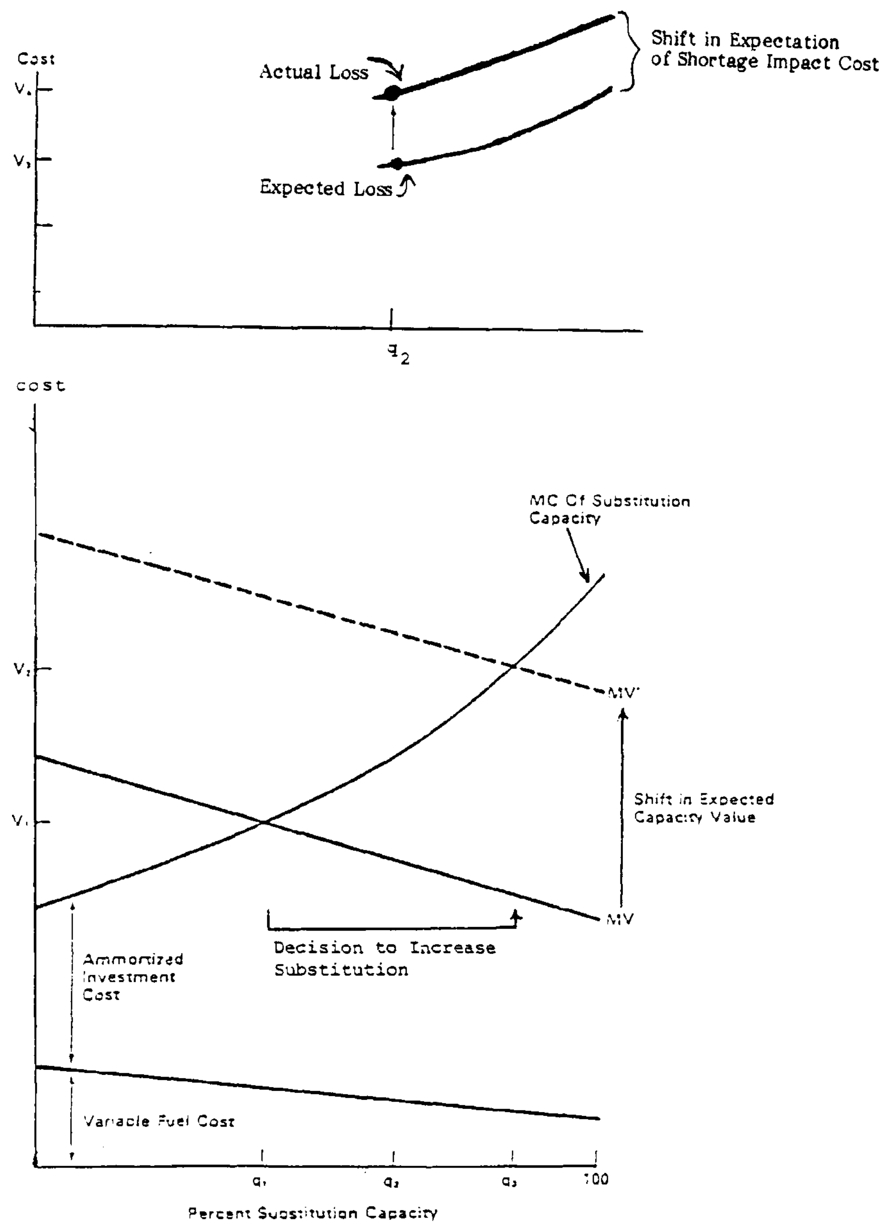


Figure 13: Decision on Substitution Capacity After A Shortage

Table 3 does not present coefficients for estimating shortage coping costs. These costs are negligible for a small shortage because users don't reevaluate their shortage expectations for the reasons stated above. The model and empirical estimates in Table 3 will become clearer after discussion of severe shortages in the next chapter.

Chapter 6

METHODOLOGY FOR SINGLE SHORTAGE WITH UNLIMITED CURTAILMENT

The 1976-77 natural gas case study in this report's empirical work failed to provide observations for this section because the shortage was too small. However, isolated users who were curtailed 100 percent provided perspective and clues on how the methodology must appear.

Unlimited Curtailment in a Single Shortage

The unlimited curtailment requires three major extensions from the small shortage:

1. Indirect user costs are substantial in relation to direct user costs (the shaded areas C and D in Figure 14 for all indirect users are large relative to shaded areas A and B and must be estimated explicitly) and can, in turn, generate larger direct user costs.

2. Impacts can extend to the final consumer in the following sequence:

   Stage 1 — direct user as a producer

   Stage 2 — indirect user as a producer

   Stage 3 — final consumers

3. Two losses beyond market values of goods and services can be significant:

   a. Macro-economic effects from lower income and unavailable products

   b. Employee sacrifice from loss in wages and poor working conditions

It should be noted that Items 1 and 3b above were handled as pre-specified increments to direct user costs in the methodology for small shortages. The final consumer impacts in Item 2 and macro-effects in Item 3a were disregarded because they are insignificant in small shortages.

In a severe shortage, the costs from loss in sales (Areas A and C in Figure 14) are larger than the extra costs from continued or delayed production (Areas B and D in Figure 14).

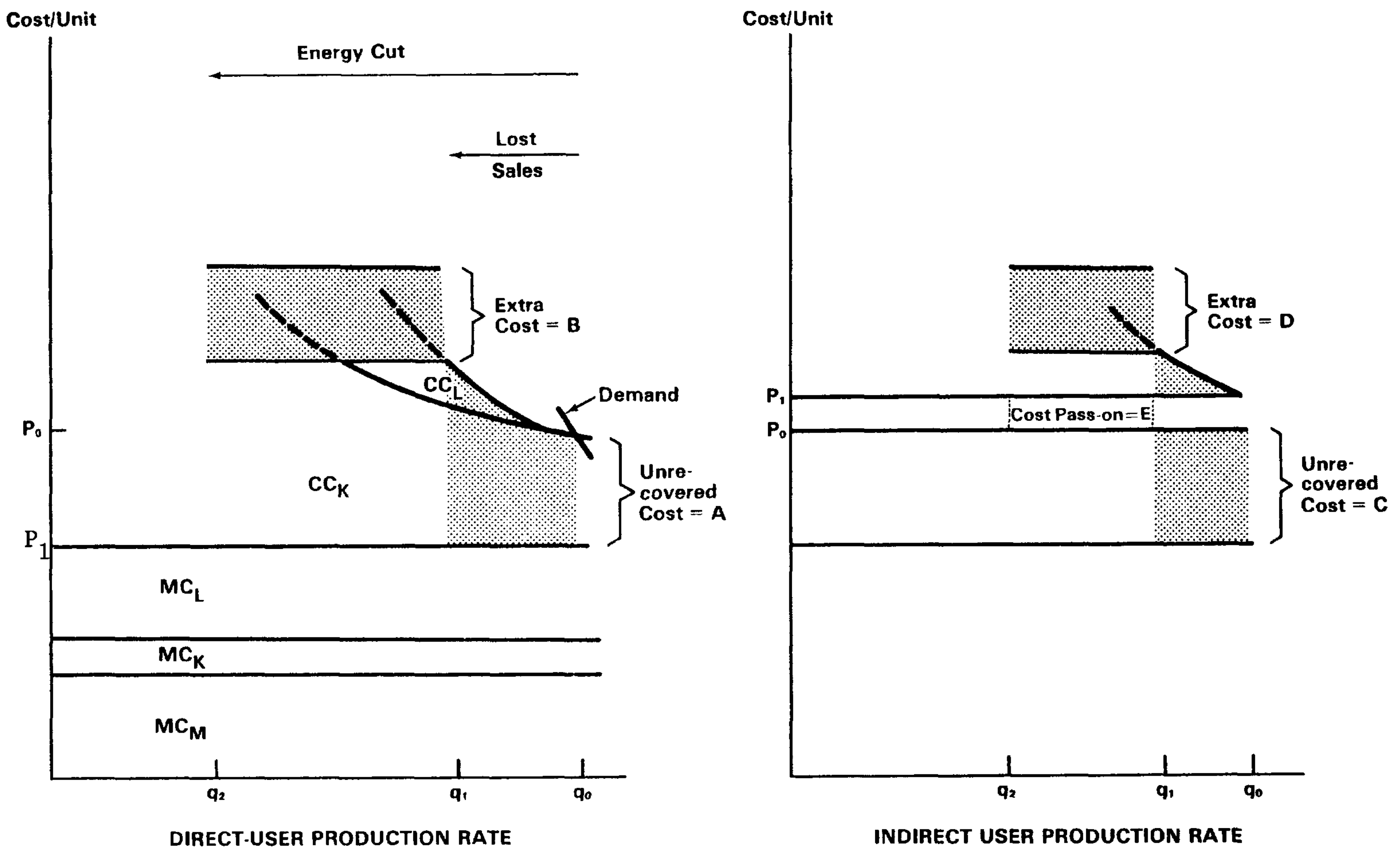


Figure 14: Direct and Indirect User Cost Comparison

Modifications of input-output analysis seem the best way to estimate effects from extensive loss in sales.

Figures 10 and 14 help us go from the small to the large shortage situation. These schematics are complex, but the reader must comprehend the complex real-world phenomena before he can apply the methodology reliably.

Figure 14 basically resembles Figure 10, but several details are added for identifying significant new shortage costs. The shortage impact costs are the same two items:

> Unrecovered cost — the Area A loss when sales are reduced from normal level q_0 to q_1 and fixed costs are not recovered.
>
> Extra cost — the Area B loss from additional cost due to (1) fuel, (2) making up postponed production, (3) lower operating efficiency with less energy, and (4) damage costs.

These costs can occur at both the direct user and indirect user levels, as shown on Figures 10 and 14.

Unrecovered costs are easily understood by subdividing the three major production costs into two parts:

1. Variable cost (at the margin)
   a. Marginal cost of materials, MC_M
   b. Marginal cost of capital, MC_K
   c. Marginal cost of labor, MC_L
2. Fixed costs (for given production level)
   a. Common cost of capital, CC_K
   b. Common cost of labor, CC_L

Once a facility is in place, fixed costs are larger than when a facility is being planned; furthermore, the fixed costs are common to all output units, whether normal or curtailed production. Therefore, fixed costs per unit of production increase as sales are lost because the "fixed costs" must be allocated (are common) to a smaller number of production units. In addition, the cost of retaining employees during interrupted production is a common cost.

Costs passed-on by direct users are not counted twice, as indicated by the unshaded area in the right-hand side of Figure 14. However, the passed-on cost is important for the indirect user's decision and ripple effects — it can cause the indirect user to purchase an alternative product and thus cause the direct-user to lose sales. This is discussed using the Figure 15 context below.

The shortage impact sequence and producer/consumer decisions can be outlined using Figure 15 as follows:

1. At the shortage onset, the direct user faces "extra costs" as shown by Area A.

2. If "extra costs" per unit are larger than losses from foregone sales, he will cut production and incur Area F loss from "unrecovered costs."

3. If the delay in satisfying indirect users (customers) is excessive, customers will change products and/or lose sales and force the direct user to lose sales. Again, the direct user incurs Area F loss from unrecovered costs.

4. Indirect users will incur either the extra cost (Area D) or the unrecovered costs (Area G).

5. Consumers will lose utility (product satisfaction) in Area E because they must wait for goods and services. If they lose too much, they will switch to a new product and force the sales reduction in Area G.

6. Employees will incur the Area H loss because a short-run surprise layoff with an income cut has a higher level of loss from wage interruption than it gains in leisure opportunities from work interruption.

7. Reduced employee income and lower consumer purchases can trigger the economic multiplier effect (see Figure 8, Row 13, Column 6) which then causes sale loss and unrecovered costs in Areas F and G.

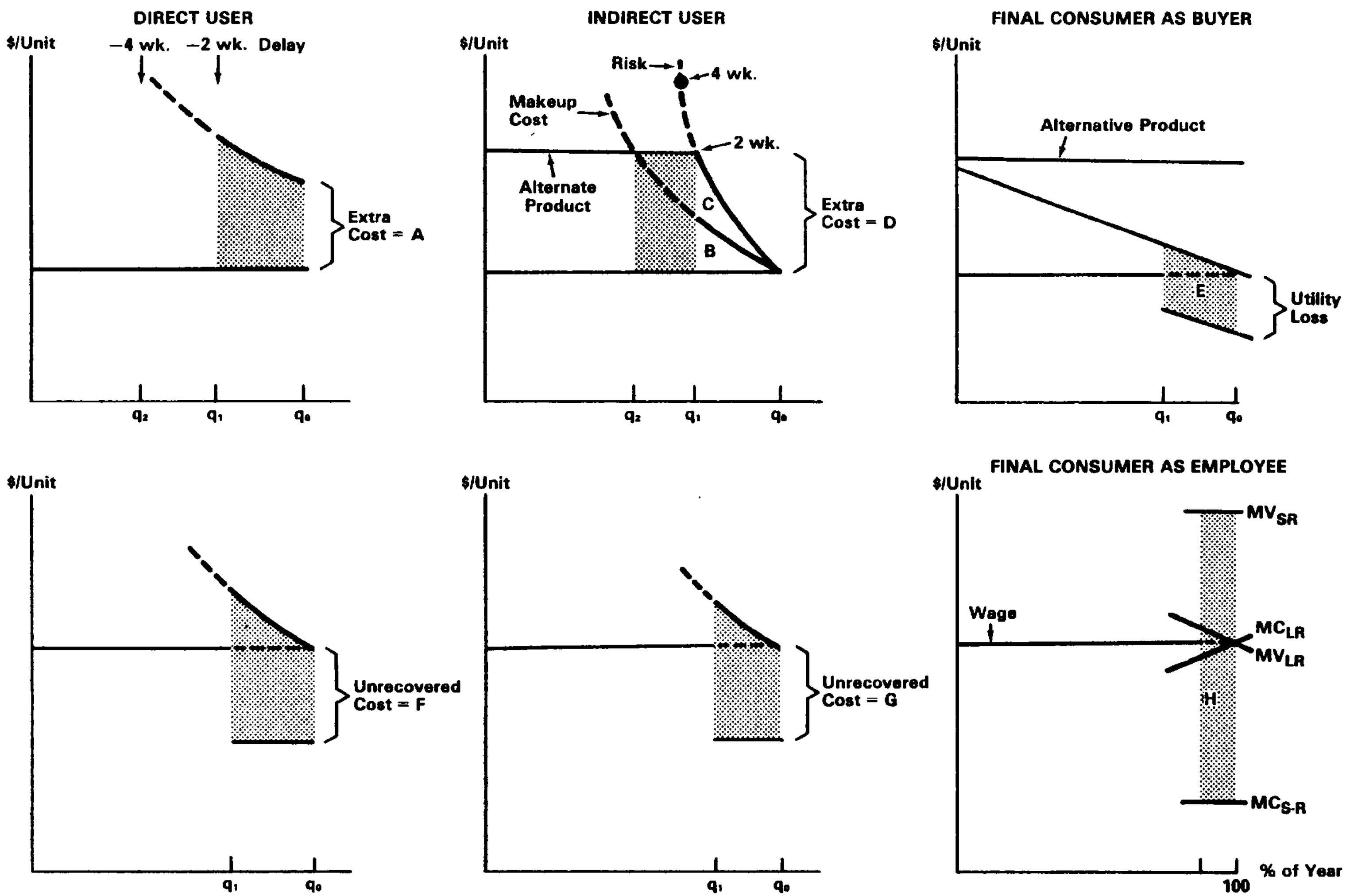


Figure 15: Cost of (1) Delays, (2) Sales Loss, and (3) Employee Income

As noted, the shortage impact sequence is complex, but a good methodology must portray the real world.

Before studying the more technical discussion in Appendix C, it is helpful to define losses from the indirect user, the consumer, and the employee.

The indirect user and direct user shortage impact losses are the same type —"unrecovered costs" from sales loss and "extra costs" from maintaining production without normal inputs — but the former can be the larger loss in a severe shortage, whereas it is a smaller loss in a small shortage. The coping costs are of a different type, but these are relevant only for the repeated shortage.

The "extra costs" to maintain production by direct and indirect users can be summarized as follows:

	Direct User		Indirect User
1.	Substitute fuel a. Greater cost per unit b. Less desirable fuel	1.	Substitute product or supplier a. Greater transportation b. Less desirable product
2.	Overtime labor cost to make up lost production	2.	Same
3.	Damage (e.g., freezing goods or ruining in-process production)	3.	Unlikely
4.	Lower efficiency a. Cold working conditions b. Use of less energy c. Change of production schedule	4.	Less likely than in the case of the direct user

The ratio of output to input can differ greatly between and among direct and indirect users. Therefore, the above costs must be estimated in an input-output (I-O) framework where input-output ratios are considered explicitly.

The "extra costs" per unit output can be computed for each input-output sector and applied to the reduced volume of production (temporary or permanent) — the reduced volume that is determined by the I-O analysis discussed more fully in Appendix C. The volume of reduced production must be divided into (1) lost sales and (2) maintained sales at increased cost. The decision to maintain or forego sales should be based on cost of production, as discussed in Appendix C.

The unrecovered costs per unit reduction in output (see Areas A and C in Figure 14) differ among economic sectors. However, these can be expressed in a function of the "value added" computation in input-output models. The functional relationship between unrecovered costs and output reduction can be built up in three parts as follows:

1. Fixed cost/unit at the margin (see "P_0 - P_1" at quantity q_0 at the left of Figure 14)

2. Increment to fixed-cost/unit as sales are reduced (see the increase in cost CC_K as "q" drops below q_0 in Figure 14)

3. The implicit labor cost when employees quit during layoffs (see cost CC_L as "q" reduces in Figure 14)

The sum of these costs can be expressed as a function of sales loss by I-O sector and this function can be applied to the new sales vector from the I-O analysis.

Details on the modification of I-O models to handle the above estimation is discussed in Appendix C and summarized in five steps below:

1. Add restrictions on volume of energy

2. Add inventories to the final demand vector to account for production without normal energy (or product supply)

3. Modify the I-O coefficient A_{ij} to account for substitute energy (and products) and, thereby, allow continued production

4. Modify the I-O coefficient A_{ij} a second time or add another coefficient to account for extra costs of production when energy (or product) is short

5. Scale down the final demand vector to account for reduced final demand due to (1) reduced employee income and (2) the multiplier effects

The fifth step might require an iterative use of the I-O model, but this can be incorporated, as indicated in Appendix B.

The above steps help us to review the six parameters that shift the shortage impact curve -- the six parameters shown in Figure 9, Chapter 4. The steps for modifying parameters 1 through 6 are outlined below.

Step 1:	Restrict volume by sector	Parameter 2:	The larger the storage duration, the greater the energy restrictions on I-O sectors.
Step 2:	Add inventories to final demand vector	Parameter 4:	The greater the warning time, the greater the opportunity to increase inventories, and thereby reduce impacts.
		Parameter 5:	The greater the excess production capacity and the inventory levels, the lower the impacts.
Step 3:	Modify I-O coefficients to allow production	Parameter 6:	The more that curtailment is focused on users who can cope best, the more the smaller A_{ij} modifications will come into use.
Step 4:	Modify coefficients for extra cost	Parameter 1:	The greater the geographic coverage, the higher the cost/unit of the substitute.

		Parameter 3:	The more that users underestimate shortage potential, the greater the value of the new coefficient A_{ij}.
Step 5:	Scale the final demand vector	Parameter 1:	The smaller the geographic area, the smaller the final demand vector that is at stake.
		Parameter 1-6:	The more that all parameters tend to increase layoffs, the greater the reduction (the scaling in Step 5) in final demand resulting from macro-economic effects.

The above summaries and outlines of methodology provide a guide to the technical aspects of shortage cost estimation in a severe shortage.

Chapter 7

METHODOLOGY FOR REPEATED SHORTAGES

This section focuses only on the additional methodology required beyond that needed for a single shortage. There are two major additions:

1. The discounted value of probable future shortages in contrast to an actual present shortage, and

2. The sum of shortage coping costs and shortage impact costs in contrast to impact costs only.

Repeated Shortages

The cost of the 1976-77 natural gas shortage (as with other single shortages) and the cost of repeated shortages can be defined as follows:

1. Single shortage — the difference in costs with and without a single specified shortage occurring at a specified date and, thereby, establishing the 12 parameters and percentage shortfall shown in Figure 9.

2. Repeated — the difference in costs with and without the possibility (or changed probability) of shortages each year within the planning horizon.

Cost analysis of a single shortage excludes user expectation and, therefore, preparatory measures; however, a single shortage can cause reevaluation of expectations about the underlying distribution of shortages, thereby giving the analyst an opportunity to analyze repeated shortages. Repeated shortages, on the other hand, include expectations of future shortages; assessment of repeated shortages must include both shortage coping costs and shortage impact costs.

Shortage Impact Costs

The "with and without" situations for repeated shortages are particularly hard to describe because the following scenarios about repeated shortages may occur:

1. Lower probability or severity of shortages but not their complete elimination, so that some impacts shown in Figure 16 continue.

2. Lower actual probability but not necessarily lower user expectations; these expectations lead to the shortage coping cost curve in the lower part of Figure 16.

3. Lower shortage impact costs by improved allocations but not necessarily a reduction in overall shortage quantity (see the 12 factors that can shift shortage costs listed in Figure 9).

The additional methodology is presented in detail in Appendix C and is summarized below.

The present value calculation and the summation over various severity levels can be handled in a straightforward fashion:

$$\text{Shortage Cost} = \sum_{t=1}^{M} (1+r)^{-t} \left[\sum_{L=O}^{100\%} P_L \ (IC + CC)_L \right]_t \qquad (7\text{-}1)$$

where r is the annual discount factor, the time periods "t" extend to a reasonable time horizon "M," and the shortage impact costs (IC) and shortage coping costs (CC) are considered at shortage severity levels from 0 to 100%.

The shortage impact and shortage coping costs functions in Figure 9 are redrawn in Figure 16, along with the expected annual costs. In other words, each curve shows what the cost would be for a given level of shortage; the annual loss is the expected or average annual loss considering the associated probabilities. As indicated in Figure 16, the expected costs are C_1 and C_2 for an implied set of values for the 12 parameters listed in Figure 9 -- the 12 parameters for the 1976-77 natural gas shortage are given in Appendix A.

The "with and without" situation for repeated shortages can be illustrated in the Figure 16 schematic as follows:

1. Lower actual probability and lower user expectation — this lowers the shortage impact cost (IC_L) with annual loss C_2, and lowers the coping cost curve in (CC_L) with annual loss C_1 in Figure 16.

2. Lower actual probability without change in user expectation — this lowers the shortage impact cost curve (IC_L) as well as the annual loss (C_2), but does not lower the shortage coping cost curve (CC_L).

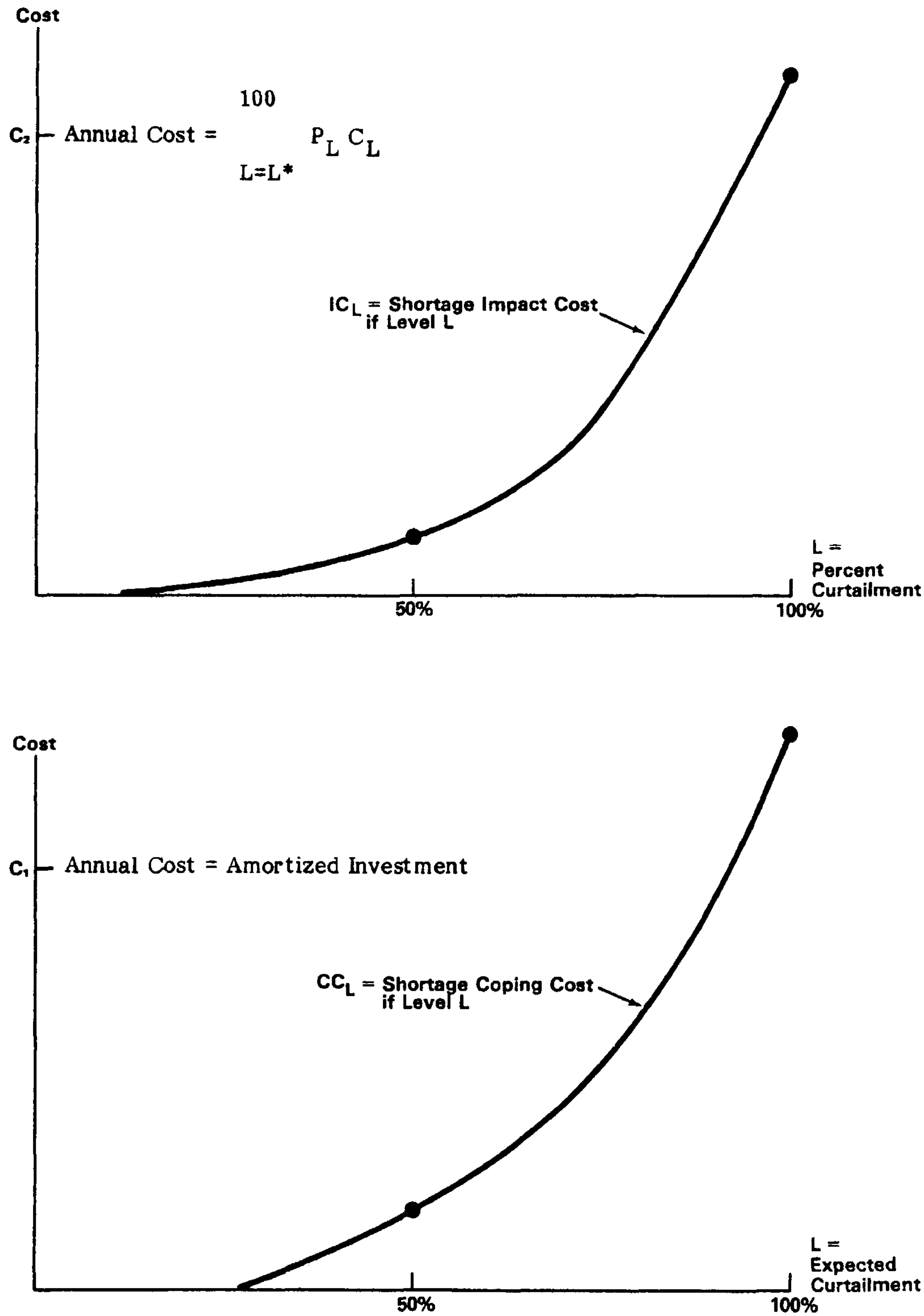


Figure 16: Aggregate Curves and Expected Annual Costs[a/]

[a/] Annual impact cost is the sum of probability (P_L) times cost for every possible shortage level above the L* substitution capability

The fact that shortage coping costs lead to lower future shortage impact certainly illustrates the need for updating shortage impact evaluation parameters after each shortage that can significantly change user expectations and change some of the 12 parameters in Figure 9.

Shortage Coping Costs

Coping costs are not analyzed for single shortages; coping costs are defined as any coping process for which the cost must be amortized over multiple shortages. Any costs that can be attributed solely to a specific shortage are defined as shortage impact costs because they are an impact of that specific shortage.

Several examples and explanations of coping costs are given in the previous subchapters. This subchapter is a concise summary of the approach to estimation and evaluation of the many important factors that must be considered in estimating coping costs.

Figure 17 summarizes the coping adjustment and coping costs for the "repeated shortage" situation. First, for each user, a new (single) shortage is likely to shift two aspects in his perceived shortage danger:

1. Probability — e.g., his estimated probability of a shortage requiring q_2 or greater substitution capacity in Figure 17 can increase.

2. Curtailment loss — e.g., the V_4 shortage impact cost for a shortage severity of q_2 in Figure 17 could be less or greater than his prior estimate of V_3.

As shown in Figure 17, a single shortage of level q_2 can shift the entire curve of "perceived" marginal value (MV) and the entire curve of perceived shortage impact cost (IC) — i.e., the whole curve can shift even though the observed shortage is a single event at a specified severity q_2.

The coping cost following the shortage causing the hypothetical shift in Figure 17 is the area under the MC curve between substitution levels q_1 and q_3. This assumes that coping investment was at the decision level q_1 prior to the shortage which causes the shifts shown in Figure 17.

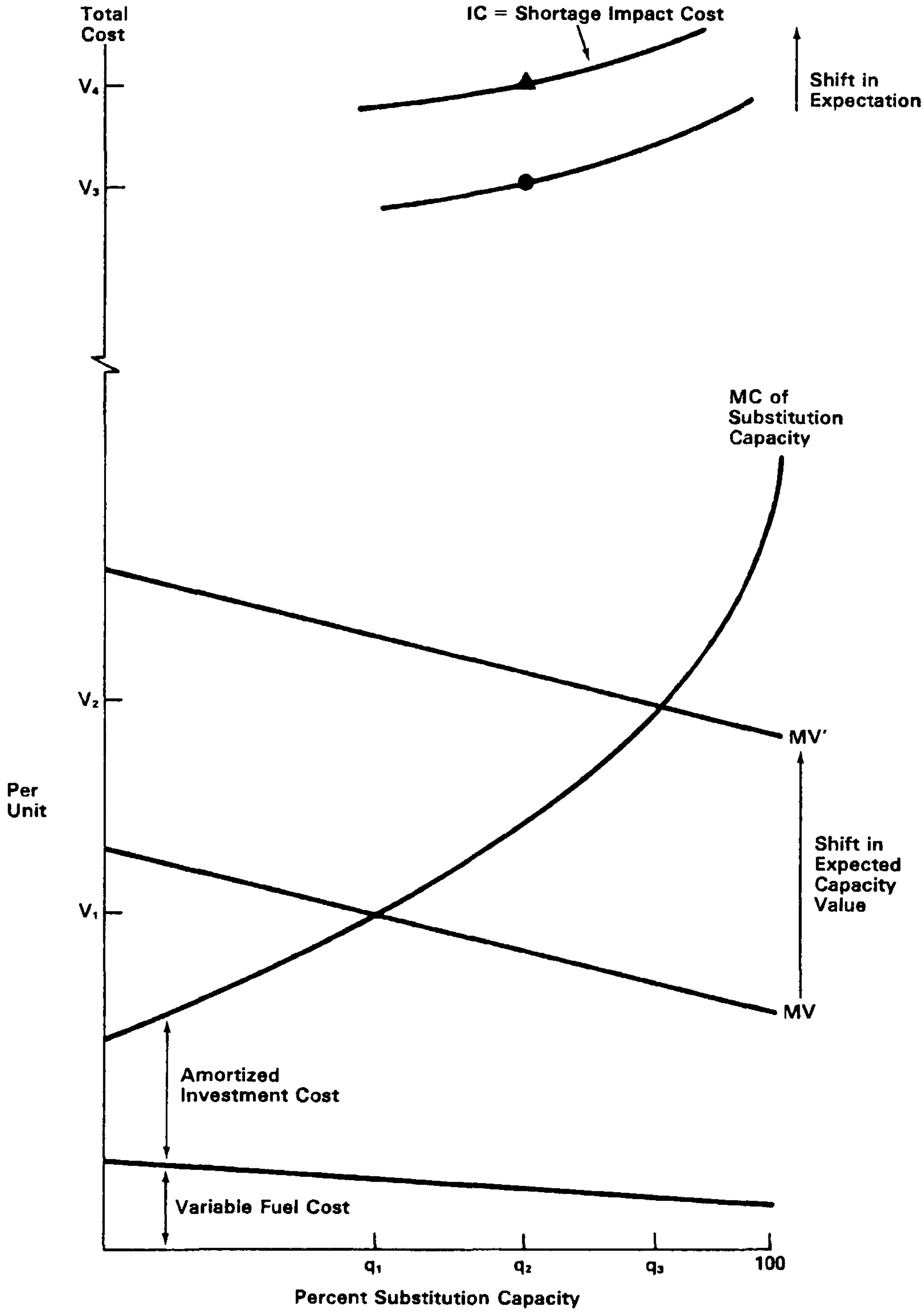


Figure 17: Decision on Substitution Capacity

Chapter 8

COMPARISON OF ELECTRICITY AND GAS SHORTAGES

There are many similarities in shortage impacts between electric power shortages and natural gas shortages. There are also interesting differences with respect to policy decisions for reducing shortage impacts. Some of the comparisons are apparent from the two case studies discussed in this report: (1) the 1976-77 natural gas shortage covering many states for several months and (2) the Key West electric power shortage covering most of one Florida county for 26 days. Other comparisons are available from a conceptual analysis of energy shortages.

Methodology Developed from the Natural Gas Case Study

Although the main shortage evaluation methodology in this report was developed primarily for the 1976-77 natural gas shortage, the methodology has direct application to electricity.

In the first place, both electric and gas capacity shortages occur because it is too expensive to provide sufficient capacity for peak demands with low probability. Similarly, capacity shortages can occur at various aggregation levels within the national supply network (a distribution segment, an entire local distributor, or a group of distributors).

The same two distinct shortage situations need to be identified for applying the methodology to electricity; namely,

- Peak-day capacity shortage -- natural gas curtailment when pipes are too small to meet peak-day demands. This is directly analogous to limited electrical generating capacity.

- Winter energy shortage -- natural gas curtailment when winter weather creates a November-March demand in excess of production plus storage. This is analogous, for example, to a coal strike limiting electric power production during the strike period; it is also analogous to implicit energy limits when electric power plants are curtailed by referendum or other means.

In both of the above shortage situations, the methodology can be used for electricity in two ways:

1. Basic methodology can be used to structure an evaluation of electric shortages.

2. Parameter estimates from the 1976-77 natural gas shortage can be utilized directly as a first approximation of shortage costs per unit of shortage.

The most important aspect of the methodology for electricity application is the clear separation between shortage coping costs and shortage impact costs. The coping investment decision portrayed in Figure 18 is equally applicable to electricity and natural gas despite the different choices available between user and supplier coping.

There are, however, several important differences between electric power and natural gas shortage impacts that must be honored:

1. The natural gas user can better allocate his share of continuing supply to priority uses; therefore, an X% reduction in gas to a user can have less impact than an X% reduction, in, say, voltage in electric power supply.

2. Natural gas energy shortages can be anticipated further in advance and the energy shortage (as opposed to capacity shortage) can be allocated in many ways; therefore, the empirical estimates for natural gas capacity shortages are more applicable to electric power than are the estimates for energy shortages.

3. The electric power supplier can sometimes provide less expensive coping solutions than can the user; therefore, the coping cost function must include supplier as well as user actions and costs in electric power.

All three differences are discussed below, and the third difference is discussed further in Reference 65.

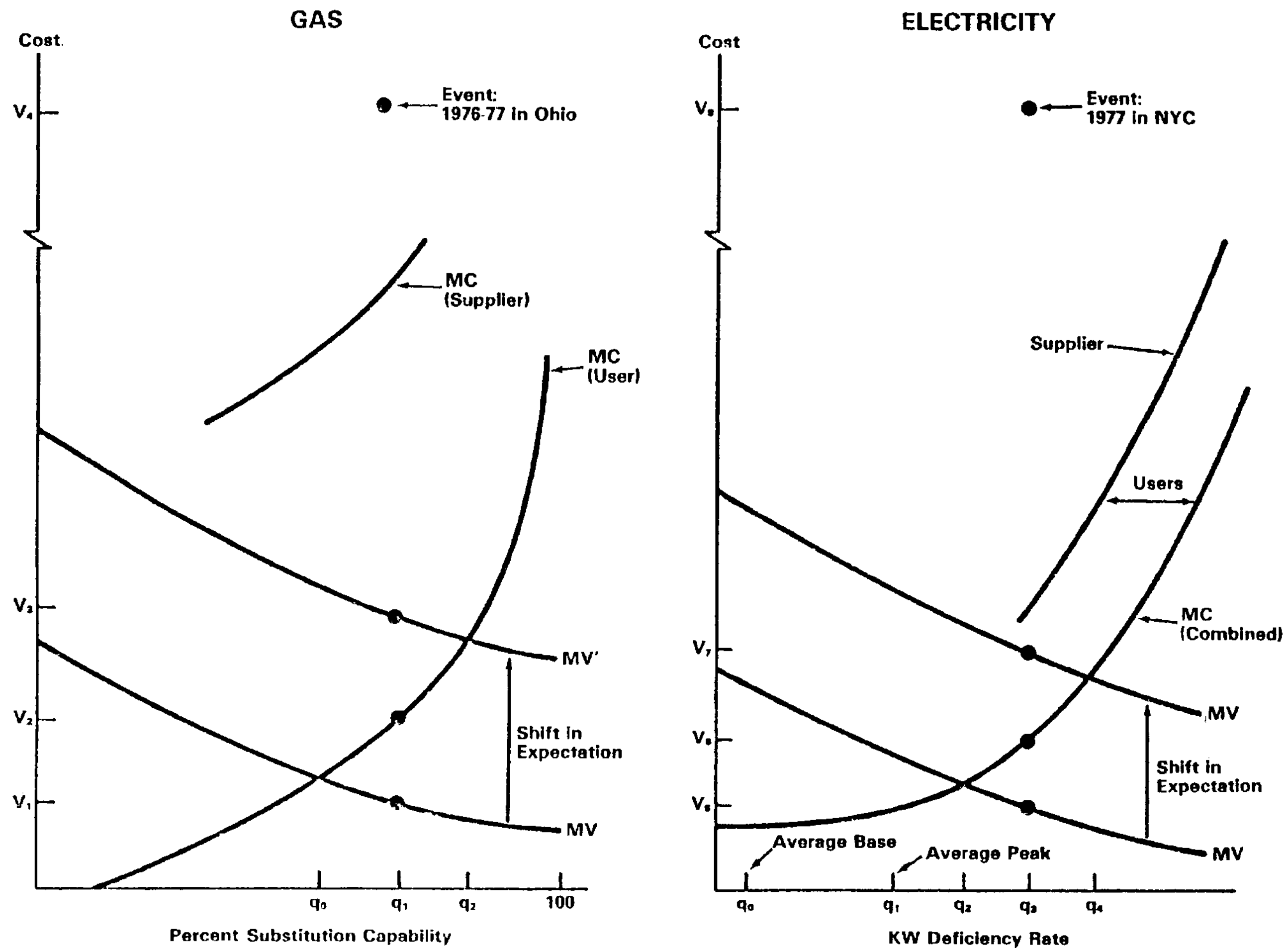


Figure 18: Investment Decision For Coping With Or Preventing Shortages

Impact Cost Similarities: Electricity and Gas

A major difference between electric power and natural gas is the ability of the user to select highest-priority uses. The natural gas user can allocate his X percent of continuing supply to his highest priority use; the electric power user has no way to concentrate his X percent. The electric power user must live with an X percent reduction in voltage because he cannot turn off some uses to attain a 100 percent voltage for remaining uses.

We note, however, that the electric power supplier can arrange for allocation by interrupting service to some users. This fits nicely with the supplier-user cooperation depicted by the coping mechanism in Figure 18 and discussed in the next subchapter. In other words, the supplier plays a bigger role in the electric power coping and allocation process than he does in natural gas. The shortage costs -- shortage impact costs and shortage coping costs -- per unit of shortage might be very similar because of the cancelling effects of more user options in gas and more supplier options in electricity.

In general, natural gas energy shortages last 1-5 months and capacity shortages last 1-25 days. In contrast, electric power shortages are more often measured in a few cycles, a few minutes, or a few hours. Even so, each of the differences can be delineated and adjustments to the proposed methodology can be incorporated.

Coping Cost Similarities: Electricity and Gas

Relevance of methodology developed for natural gas to electricity is more easily understood after a review of important coping costs. These costs are as properly assigned to shortages as are impact costs, but they are more difficult to assess.

Figure 18 shows the investment decision for coping with natural gas shortages, as well as extensions for making the entire shortage cost estimation methodology applicable to electricity. Each half of Figure 18 shows (1) an event, indicated by the large dot at the top and (2) the marginal cost and marginal value curves for various levels of coping capacity. For example, relevant estimates for a natural gas curtailment of q_1 percent cutback are as follows:

V_4 = the shortage impact cost each time that a curtailment of q_1 occurs

V_1 = the marginal value of coping capacity q_1, as estimated by a user prior to the event

V_3 = same as V_1 but a re-estimate after an event

V_2 = the marginal cost of coping capacity at Level q_1

All of the above values were defined in terms of a user because the supplier's marginal cost -- MC (Supplier) -- is larger than the user's. This is because the in-place pipes are expensive to change.

The marginal cost of coping for electricity is different because it includes both supplier and user. The shortage index also changes; by comparison, the gas user on the left of Figure 18 has an upper limit of 100 percent substitution. The supplier contribution on the right is open ended and, therefore, capacity is expressed as a fraction of the "average base" load. The following definitions help the discussion:

q_0 = average generating requirement

q_1 = average peak-day requirement

q_2 = the optimum generating/substitution capacity if the marginal value curve, labeled MV is correct

q_3 = the coping capacity requirement if, say, the 1977 NYC event were to be handled efficiently

q_4 = the optimum generating/substitution capacity if the post-event estimate of marginal value (MV) is correct

The reader must keep in mind that each shortage (i.e., each event) causes shortage impact costs (see V_8) and shortage coping costs (the cost of increasing capacity from level q_2 to q_4 in Figure 18).

In one sense, the energy user can be more efficient than the supplier in coping investment because he develops substitution capacity for only critical needs; the supplier must satisfy everybody who taps in, unless the user is curtailable.

The methodology in this report has the following principal advantages: it can be applied directly for obtaining a first aproximation; it can be used as a framework for delineating a detailed methodology for a specific shortage scenario; and it can be used as a basis for overall improvement in energy shortage evaluation.

Applications of Methodology

The methodology is focused on shortage impact costs and shortage coping costs under given conditions. It does not include an extension to costs that would exist if coping mechanisms were optimum.

Whereas coping cost can be ignored for a single shortage, it cannot be ignored in the real world simulation when each shortage prompts users to reevaluate their coping capacity. The following outline of applications helps to understand applications of the methodology:

1. Single shortages with a given severity.

2. Increased severity for a specific shortage.

3. Repeated shortages (i.e., a probability of more than one shortage per year and a probability of shortages in each of several years)

The term "increased severity" is selected deliberately; it encompasses several possible parameter changes in the following basic formula for average annual shortage cost (shortage impact plus shortage coping costs):

$$E\,(\text{Loss}) = \sum_{q=q_0}^{100\%} P_q\,(SC_{q,q_0}) \qquad (8\text{-}1)$$

where SC_{q,q_0} is the expected shortage cost for curtailment q when coping capacity is q_0 and P_q is the probability of curtailment q or larger.

The most common changes that will effect parameters in Equation 8-1 are listed below:

Change 1: An increase in the actual probability (P_q) of shortages above coping capacity q_0.

Change 2: An increase in the shortage impact cost (SC_{q,q_0}) whenever a shortage occurs, possibly because coping capacity q_0 has changed.

Change 3: A change in the accuracy with which users assess the probability and consequences of shortages.

Obviously, the methodology for a single shortage is better than the one for repeated shortages. The 1976-77 natural gas curtailment which was used to calibrate and help form the methodology was a single shortage.

All of the basic approach and suggested steps in shortage evaluation can be utilized directly for electricity shortages after the extensions shown in Figure 18 are incorporated. That is, the coping mechanism for electricity capacity shortage must include both the user and supplier, whereas it is mainly user coping that matters in natural gas shortage costs.

The report's methodology deliberately avoids the term "direct" and "indirect" impacts because these imply a level of difficulty without significance for users. Instead, the methodology is divided between (1) small shortages in which virtually all costs can be identified at the direct user level and (2) severe shortages in which significant impacts exists for indirect users and consumers.

The methodology can be used as a framework for delineating a detailed methodology for a specific shortage scenario, it can be used as a basis for overall improvement in energy shortage evaluation, and it can be used to help design programs which will reduce shortage losses.

Case Studies on Shortage Costs

There have been several electric power shortage studies. None of the shortages have been as long in duration as the Key West shortage described in this report, and none of the impact evaluation has been as comprehensive.

Table 4 gives a comparison of available shortage cost estimates, including clear delineation of the impacts considered.

Table 4

Comparison of Capacity Shortage Cost Estimates

		For This Report				
		Natural Gas[a]	Electric[a]	NYC[b] Blackout	NERA[b] Estimate	Canada[b] Study
A.	Total Loss					
	1. $ loss per kWh		$2.30	$4.11	$1.00	
	2. $ loss per Mil BTU	$54.45	$670.00			
	3. $ loss per hour of shortage					$91
B.	$ loss/kWh by component					
	1. Producers		$2.00			
	2. Employees		$ .10			
	3. Consumers		$ .20			
	4. Macro-effects		$ .00			
	TOTAL		$2.30			
C.	$ Loss/Mil BTU by Component					
	1. Producers	$49.95				
	2. Employees	$ 4.50				
	3. Consumers	Neg.				
	4. Macro-effects	$00.00				
	TOTAL	$54.45				

[a] The natural gas figures were developed in a case study of shortages in four states during the severe winter of 1976-77; the electric figures come from a case study of the 26-day electric power shortage in Key West, Florida, during the summer of 1978.

[b] See References 46, 52, 53, and 58.

GLOSSARY

Annual Production Shortage -- The shortage caused by wellhead price controls.

Category of Gas Use -- See substitutable (Category C), non-substitutable (Category B), and non-curtailable (Category A); see Reference 60.

CES -- City Electric System, the electric utility serving all of Key West, Florida.

Coping Cost -- See shortage coping costs.

Curtailment -- The volume by which energy delivery falls short of user expectations; see cutback for loss in production resulting from energy curtailment.

Cutback -- The cutback in production or delivery of goods/services because of the curtailment in energy supply; see curtailment for reduction in energy supply.

Distribution of Shortages -- The probability distribution of shortages each year by severity of curtailment.

Extra Cost -- The additional cost of producing the same number of units, e.g., the extra cost of substitute fuel and the extra cost of reduced efficiency.

Groups -- Four groups in the production-consumption cycles are (1) producers with direct and indirect energy users, (2) employees, (3) consumers, and (4) macro-effects on the general public.

Impact Cost -- See shortage impact cost.

kWh -- kilowatt hours

M - Thousand, as in thousand cubic feet (Mcf).

Mcf -- Thousand cubic feet of natural gas.

MMBtu -- Million Btu's; the approximate amount of Btu's in an Mcf of natural gas.

MWh -- Megawatt hours.

Peak-Day Capacity Shortage -- The inability of gas suppliers to transport sufficient gas through pipes even if gas supply were adequate.

Shortage -- The difference between demand and supply under the system of curtailments and load growth that is in effect; see annual production, winter season, and peak-day shortages.

Shortage Coping Cost -- The cost of investments for fuel substitution and for other means to cope with shortages; any shortage cost that must be amortized over multiple shortages.

Shortage Impact Cost -- The cost of production delays and other impacts beyond the ability to cope.

Single Shortage -- The Mcf shortfall during a winter season (November 1 - March 31 each year).

Stages -- Four stages in ripple effects are (1) direct user as a producer, (2) indirect user as producer, (3) final demand, and (4) macro-effects.

Unrecovered Cost (Profits) -- The producer loss when sales are reduced, e.g., the profit margin on lost sales and the capital costs that would normally be covered by the lost sales.

Willingness-To-Pay -- A measure of the value of preventing (or reducing) shortages; it is the amount that all affected parties would be willing-to-pay to prevent (or reduce) an energy shortage.

Winter-Season Energy Shortage -- The amount by which accumulated demand exceeds supply during the November 1 - March 31 period; supply can be less than base-period allocation and demand can be greater than base-period allocation for the November 1- March 31 period.

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APPENDIX A

PARAMETERS FOR THE 1976-77 GAS SHORTAGE

The 1976-77 gas shortage provided one national observation and several state observations on shortage cost functions -- the shortage impact cost and shortage coping cost functions shown in Figure 9. The reader should recall that a simple function relating shortage costs to curtailment level will shift as values for the 12 parameters listed in Figure 9 change. The purpose of this appendix is to establish the values for the 12 parameters and the value for the percentage curtailment (the horizontal axis).

The natural gas curtailment in four example states is summarized in Table A-1. These four states do not provide four observations for estimating either cost curve shown on Figure 9 because the other 12 parameters vary considerably, as shown in Table A-2.

The precision in Table A-2 parameter estimates is less than desired; the empirical as well as theoretical work for this report is so new that there was no opportunity for precision in all estimates. The major goal was to identify all significant aspects in energy shortage evaluations and provide, at least, a tentative estimate as a start in developing a sophisticated and practical methodology.

TABLE A-1

1976-77 NATURAL GAS CURTAILMENT

	Line No.	Ohio	Kentucky	Tennessee	Alabama
A. 1976 Total Sales	1	973	180	201	225
B. Nov.-March Allocation					
Non-curtailable	2	440	62		68
Non-substitutable	3	160	42		23
Substitutable	4	98	16		62
C. Jan.-Feb. 1977 energy curtailments[a/]					
Non-curtailable	5	zero	zero	zero	zero
Non-substitutable	6	38%	44%		59%
Substitutable	7	91%	100%		86%
D. Peak-day Curtailment[a/]					
Non-curtailable	8	none	none	none	none
Non-substitutable	9	6-23 days; Avg.13	5-28 days; Avg.9	0-42 days; Avg.10	10-36 days; Avg. 33
Substitutable	10	N.A.	N.A.	N.A.	N.A.

a/ Average across distribution companies

TABLE A-2

TWELVE PARAMETER VALUES -- 1976-77 GAS SHORTAGE

	Ohio	Kentucky	Tennessee	Alabama
1. Geographical Coverage	Within each state, the shortage was fairly uniform, but impacts would have been worse if other surrounding states would have had curtailment as severe as these four states.			
2. Shortage duration	8 weeks	6 weeks	4 weeks	4 weeks
3. User under-estimation	Yes	No	yes	yes
4. Warning Time	Surprise	Above	Below average	Average
5. Availability Capacity/Inventories	Average	Average	Average	Average
6 Peak Curtailment focused	No	No	No	No
7. Priorities lowered	Yes	No	Yes	No
8 User over-estimate	No	No	No	No
9. Increased shortage potential	Yes	Yes	Yes	Yes
10. Prior investment level	Little	High	Moderate	Moderate
11. Energy Curtailment focused	No	No	Yes	Yes
12. Quality of User Information	Poor	Above Average	Moderate	Above Average

Appendix B

MODELING SUPPLY SHORTAGE IMPACTS
(Single Shortages with Severe Curtailment)

This discussion suggests and outlines the use of modified input-output models for estimating shortage impact costs for severe supply shortages--severe in that there are significant impacts that cannot be identified at the direct user level; see Figure 8.

The approach suggested in this appendix is for a single shortage; the general approach is reviewed in Chapter 6.

This appendix focuses on shortage impact costs since shortage coping costs should really be related to repeated shortages. Appendix C focuses on repeated shortages.

The methodologies in this appendix and Appendix C are not perfected for immediate application. However, they advance the state of the art in shortage evaluation and provide a much needed point of departure.

Introduction

Russian planners concerned with allocating resources for investment between different industries invented input-output analysis in the early 1920's, at about the same time that Leontief was beginning to construct similar models of the U.S. economy. The Second World War provided a further impetus for solving complex scheduling problems and led to the development of activity analysis, transportation, and linear programming (LP) models. These models, associated with the distinguished names of some of the leading mathematicians and economists of the period such as von Neumann, Kanotorovich, Koopmans, Dantzig, and others, have an elegance, logic, and applicability which generates a continuing appeal to planners everywhere. Their increasing sophistication and complexity has been matched by rapid developments in computer technology which make it feasible to contemplate the solution of models containing many thousands of variables.

The most promising type of model would seem to be a multiregional inter-industry intertemporal activity analysis model; the long title contains almost a complete description of its form and structure. Each firm has available to it a variety of possible activities, each of which takes inputs to produce outputs. As normally modeled, such activities are linear, describing constant returns to scale production in which outputs are proportional to inputs. The inputs come from other industries, possibly via transportation activities from other regions, or from stocks and produce outputs which may be used now or stored for later use. Interregional models specifically concern themselves with shipments between spatially separated firms, while intertemporal models recognize the possibility of storage and investment as indexes of output. If we had such a model for the U.S. and if we believed that the U.S. economy behaved as if it were perfectly competitive, then the market equilibrium of the economy would emerge as the solution to the maximization of consumer surplus plus profits of the model. In other words, it is not necessary that the U.S. economy be planned for a planning model to describe market equilibrium, for just as a planner seeks an efficient plan, so the invisible hand of the marketplace finds an efficient solution provided the market is competitive. Such a model would yield immediate answers to the two central questions raised by the presence of shortages:

1. How could resources be reallocated to minimize the cost of the shortage?

2. What is the cost of the shortage?

The first question is relevant where it is thought that the unguided market will respond too slowly to the crisis, so that key resources are better allocated by administrative fiat. The second question must be answered in any cost-benefit analysis of the desirability of publicly provided measures to reduce the likelihood or duration of potential shortages. Let us consider the structure and use of such models.

Structure of the Model

All activity analysis models of resource allocation must specify an objective which is to be maximized, a description of the activities available, and the constraints. */ The choice of each specification typically has a considerable effect on the nature of the solution and the difficulty of computing the solution. The model may be greatly simplified by imposing additional constraints or eliminating some activities, and, as a result, the solution may, but not necessarily

*/ For some purposes simulation models may be used in place of optimizing models, in which case objectives may be left unspecified.

will, be changed. The skill of the modeler lies in simplifying the model while retaining, as closely as possible, the original more complex model as the solution. Thus, the Leontief simplification replaces a range of alternative processes for each product by a single process. The simplification is rigorously defensible, as there is but one nonproduced input, no joint products, and constant returns to scale. It may continue to be a good approximation in other circumstances and has the advantage not only of simplifying the solution, but of greatly economizing on data requirements. Before discussing these issues, let us examine the components more closely.

Objective

Ambitious models maximize social welfare, which is usually measured by profits plus the Marshallian measure of consumers' surplus. If demand schedules are linear, quadratic programming can be employed and consumer surplus is easily calculated. In Figure B.1, the demand schedule is

$$p = a - bq \quad . \qquad \text{(B-1)}$$

Consumers' surplus is the triangle CBD, which if OA is $\bar{q}$, has area $1/2b\bar{q}^2$.

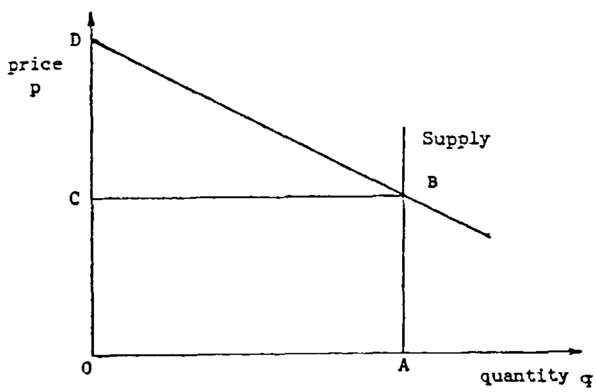

Figure B-1. Consumers' Surplus

If, however, we are measuring the impact of a temporary, local shortage, then it may be acceptable to maximize the value of net regional output, at fixed, given prices, thus simplifying the model from quadratic to linear. As it stands, this ignores the costs of unemployment caused by the shortage. Typically in these models, labor is considered as a primary input inelastically supplied at zero marginal disutility up to full employment, and the social costs of unemployment are assumed to be zero. This simplification may be satisfactory when the equilibrium solution is full employment but seems unreasonable when analyzing shortages (or, indeed, problems involving structural unemployment). Unemployment has two consequences--a fall in income leads to a fall in consumption, which reduces utility, while a fall in hours of work is offset by an increase in leisure, which increases utility. The first is <u>approximately</u> measured by the fall in the value of net output caused by the shortage or, more accurately, by the fall in consumer surplus, but the second component is missing. How important is this component?

Consider the following simple model. A temporary shortage reduces hours worked by a fraction, but workers know that this will be made up in extra overtime after the shortage, at the same wage rate w.*/ Total income over the year is therefore unchanged, and we suppose that they consume at the same rate throughout the period. Let the dollar value of the disutility of labor be V(L), then the worker supplies L hours. Market equilibriums requires

$$\frac{dV}{dL} = V'(L) = w. \qquad \text{(B-2)}$$

If the shortage lasts one period, and is entirely made up in the next period, the disutility of the shortage is

$$C = V(L(1-\alpha)) + V(L(1+\alpha)) - 2V(L) \qquad \text{(B-3)}$$

which, by Taylor series expansion gives approximately

$$C = \alpha^2 L^2 V''(L) \quad . \qquad \text{(B-4)}$$

Suppose the elasticity of labor supply is η

$$\frac{L}{w}\frac{dw}{dL} = \eta = \frac{LV''}{w} \quad . \qquad \text{(B-5)}$$

Then

$$C = \alpha^2 \eta w L \qquad \text{(B-6)}$$

*/Alternatively, the wage could go to different workers; it could also be higher as in the usual 150 percent for overtime.

or, expressing the cost as a fraction of the total wage earnings over the two periods,

$$\frac{C}{2wL} = L/2\alpha^2. \tag{B-7}$$

If, however, the shortage lasts one period and is made up over the following n - 1 periods, the fractional cost is

$$\frac{C}{nwL} = \frac{1}{nwL}\left\{V(L(1-\alpha)) + (n-1)V(L(1+\frac{\alpha}{n-1})) - nV(L)\right\} \tag{B-8}$$

$$\frac{C}{nwL} = L/2\ \frac{\alpha^2\eta}{n-1} \tag{B-9}$$

which can clearly be made very small.

Thus, the costs of unemployment are smaller the more widely spread out they are over people and over time. If everybody were able to make a minor readjustment in their hours, then the costs would be minimal and would be <u>overstated</u> by the value of the fall in output (since this would ignore the benefits of leisure). If, on the other hand, the impact of the shortages were concentrated on a small group of workers who had to make a significant adjustment to their labor supply, then the costs might be understated.

The possibility of intertemporal substitution (either by running down stocks or by delaying delivery and increasing subsequent production) means that the value of output should be written

$$\sum_{t=1}^{T} py_t \tag{B-10}$$

where "y_t" is production in week "t", and the economy has fully returned to normal by week "T". Earlier falls in production may be compensated by later increases.

Activities

The most general formulation of activity j is a pair of vectors (a_j, b_j). If the activity is run at intensity x_j then the vector of inputs $a_j x_j$ is transformed into a vector of gross outputs $b_j x_j$. This formulation allows for joint production but is cumbersome. It can be simplified if there is only one output, in which case the technology is described by the vector of input coefficients $\underset{\sim}{a}_j$. The input requirements of good i are then just $x_j a_{ji}$. Input-output analysis seeks a classification of industries which permits the output to be expressed as a single (aggregate) commodity.*/

Impacts are either intermediate goods or primary factors and are either mobile or fixed. Intermediate inputs can be supplied from stocks, from within the region, or from outside the region by transport activities, and their costs depend on which source is used. Primary factors are typically regionally specific and may be fixed in the short run. Their input is typically limited by capacity, but in the case of labor, overtime may be considered as a form of drawing down of stocks.

Outputs, likewise, may be stored (if storable), consumed locally, or exported. To give a simple example, for a Leontief technology matrix A (the matrix whose columns are the input vectors $\underset{\sim}{a}_j$),

$$\underset{\sim}{c} + \underset{\sim}{s} + \underset{\sim}{e} - \underset{\sim}{m} \leqq \underset{\sim}{y} = (I - A)\underset{\sim}{x} \qquad \text{(B-11)}$$

where

"$\underset{\sim}{c}$" is the vector of local consumption

"$\underset{\sim}{s}$" is the increase in stocks

"$\underset{\sim}{e}$" is the vector of exports

"$\underset{\sim}{m}$" is the vector of imports

"$\underset{\sim}{y}$" is the net production vector.

The value of net output is then

$$Y = \underset{\sim}{p}_c \cdot \underset{\sim}{c} + \underset{\sim}{p}_e \cdot \underset{\sim}{e} - \underset{\sim}{p}_m \cdot \underset{\sim}{m} \qquad \text{(B-12)}$$

where "$\underset{\sim}{p}_z$" is the vector of prices of vector "z". In this formulation for good i either

*/Estimates of activity coefficients with particular attention to energy flows are in Jack Faucett Associates, Inc., National Energy Accounts: Energy Flows in the U.S., 1947 through 1974, 1978.

$$p_{mi} > p_{ci} > p_{ei} \quad \text{and} \quad e_i = m_i = 0 \; , \; y_i > 0 \; , \qquad \text{(B-13)}$$

or

$$p_{mi} = p_{ci} > p_{ei} \quad \text{and} \quad e_i = y_i = 0 \; , \; m_i > 0 \; , \qquad \text{(B-14)}$$

or

$$p_{ei} = p_{ci} < p_{mi} \quad \text{and} \quad m_i = 0 \; , \; e_i > 0 \; , \; y_i > 0 \; . \qquad \text{(B-15)}$$

Constraints

The values which the choice variables can take are typically limited by various constraints, which, using the simple model above, can be illustrated for a typical case as follows:

1. Capacity constraints: $\underset{\sim}{x} \leqq \bar{\underset{\sim}{x}}$ (B-16)

2. Transport capacity constraints: $\underset{\sim}{m} \cdot \underset{\sim}{w} \leqq \bar{M}$ (B-17)
   (w is the vector of tons per unit of the commodity, and in this formulation, there is merely a tonnage constraint. More complex constraints are of course possible, and one of the main commercial uses of LP is to solve complex transport and scheduling problems.)

3. Supply limitations: $\underset{\sim}{m}^r \leqq \bar{\underset{\sim}{m}}^r$ (B-18)
   (e.g., imports from region r are limited by regional capacity.)

4. Factor availability: $B\underset{\sim}{x} \leqq \underset{\sim}{k}$ (B-19)
   (b_j is a vector of primary inputs needed to produce good j, k is a vector of factor availabilities. As shown, factors are mobile between industries; to the extent that they are not, capacity constraints (i) operate.)

5.. Non-negativity: $\underset{\sim}{c} , \underset{\sim}{e} , \underset{\sim}{m} , \underset{\sim}{y} , \underset{\sim}{x} \geqq 0$. (B-20)

6. Storage constraints: $\bar{S} \geqq \sum_{t=1}^{n} s_t \geqq 0 \quad \text{all } n$. (B-21)

   (Stocks cannot exceed storage capacity, nor become negative.)

7. Demand constraints: $\sum_{t=1}^{T} \underset{\sim}{y}_t \leqq \bar{\underset{\sim}{y}}$ (B-22)

(These raise troubling problems. The competitive assumption is that unlimited sales can be made at fixed prices, which is unreasonable. A better assumption is that the region faces a downward sloping supply schedule as in Figure B.1, but this requires quadratic programming. It may be simpler to take normal output as a temporary ceiling to prevent the model from picking a small number of industries to greatly expand. Capacity constraints will reduce the importance of demand constraints, which otherwise impose an ad hoc solution.)

Solving the Model

The aim of the exercise is to answer the two initial questions. First, we solve the following problem:

$$Y^{o} = \text{Max} \sum_{t=1}^{T} Y_t \;; \quad Y_t = \underset{\sim}{p}_c \cdot \underset{\sim}{c}_t + \sum_r \underset{\sim}{p}_e^r \cdot \underset{\sim}{e}_t - \sum_s \underset{\sim}{p}_m^s \cdot \underset{\sim}{m}_t \qquad \text{(B-23)}$$

subject to the normal constraints. The export and import prices may be determined by transport costs and supply costs:

$$\underset{\sim}{p}_m^s = \underset{\sim}{p}_o^s + \underset{\sim}{t}^s \qquad \text{(B-24)}$$

$$\underset{\sim}{p}_e^r = \underset{\sim}{p}_o^r - \underset{\sim}{t}^r \;, \qquad \text{(B-25)}$$

where "r", "s" denote regions, "t^r" is the vector of transport costs to (or from) region r, and "p_o^r" is the vector of prices in region r. More ambitious models would solve for these prices (and supply availabilities) by modeling each of the other regions (see, for example, Takayama and Judge, 1971), but if the shortage is local, such refinements are probably not worth the proportional increase in complexity.

Next, solve the problem

$$Y^{n} = \text{Max} \sum_{t=1}^{T} Y_t \qquad \text{(B-26)}$$

subject to the normal constraints and the net supply availability of the fuel subject to shortage (commodity f) for n weeks:

$$m_{tf} \leq \bar{m}_{tf} \,, \qquad t = 1,2,\ldots,n \,.$$

$t = 1, 2, \ldots, n$.

The net availability is the supply at date "t" less the extra domestic and heating consumption caused by the cold weather which either has priority or which cannot be controlled. If the solution to the first problem is Y^o and the second is Y^n (m_{tf}), then the cost of the shortage is

$$C^n = Y^o - Y^n(\bar{m}_{tf}) \ . \tag{B-28}$$

The primal solution to the second problem (the levels of quantities x, m, etc.) gives the allocation rule for key variables (in particular m_{tf}), while the dual solution gives the scarcity price of the fuels (and possibly other goods and transport services) in short supply. If this price is above the cost of making the good available by some other activity not already included in the specification of the model, then it will be worthwhile employing this method.

This method can be used to graph the cost of shortages as a function of the duration of the shortage, or its intensity; as shown in Figure B.2.

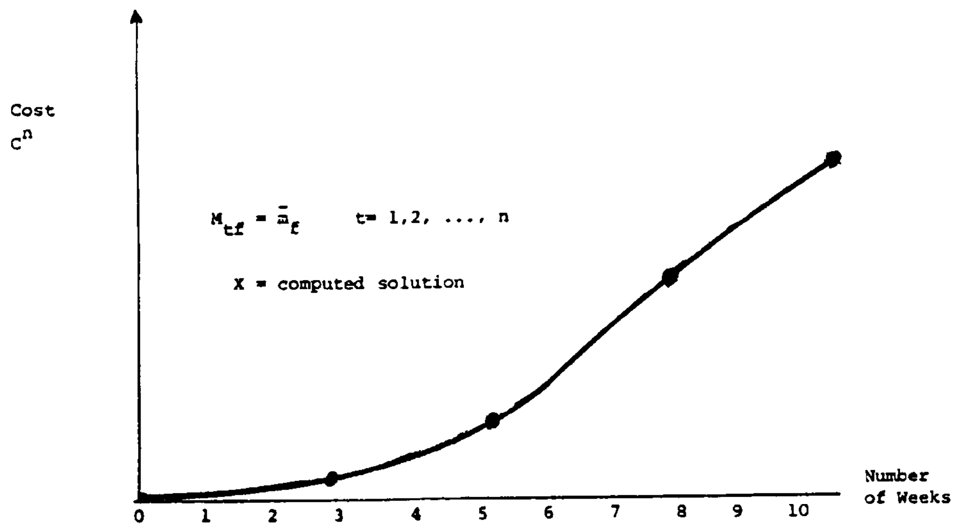

Figure B-2. Costs of Shortage as Function of Duration

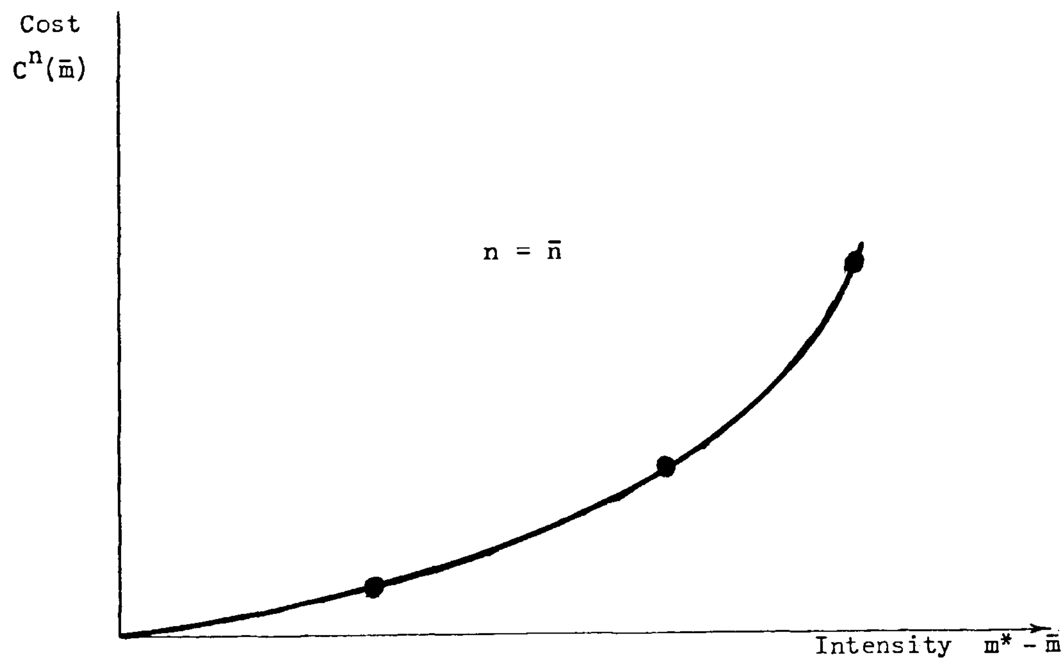

Figure B-3: Costs Of Shortage As Function Of Intensity

Each data point in these graphs requires a new calculation of Y^n, but only a few points are needed to sketch the curves. Given these, it is possible to choose the best balance between the intensity of the shortage and its duration if the problem is one of limited available stocks of the short fuel.

Casual observation suggests that a mature industrial economy has remarkable flexibility and can cope with temporary disruptions with remarkably low cost. Studies of the effect of saturation bombing in Germany during World War II showed that apparently massive damage led to little fall in production. The most effective bombing destroyed railway maintenance shops, which eventually led to widespread paralysis of the railway system, whereas bombing marshaling yards had purely temporary effects.

A less dramatic example was the "3-day week" implemented as a means of conserving coal during the British miners' strike of 1974. The strike took a long time to have any effect, and then, when manufacturing industry was subject to a dramatic cut in electricity supplies (of over 50 percent), the fall in output was extremely small and, averaged over the year, almost imperceptible. This suggests that the graph in Figure B.2 will be very flat for many weeks, only rising when stocks have been exhausted and constraints in key industries have spread more widely.

Notice that the scale of weeks in Figure B.2 can be associated with decreasing probabilities of a shortage of that duration, and hence can be used to calculate expected costs. Likewise, in Figure B.3 the intensity will depend on the severity of the weather and will also be associated with a probability.

The key problem with modeling shortages is, therefore, to find a plausibly flexible formulation which does not exaggerate the rigidity of the economy and, hence, overestimate the costs of the shortage.

Evaluation

The advantages of such models are obvious, for they can be used to devise policy responses not only to shortages of natural gas, but to other sudden impacts such as strikes, transport disruptions, and similar phenomena. What, then, are the limitations of these models? The most obvious is that of data availability. Each production process which is or could be used must be specified, each constraint carefully identified, each potential source of alternative supply located and costed. The easier it is to substitute one input for another (coal for oil, imports for local goods), the more activities must be defined. The less easy it is to substitute, the more finely must the commodity classification be drawn. The Leontief assumption is that there is no substitution between commodity groups and complete substitution within groups, and, as such, is unsuited for modeling fuel requirements. It has the great advantage that a single observation (in the shape of a census of industrial production) is sufficient to identify the technology matrix, but it greatly exaggerates the rigidity of the production structure. The Leontief system has been extended to model interregional trade (see, e.g., Polenske's summary of the multiregional input-output model of the U.S., which distinguishes 87 industries and 51 regions (states and D.C.), reported in Judge and Takayama, (1973), but the fixed-coefficients assumption is even more damaging in this context, where it is highly inappropriate to assume that trade patterns (trade coefficients) are fixed. Trade allows enormous flexibility and, in the context of a localized fuel shortage, relieves bottlenecks by allowing the import of key intermediate goods normally produced locally. To assume that because such goods were not imported in the ban period they cannot be during a crisis is greatly to exaggerate the dislocation of the shortage.

The Leontief system is, however, useful for identifying heavy users of fuel, and, hence, pinpointing industries for which alternative activities need to be identified. Consider the simple model with no trade, net output $\underset{\sim}{y}$, and gross output $\underset{\sim}{x}$:

$$\underset{\sim}{y} = (I - A)\underset{\sim}{x} \tag{B-29}$$

$$\underset{\sim}{x} = (I - A)^{-1}\,\underset{\sim}{y} \quad . \tag{B-30}$$

If fuel demands are a_i per unit gross output of good i, then total demands are

$$\underset{\sim}{a}\cdot x = \underset{\sim}{a}\cdot(I-A)^{-1}\underset{\sim}{y} \tag{B-31}$$

and the gross fuel demand per unit of net final demand is given by the vector $\underset{\sim}{b}$:

$$\underset{\sim}{b} = \underset{\sim}{a}H \ , \quad H \equiv (I - A)^{-1} \ . \tag{B-32}$$

The H matrix is typically assumed constant, independent of the region, and is known, so that if the a vector is known, it is easy to calculate the fuel allocation to produce the desired local pattern of net production. The advantage of this approach is that a particular industry may have high fuel needs per unit of gross output (high a_i), but the gross output may be critical for maintaining production in the sectors. Such industries might be discriminated against on the basis of the a vector but actually have a low b vector. On the other hand, the a vector is relevant where goods can be imported. If good i can be imported, the fuel saving is $a_i x_i$, which could be substantial. The input-output table can be used to identify key industries, for which data on substitution possibilities (alternative production techniques and imports) can then be collected.

The Problem of Identification

If the economy is reasonably flexible, so that the basic long-run constraint is labor, and if it evolves reasonably steadily, then the input-output coefficients will probably remain fairly stable. Observation will lend support to the Leontief fixed-coefficient assumption, even if there is, in practice, a wide range of alternative techniques of production. Leontief models are thus well suited to medium-term structural forecasts, but are highly unsuited to predicting the response to a short-term shortage, or, indeed, any large change in the economic environment which significantly alters relative factor prices. To assume away substitutability in such cases is to completely prejudice the answer to the problem. Given a choice between using such a model and relying on economic intuition, the latter is almost certain to be more reliable. The main advantage of the programming approach lies not in the solution to the original primal problem, which is what planners tend to be interested in, but in the interpretation of the solution to the dual problems. It makes precise the intuitive motion of opportunity cost or scarcity (or shadow) prices and helps intuition by relating these prices to specific constraints.

INTERPRETATION OF THE DUAL VARIABLES

The dual to the original LP problem gives shadow prices for the constraints and identifies the binding constraints or bottlenecks. These prices have a good guess at the nature of the solution. In short, thinking in terms of shadow prices provides a simple criterion for allocating fuel between alternative uses. The scarce fuel will have a high shadow price, and industries will only be operated if they do not make losses when calculating costs of production at shadow prices. The only non-zero shadow prices will be for fuels, imports, and other scarce inputs. Typically, labor and capacity shadow prices will be zero. Thus, the higher is the local value added per unit of fuel, the higher should be the priority for fuel allocation, other things being equal. On the other hand, the easier it is to intertemporally reallocate production, the lower should be the priority. The reasoning here is that the opportunity cost of postshortage production will be lower, and if the value of the output does not depend sensitively on when it is produced, then profits will be increased by delay. Thus, at one extreme, consumer durables can be purchased later with little opportunity cost, while at the other extreme, newspapers cannot. The difficulty, of course, lies in defining the degree of intertemporal substitution and is related to the problem of specifying demand and demand constraints. Much will depend on the size of output stocks, the speed with which competitors elsewhere respond to meet any shortfalls, and the extent to which they can be successfully undercut in subsequent competition. It is doubtful that the ad hoc assumptions typically made in activity analysis models will approximate reality. An operational understanding of the nature and extent of these substitution possibilities must rely on microeconomic survey and engineering data. Observations glanced at the macroeconomic level cannot suffice. Specifically, macroeconomic models estimated with data on normal patterns of demand are likely to be a poor guide to disequilibrium responses.

Conclusion

Multiregional intertemporal activity analysis models are enormously demanding in their requirements and, so far, have been largely limited to sectors of the U.S. economy where data is readily available. The activity analysis developed by Jack Faucett Associates [32] is impressive in its detailed account of energy flows.

The World Bank's attempt to build a model for the simpler economy of Mexico (Goreux and Manne [31]) was largely confined to power and agriculture with a simplified industrial sector but took 17 man-years to construct. It is tempting, therefore, to seek simpler models, of which the leading example is the Leontief input-output fixed-coefficient model. These models can provide insights and help devise criteria for allocating scarce inputs, but unfortunately simple fixed-coefficient models are of little value for the measurement of shortage costs. Such costs depend crucially on the degree of substitutability in the economy, and, roughly speaking, the more effort is expended identifying the range of substitutability, the greater it will be found. The scarcity cost measured by a model is thus a possibly good inverse measure of the cost of the model, but it is unlikely to measure the actual scarcity cost. Ex post empirical studies are likely to provide far more useful detail than ex ante planning models based on aggregate macroeconomic data.

Reference 30 contains excellent critiques of large-scale model building, as does Reference 31, which also presents various model of sectors of the Mexican economy. Reference 32 is a detailed activity analysis with particular attention to energy flows in the U.S. economy. Reference 33 is a recipe book of specific models designed for various purposes, while Reference 34 is a collection of models mainly for the U.S. and mainly agricultural. References 33 and 34 have an extensive bibliography, especially Reference 34.

Appendix C

A MODEL OF COPING BEHAVIOR FOR REPEATED SHORTAGES

Shortage costs for repeated shortages must be analyzed in the following parts:

1. Total Shortage Impact Costs for Various Shortages (i.e., for given shortage severity and given coping capacity)

2. Change in Shortage Impact Costs for:

   —Change in shortage severity

   —Change in coping capacity

3. Shortage Coping Costs

   —Change in shortage severity

   —Change in user information but no change in actual shortage severity.

The first item can be estimated by multiplying the shortage impact cost estimates for a single shortage by the probabilities. Item 2a can be estimated in a similar fashion. The remaining sections in this appendix focus on Item 3 above.

The methodology for shortage cost estimates under repeated shortages is not complete; the project scope did not allow refinement. However, the basic approach in Chapter 7 and Appendices B and C are a sound and helpful beginning.

The following sections outline and discuss the basic approach for shortage coping decisions and associated costs; it uses natural gas as an example of a shortage in a specific type of energy.

Introduction

The economic impact of a curtailment in natural gas supply depends on the capabilities of gas users to substitute alternative fuels and alternative sources of gas. The latter includes such drastic measures as on-site drilling for natural gas, shortage facilities, and possibly investment in the manufacture of synthetic gas. The capability to use alternative fuels (propane, oil, coal, electricity) is rarely available without some investment by the consumer. Investment costs include the incremental cost of convertible boilers and the cost of fuel storage, piping, and pumping equipment.

Investments in alternative fuels and alternative sources of supply are examples of coping reactions to curtailments in natural gas supply. These measures have the ultimate effect of reducing the economic impact on the consumer from natural gas shortages. Coping through investment in substitutes is a response to rationing. The substitution may be only for peak demands or may be for longer terms. All customers who are rationed out of the market for natural gas must provide for alternative sources of fuel or do without any fuel. Customers who are rationed for short periods, either seasonably or during periods of peak demands, face constraints that are similar to those faced by customers who are denied use of natural gas over the long term. The differences, which are only a matter of degree are the following:

(i) A natural gas curtailment of short duration permits use of interim measures--such as rescheduling vacation time, production runs, and production from inventories that are infeasible over long periods of time.

(ii) If long-term rationing is imposed to minimize the cost of curtailing natural gas demand, then on average rationed customers should face lower coping costs than those remaining in the market.

Rationing is generally imperfect, with the result that rationed customers often have a higher willingness to pay for natural gas than do consumers who are allowed to purchase gas without constraints. Data collected by Jack Faucett Associates show average coping costs ranging from a negligible increment over the standard production process to very large incremental costs. When capital costs are adjusted to account for actual utilization and a high rationing probability is assumed, total average coping costs are approximately $25.00 per MCF, with much higher costs emerging under more plausible expectations.

The observation that some consumers are willing to pay as much as $25.00 per MCF for a natural gas substitute, while other consumers who are not rationed pay about $2.00 per MCF, suggests considerable inefficiency from rationing. Although price rationing could eliminate this inefficiency, the effects on income distribution make price rationing a politically unacceptable policy instrument for very shortrun resource allocation. The survey results which show that some users are willing to pay extremely high effective average costs for production flexibility suggests that in a short-term shortage circumstance the market price would have to reach very high levels to equate supply and demand. The total cost of equilibrating supply and demand are minimized by the price system but without regard to income effects.

The price movement required to equate supply and demand is reduced when consumers have time to search for substitute fuels and producers have time to develop alternatives. For this reason, the adverse income distribution effects of the price system become less serious as the time permitted for market equilibration is increased. Over the very long term, the efficiency aspects of the price system should predominate.

Model Specification

A model sufficiently general to capture the effects of potential shortages on investment in substitute fuels includes at least two production techniques, one using regulated natural gas and another using a different fuel (which may be unregulated natural gas). The decision to provide coping capability in the event of a curtailment of natural gas supply is the ex ante decision to invest in productive capacity utilizing an alternative source of fuel. The model described below permits a detailed examination of the factors which determine investment in substitute capability at the level of the individual firm. The model is specified to account particularly for the reaction to possible supply curtailment, but the model also permits a general comparison of responses to price and quantity rationing.

The procedure used to model the choices of a representative firm is an extension of activity analysis to account for substitution possibilities. The firm is assumed to produce a single output (commodity j).* Each activity is described by a vector, $\underset{\sim}{a}_{\cdot j}^{k}$, where k = 1,...,K indexes a particular production technique. The component a_{ij}^{k} is the use of commodity i required for gross production of one unit of commodity j using technique k. When each technique is used at intensity x^k, total output is

$$\sum_{k=1}^{K} x^k (1 - a_{jj}^k) \qquad \text{(C-1)}$$

*The extension of multiple outputs is straightforward, but cumbersome, if each output is produced with a separate production process. When joint production takes place, the use of linear activity analysis may give misleading results.

This model is easily extended to account for the intertemporal character of production. Let x_t^k be the intensity of technique k at date t and let P_{it} be the present value of one unit of commodity i at time t. Net production profits over a time horizon of T years are

$$\Pi_j = \sum_{t=0}^{T} \sum_{k=1}^{K} \left\{ P_{jt}(1 - a_{jj}^k) - \sum_{i=1}^{I} P_{it}\, a_{ij}^k \right\} x_t^k \tag{C-2}$$

The substitution problem reduces to determination of the optimal levels of use for each production technique at each date. With constant returns to scale, there normally would be a single best technique for any factor prices. The use of more than one technique may be desirable, given that plant investment is not reversible (i.e., production configurations cannot be changed without cost), if factor prices are variable or if factor supplies are curtailed. Conditions such that investment in more than one technique is profitable will be demonstrated assuming:

(i) only two techniques ($K = 2$);

(ii) $a_{jj}^k = 0$, for $k = 1,2$;

(iii) only two productive factors: capital ($i = 1$) and fuel ($i = 2$).

The assumption of constant returns to scale implicit in activity analysis is not unreasonable at the time of the initial investment. However, once capital is fixed in place, the technique exhibits decreasing average cost as utilization increases to the level of installed capacity. Since the focus of this study is on investment for flexibility in response to shortages, it is necessary to account for utilization at less than full capacity. This is easily accomplished by calculating capital costs based on initial installed capacity, x_0^k, rather than the actual intensity of use, x_t^k. With these conditions, and letting $R_{jt}(x_t^1 + x_t^2)$ denote total revenues, the profits of firm j may be expressed as

$$\Pi_j = \sum_{t=0}^{T} \Big[R_{jt}(x_t^1 + x_t^2) - P_{2t}a_{2j}^1 x_t^1 - P_{2t}a_{2j}^2 x_t^2 - P_{1t}a_{1j}^1 x_0^1 - P_{1t}a_{1j}^2 x_0^2 \Big] \tag{C-3}$$

In general, the two production techniques will use different fuel sources, so that the use of a common fuel price, P_{2t}, may seem in error. This presents no difficulty if we treat the term

$$P_{2t} a^k_{2j} \equiv P^k_{2t} \tag{C-4}$$

as the effective unit fuel cost for technique k, which accounts for the different fuel used. Alternatively, the model could be extended to allow for three inputs, capital plus two types of fuels. The procedure adopted here allows for more concise notation. A similar procedure may be used to define an effective capital cost for each technique which accounts for possible differences in depreciation and taxes for the two techniques. With this convention, profits simplify further to

$$\Pi_j = \sum_{t=0}^{T} \left[R_{jt}(x^1_t + x^2_t) - P^1_{2t} x^1_t - P^2_{2t} x^2_t - P^1_{1t} x^1_0 - P^2_{1t} x^2_0 \right] \tag{C-5}$$

Equation C-5 describes the actual profits earned by firm j given the available techniques and market prices. Production is constrained so that $x^k_t \leq x^k_0$ for all t. In addition, production may be constrained by curtailment of supply. Analysis of the firm's response to the possibility of natural gas curtailments requires introduction of "events" which distinguish dates where rationing is a constraint from those dates where rationing is not in effect. Let the superscript r denote the event that natural gas is rationed, let α_t denote the probability that gas is rationed at date t, and let γ_t be the percentage of installed natural gas capacity that can be purchased during a period of supply rationing.

We assume that only the first technique uses natural gas subject to supply curtailment. The firm's utilization of the alternative production technique is not constrained by regulation. Expected profits are*

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*This assumes interest costs are independent of natural gas curtailments, which is reasonable for curtailments of short duration.

$$\Pi_j = \sum_{t=0}^{T} \left\{ (1 - \alpha_t) \left[R_{jt}(x_t^1 + x_t^2) - (P_{2t}^1 x_t^1 + P_{2t}^2 x_t^2) \right] \right. \tag{C-6}$$

$$+ \alpha_t \left[R_{jt}(x_t^{1r} + x_t^{2r}) - (P_{2t}^{1r} x_t^{1r} + P_{2t}^{2r} x_t^{2r}) \right]$$

$$\left. - P_{1t}^1 x_0^1 - P_{1t}^2 x_0^2 \right\} .$$

The firm managers choose x_0^1 , x_0^2 , x_t^1 , x_t^2 , x_t^{1r} , x_t^{2r} (initial capacities and production levels) to maximize expected profits subject to the constraints*

$$x_t^1 \leq x_0^1 \quad , \quad x_t^2 \leq x_0^2 \quad , \tag{C-7}$$

$$x_t^{1r} \leq \gamma_t x_0^1 \quad , \quad x_t^{2r} \leq x_0^2 \; .$$

Missing in this formulation is the possibility that the firm may be rationed in its cumulative demand for natural gas over the winter season. The model formulated in this paper presumes only the rate of gas demand is curtailed. The introduction of seasonal constraints is theoretically straightforward. If x^r is the maximum allowable consumption over the season and if the season lasts periods, the constraint takes the form

$$\sum_{t}^{t+\tau} x_t^1 \leq x^r \tag{C-8}$$

where the constraint is repeated for every winter season, "t". The cumulative demand constraint is omitted in this paper because it introduces considerable notation and this model is primarily for illustration. Cumulative demand constraints could be included without difficulty in a computer-assisted calculation of the investment model.

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*The implications of managerial behavior that departs from profit maximization will be explored later in this paper.

A reasonable assumption is that the firm uses the first technique at capacity unless it is rationed. In addition, we assume that the second technique is used only when natural gas is rationed and at that time it is used at installed capacity. These assumptions serve merely to emphasize the role of investment for coping with rationing and are generally consistent with survey results on the organization of production. With these assumptions, the conditions for investment in the technique using natural gas subject to curtailment is (with MR denoting marginal revenue)

$$\sum_{t=0}^{T} \left\{ (1 - \alpha_t) \left[MR_{jt}(x_0^1) - P_{2t}^1 \right] + \gamma_t \alpha_t \left[MR_{jt}(\gamma_t x_0^1 + x_0^2) - P_{2t}^{1r} \right] - P_{1t}^1 \right\} = 0 \qquad \text{(C-9)}$$

The condition which determines investment in the alternative production technique is

$$\sum_{t=0}^{T} \left\{ \alpha_t \left[MR_{jt}(\gamma_t x_0^1 + x_0^2) - P_{2t}^{2r} \right] - P_{1t}^2 \right\} = 0 \qquad \text{(C-10)}$$

Equation C-10 is easily interpreted. The firm should invest in an alternative technology at the level which equates marginal revenue to expected cost. The marginal revenue and operating cost are reduced by the expected proportion of time, α_t, the alternative will be used. To put this another way, suppose the time variation of revenues, prices and probabilities can be ignored, so that equation C-10 can be written simply as

$$MR(\gamma x_0^1 + x_0^2) = P_2^{2r} + \frac{P_1^2}{\alpha} \quad . \qquad \text{(C-11)}$$

The firm should equate marginal revenue to the variable marginal cost of the alternative fuel plus the fixed cost of the alternative technique scaled up by the expected proportion of time over which the alternative technique will be used. This result is identical to the peak-load pricing rule developed for public utilities. Peak electricity users should pay a unit capital charge that is multiplied by the inverse of the proportion of time the capital is in use.

(See, e.g., Turvey [41], for a discussion of peak load pricing.) The same conclusion applies here, where the capital for the alternative technique is idle unless natural gas is rationed.

A similar result governs the efficient level of capacity installation for the technique which uses regulated natural gas. The formula (equation C-9) is complicated by the possibility that some natural gas may be available during a period of supply curtailment. Other complicatons may arise if the purchase terms of natural gas, the probability of rationing, and the severity of rationing depend on the investments of the firm in its primary and alternative techniques of production. These considerations may have important policy implications, as firms will choose investments to position themselves favorably with respect to curtailment policies.

This analysis has presumed that the firm's managers seek to maximize expected profits. If managers are averse to risk, these investment formulae must be modified. Since sales and hence profits would be adversely affected by natural gas rationing, risk-averse managers would have a greater incentive to invest in alternative production techniques to cope with natural gas curtailments. Indeed, the empirical results using this model and survey data collected by Jack Faucett Associates suggest that managerial risk aversion may be the single most significant determinant of investment in substitute capacity. The model presented in this section can be easily extended to account for managerial aversion to risk. The assumption that firms maximize expected profits must be replaced by an objective function that places a negative weight on the variation in the level of profits. This is usually done by introducing the concept of a managerial utility function, $U(\pi)$, which transforms profits to an index of managerial security. If Π_S is the total firm profit during a shortage, $\Pi 0$ is the profit in the absence of a shortage, and α is the shortage probability, the expected utility of profits is

$$(1 - \alpha)U(\Pi_0) + \alpha U(\Pi_S) \qquad \text{(C-12)}$$

Halter and Mason [40] describe the application of utility theory to firm investment decisions and offer a methodology for measuring managerial utility functions. The measurement of individual utility is difficult but not impossible. One approach is to assume that the utility of profits can be expressed simply as

$$U(\Pi) = \overline{\Pi} - k \text{ var } (\Pi) \quad , \qquad \text{(C-13)}$$

where "$\bar{\pi}$" is the expected level of profit, "var (π)" is the expected variance in profits (due to shortages and other events), and "k" is a constant. The constant, k, is a measure of the degree of risk aversion. A very large k for each manager can be measured either by interview techniques (as described in Halter and Mason [40]) or by statistical observations on post-investment behavior.

An investment which appears unprofitable based on expected net earnings may be attractive to a risk-averse manager if the investment helps reduce earnings fluctuations. This is certainly the case for investments in substitutes for inputs that may be rationed. In the absence of coping mechanisms, firm profits are directly reduced by supply curtailments.

Coping investments, while costly, may substantially improve the stability of future earnings.

The benefit from investment in coping mechanisms is shown in Figure C-1. The vertical axis is managerial utility, given by equation C-13 and estimated as: [Managerial Utility = Expected Profits - k x (Variance of Profits)]. The horizontal axis in Figure C-1 is the variance in the supply of a necessary input, such as natural gas. Two curves are shown. Curve A is managerial utility in the absence of coping.

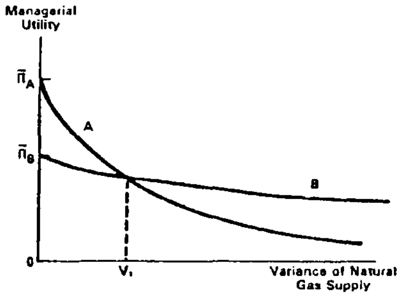

FIGURE C1. DEPENDENCE OF MANAGERIAL UTILITY ON SUPPLY VARIANCE (High Risk-Aversion)

The variance in the supply of natural gas has a large effect on the variance of profits in this case. Curve B is managerial utility after investment in coping mechanisms. Coping mechanisms reduce the dependence of profits on supply disruptions. The cost of a coping investment is borne independent of the availability of supplies.

The net effect of a coping investment is to spread the cost of a supply disruption more evenly over the daily operations of the firm. In other words, for any variance in the supply of a necessary input, such as natural gas, the variance of the firm's profits is reduced by investing in coping mechanisms. This is illustrated by Curve B in Figure C-1 which shows managerial utility as a function of the variance in gas supply when the firm has invested in coping mechanisms.

Figure C-1 shows that any assessment of the private value of coping investments must depend on expectations (the variance of supply) and managerial risk aversion (the factor, "k", which determines the slopes of Curves A and B). Figure C-1 shows that managers prefer to invest in coping if the gas supply variance is greater than V_1.

Figure C-2 is identical to Figure C-1 except that managers are assumed to be more tolerant of risk in Figure C-2 -- i.e., "k" in the following equation is smaller: [Marginal Utility = Expected Profits - k (Variances of Profits)]. In this case, managers prefer not to cope (and absorb the risk of supply disruptions) unless the variance of natural gas supply is greater than V_2.

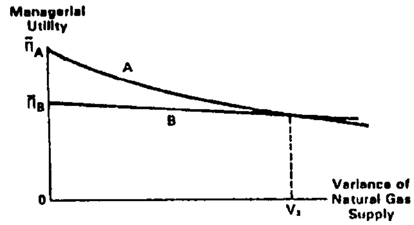

FIGURE C2. DEPENDENCE OF MANAGERIAL UTILITY ON SUPPLY VARIANCE (Low Risk-Aversion)

It is useful to note that the expected profits from investing or not investing in coping mechanisms can be compared by simply comparing the points where curves A and B intersect the vertical axis in Figures C-1 or C-2. Examining only expected profits is equivalent to ignoring the variance in profits, which amounts to setting the factor k equal to zero in equation C-13. (The vertical intercepts are the same in Figures C-1 and C-2 and are denoted by $\tilde{\Pi}_A$ and $\tilde{\Pi}_B$.) Clearly, the expected profit in the absence of coping may be higher when risk is ignored, but coping may be the preferred strategy when risk aversion is taken into account. The empirical results presented in the next section suggest very strongly that risk aversion is the dominant factor in the firm's decision to invest in coping mechanisms.

Empirical Results

Surveys of natural gas users conducted by Jack Faucett Associates show costs of alternative coping technologies that vary significantly among different users. The fuel cost increment of the alternative technology relative to natural gas ranges from a negligible amount to $4.50 per MCF. The latter is more than three times the cost of regulated natural gas. The distribution of capital costs per MCF to substitute capacity ranges from a negligible amount to $26.00. The average incremental fuel cost for six users in Kentucky and six users in Alabama and Tennessee was $1.32 per MCF and the average capital cost for the same sample was $4.93 per MCF.

Assuming an interest cost, including taxes and depreciation, of 20 percent per annum, the amortized unit capital cost of the substitute technique comes to approximately $1.00 per MCF. Since one expects capital charges comparable to fuel costs, this figure is not unreasonable. However, the figure of $1.00 per MCF presumes continuous operation at full capacity. A correct calculation of the cost of substitute capacity requires correction for the expected time of use (α in equation C-11). The average 100 percent peak curtailment for these users was 14 days. Suppose firm managers believed the circumstances leading to the winter 1976-77 gas shortage had a "1 in 100 years" probability of occurrence and that curtailments of seven days duration were expected once every five years. With these expectations, the equivalent average capital cost of the substitute technique is not $1.00 per MCF but $250.00 per MCF. Since product prices did not rise appreciably during the gas shortage, it would be impossible to justify investment in flexibility based on the additional profits made possible with the alternate production technique.

The investment in coping mechanisms of this expense requires an explanation other than the expected value of interim sales. One possibility is that firm managers expect natural gas curtailments of greater frequency. If an annual 14 day curtailment was expected, the capital cost would drop to $25.00 per MCF. This is still a very large number, and it is highly unlikely that firms could justify investments for substitution capability on the basis of the sales generated during periods of natural gas curtailment. Given the slight movements in prices during the 1976-77 winter shortage, it is not likely that firms could justify the high cost of substitution investments. Of course, if the substitute techniques are used when gas is available for flexibility in meeting peak demands, the average cost could be reduced to more reasonable levels.

The preceding section included the suggestion that investment in coping mechanisms was justified primarily as a response to risk and not as an expected profit-maximizing decision. The cost of substitute capability is not likely to be covered by the extra profits in the event of a shortage. The investment, nonetheless, may be a rational decision. It is necessary to incorporate aversion to risk along with the desire for profit. The investment in coping mechanisms should be properly evaluated as an investment in insurance. The expected cash payments from an insurance contract do not cover the premium cost, but the contract may be desirable because it offsets risk. A very similar motive appears to be the dominant factor in the decision to invest in coping mechanisms.

One cannot rule out the possibility that firms have invested in substitute production facilities to assure a continuity of employment for workers and to avoid potentially serious shortages of final consumption goods. This would make coping investments more of a public service than a profit-maximizing decision. It also is possible that firms may have overreacted to the probability of future gas shortages and the probability of long-term losses of sales; but even so, firms could not justify their investments in coping without a desire to avoid exposure to risk. The conclusion that risk avoidance is the primary motive for investment in coping mechanisms is supported by studies of industrial structure. For example, Chandler [39] conducted surveys of firms who had integrated with sources of supply. Chandler found that the most important reason for these actions was the desire to maintain an assured source of supply. Firms that relied on open market transactions sometimes found that prices did not equate supply and demand and in periods of excess demand there was the risk of quantity rationing by suppliers of inputs. The problem of momentary periods of excess demand is thus not unique to regulated markets. The investments studied by Chandler involved a change in the structure of industry as firms entered other stages of production to assure supply. There is evidence of similar behavior in the natural gas market as some firms have entered into the production of natural gas to assure continuous supplies. Even in those cases where firms have taken less extreme measures in response to gas curtailments, the desire to avoid risk again appears dominant, and, in the long run, we can expect that policies which impose shortages on firms will cause important changes in the structure of industry.