Evaluating Energy and Capacity Shortages – The 1976-77 Natural Gas Shortage
Volume 1

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ABSTRACT

This report provides (1) a methodology for estimating shortage costs and (2) an estimate of the shortage cost for the 1976-77 winter shortfall in natural gas supply. The methodology shows how to develop a comprehensive estimate of the willingness-to-pay to avoid shortages -- the producers' plus employees' plus consumers' plus the general public's willingness-to-pay to avoid the losses resulting from shortages. The 1976-77 experience indicates that total costs per million BTU's of shortage (i.e., the cost for every Mcf of curtailment to users who are not normally curtailed) are $54 for capacity and $5 for energy shortages.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This study is one of four ongoing projects under Research Project (RP) 1104 on the value of reliability to consumers. One of the other studies uses the methods developed here to make a case study of the 1978 summer electricity shortage that occurred in Key West, Florida. Another studies the theoretical economic basis for valuing reliability to the consumer. The remaining study develops the methodology of measuring consumers' valuation of reliability and designs survey methods to obtain data before shortages occur. These other studies will be reported in forthcoming EPRI publications. The survey design study is closely coordinated with a study sponsored by Boston Edison Company measuring values for its industrial and commercial customers.

The 1976-77 gas shortage occured from November, 1976, to March, 1977. The prolonged cold weather created a shortage in total available energy, and the severe peak cold weather created an additional capacity shortage. The measure used in evaluating the cost of the shortage to users, employees, product consumers, and the economy is the willingness-to-pay to avoid the shortage. This measure is expressed as dollar costs per Btu curtailed. An estimate of cost per Btu curtailed allows comparison among states, energy forms, and types of shortages (energy or capacity).

Basic data came from 100 interviews and mail questionnaires with gas suppliers, state agencies, and users in each of the states of Ohio, Kentucky, Tennessee, and Alabama.

PROJECT OBJECTIVES

The main objective of this study was to develop general methodologies for assessing the economic and social costs of energy and capacity shortages and to use the methods developed to assess the costs associated with the natural gas shortage that occurred in the winter of 1976-77. An allied objective was, on the basis of experience with application of the assessment methodology to the gas shortage, to provide modifications and improvements in the methods for possible application to assessment of the cost of electricity shortages.

PROJECT RESULTS

The methods developed in this project are a significant advancement over previous work. No previous shortage impact study was found that incorporates the breadth of impacts and the care in avoiding double accounting and overestimates. In this project, theoretical development went hand in hand with empirical data gathering. No formal, single, comprehensive model for all shortage cost estimation could be developed. Submodels for cost estimation were developed for annual production shortage, winter season energy shortage, and peak-day capacity shortage.

Costs due to annual production shortage are called coping costs from permanent fuel switching. Winter season energy shortages and peak-day capacity shortages give rise to both impact and coping costs. This study found that those affected in the four states were willing to pay to avoid the impact costs of future shortages--on the average, $1.40 per Mcf (thousand cubic feet, which roughly equals one-million Btu) curtailed for additional coping capacity following the shortage that occured. For those users who normally are not curtailed, impact costs due to capacity shortages were, on the average, $54.45 per Mcf. For those normally curtailed, the impact cost was only $1.31 per Mcf. Impact costs due to energy shortages, for those users who normally are not curtailed, were, on the average, $5.31 per Mcf; for those normally curtailed, the impact cost was $1.54 per Mcf.

Consistent with the cost estimation submodels, methods were developed to estimate the incidence of shortage costs for producers, employees, consumers, and macro-effects (economy or general public). Shortage impact costs for producers averaged $12.94 per Mcf curtailed, and $0.74 per Mcf curtailed for employees. Shortage coping costs for producers amounted to $0.96 per Mcf curtailed. Shortage impact costs for consumers and macro-effects were negligible since the 1976-77 gas shortage was a relatively small one in the total context of the types of shortages defined.

It was recommended that a methodology similar to that developed in this report could be used for electric power shortages, even though there are major differences in the supply-shortage characteristics. These differences can be delineated, and adjustments to the proposed methodology can be incorporated. The modified procedures were used in the Key West case study referred to above.

The methodological details from both case studies will be reported in a second volume to this project.

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VOLUME 1

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EXECUTIVE SUMMARY

Just as GNP is a careful accounting of value added by all sectors, shortage evaluation must be a careful accounting of value lost in all sectors. But shortage evaluation must even go far beyond GNP accounting -- it must account for employees' loss in utility from disrupted production and consumers' loss in satisfaction from delayed or lost consumption as well as change in producers' output which is GNP accounting.

The purpose of the study is to estimate the true cost of energy shortages. This report is both a case study in energy shortage effects -- the 1976-77 natural gas shortage -- and a methodology for estimating shortage costs. The case study part provides empirical estimates; it provides perspectives on robustness of a good estimation methodology; and it provides calibration of models in the proposed methodology. Data was collected from suppliers, from state agencies, and from users. Some important data must be protected because of the need to preserve confidentiality, but all data have been utilized in developing the methodology and summary estimates presented in this volume.

The methodology part provides a significant and much needed state-of-the-art improvement. Detailed shortage cost estimation methodology (to be presented in a separate volume) is summarized in Chapter 5. In brief, a series of sub-models is proposed because an all inclusive formal model is infeasible.

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 add a significant 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 indicators that shortage coping costs can equal shortage impact costs in the present types of shortages.

- 80% of shortage impact and shortage coping costs directly attribute 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 and the justifiable compensation to these selected users would have been less than 20% of the actual 1976-77 shortage costs.

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

The methodology presented in Chapter 5 focuses on the upper left, but the separate report on methodology includes all parts in the foregoing matrix. 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 sets of people (Groups) affected by shortage -- that is, there are four groups that have a willingness-to-pay to avoid shortages:

Producers -- they have extra costs if they maintain production in spite of the energy shortage or they have unrecovered costs if they lose sales.

Employees -- they have a loss in utility of income that is not included in the producer willingness to pay.

Consumers -- they have a loss in satisfaction from delays and from foregoing consumption; the part 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, and 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 classification on page S-5)[a]:

TYPICAL SMALL SHORTAGE COSTS

	Impact Costs [a]	Coping Costs [a]
1. Producers Direct plus indirect gas users)	$12.94/Mcf	$0.96/Mcf
2. Employees	.74/Mcf	Not applicable
3. Consumers	Negligible	Not applicable
4. Macro-effects	Negligible	Not applicable

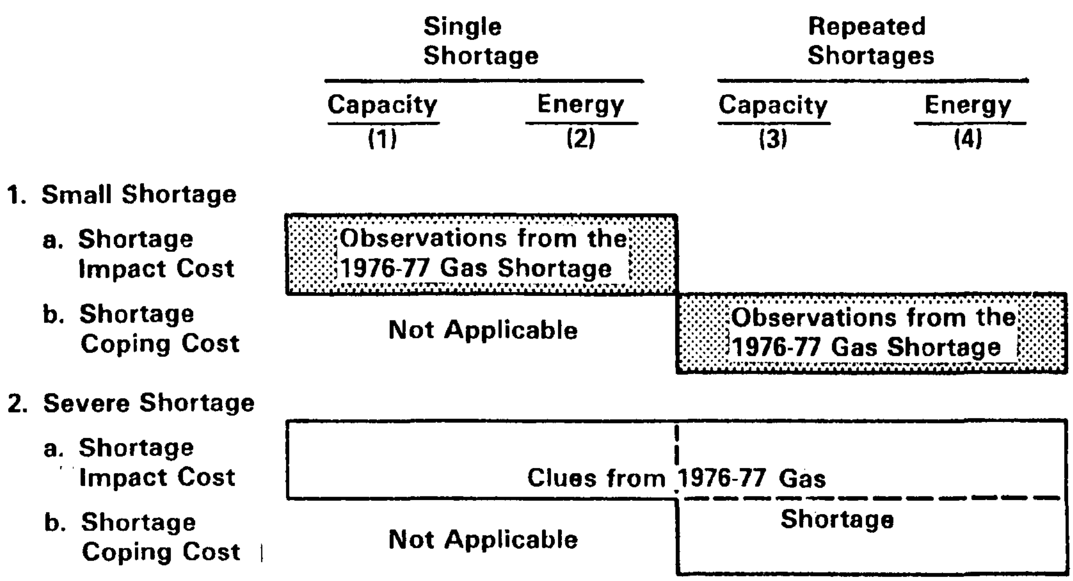
The empirical study for this report involved lengthy interviews with approximately 100 natural gas users in each of four sample states - Ohio, Kentucky, Alabama and Tennessee. Important state differences and economic sector variations are given in subsequent chapters.

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

- 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 of the following useful classification of shortage types:



SHORTAGE CLASSIFICATION

CHAPTER 1

DIVERSE AND POTENTIALLY VERY LARGE SHORTAGE COSTS

The purpose of this study is to estimate the true cost of an energy shortage. The 1976-77 winter shortage of natural gas was used as a case study because it provided the type of observations needed for developing a methodology and for providing empirical estimates of shortage cost per BTU (see glossary).

Data was collected from suppliers, from state agencies, and from users. Some important data must be protected because of the need to preserve confidentiality, but all data have been utilized in developing the methodology and summary estimates presented in this volume.

Shortage costs are diverse because of many types of initial effects and because of several stages of ripple effects. They can be very large because loss of energy which might be less than 5% of input can stop 100% of users' production; the direct-users' production, in turn, might be 5% of his customers input and it can stop another 100% of production; these two stages have a shortage cost leverage of 20 x 20 or 400 times the normal market value of energy. In addition to producers' loss, the employees of these producers suffer wage loss, and the final consumers suffer utility loss.

Figure 2 is the best introduction to diverse shortage costs; the glossary defines terms in all the figures and text. Figure 3 gives a perspective on as well as good insight into reasons for variation in shortage costs. In essence, the percentage curtailment and the twelve parameters shown in Figure 3 create the severe shortage condition in the lower half of the Figure 1 classification of shortages.

The following sub-chapters explain the reasons for diverse costs and potentially very large costs and they describe the insights to be gained from a case study of the 1976-77 natural gas shortage.

MANY TYPES AND LEVELS OF SHORTAGES

As shown in Figure 1, it is very helpful to differentiate (1) single and repeated shortages, (2) capacity and energy shortages, and (3) small and severe shortages.

These classes are not pure, but the concepts greatly simplify discussion and choice of submodels for estimating shortage costs.

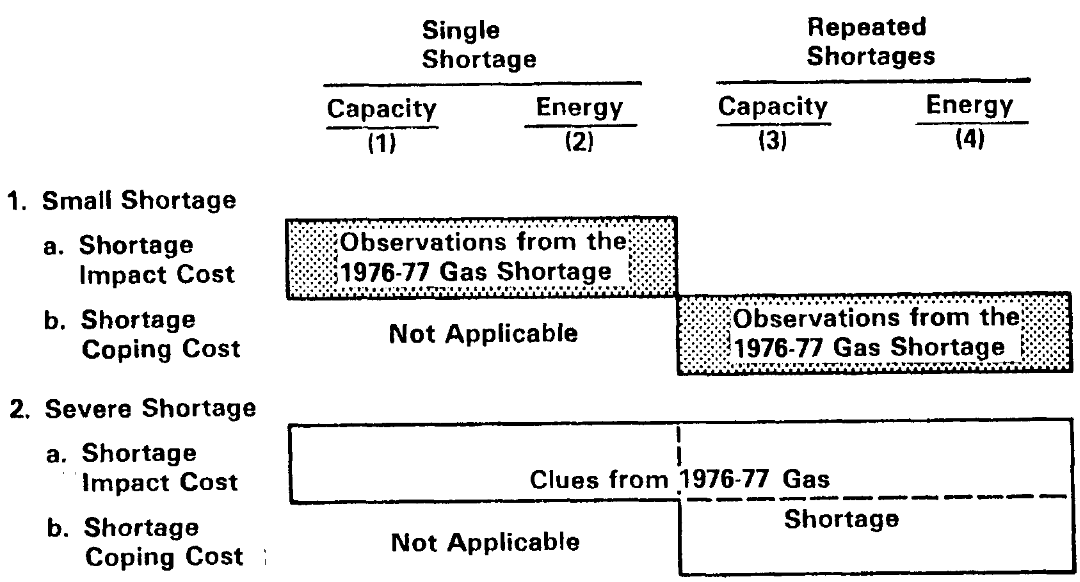


FIGURE 1. SHORTAGE CLASSIFICATION

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	[box]	Major impacts can all be measured by direct user production costs				
1. Cost of capability	3	[box]					
2. Cost of fuel	4	[box]					
B. Temporary Fuel Substitution	5	[box]					
1. Cost of capability	6	[box]					
2. Cost of fuel	7	[box]					
C. Delayed Production	8						
1. Makeup cost	9	This can create costs in Columns 1 through 5					
2. More inventory cost	10	[box]	These can be measured by direct user production costs				
D. Changed Production	11	[box]					
1. Modification for coping	12	[box]					
2. Lost sales	13	All 6 columns are important					

[a] Includes residential demand for energy.

FIGURE 2. INITIAL IMPACTS AND RIPPLE EFFECTS

Before discussing the important perspectives in Figures 1-3, it is desirable to understand the proposed case study -- the 1976-77 natural gas shortgage with the conditions given in Table 8. The case study provides valuable observations on both shortage impact costs and shortage coping costs for both a single shortage and repeated shortages; see the shaded areas in Figure 1. Individual states, and single users to an even greater extent, provide clues about impacts from severe shortages, as indicated by the boxes in Figure 1. Stated otherwise, the 100% curtailment for some direct-users along with special conditions in the twelve parameters in Figure 3 constituted a severe shortage, even though it was severe for a "small" segment of the economy in isolated geographic areas.

The following is a review of the 1976-77 natural gas shortage, using the Figure 1 context:

Single Shortage -- the gas shortage was an actual event during the November 1976-March 1977 period; on the other hand, repeated shortages cover the entire range of shortage levels and the entire range of values for the twelve parameters in Figure 3, and the associated probabilities.

Small Shortage -- 1976-77 was "small" because the nationwide costs, and costs for some states, could be identified at the direct gas user -- Stage 1 in the ripple effects.

Capacity and Energy Shortage -- the very prolonged cold in the 1976-77 winter created an energy shortage (see $q_6^*-q_4$ in Figure 6) and the very severe peak cold weather created an additional capacity shortage (the pipes were not large enough to meet demand as shown by delivery rate F in Figure 6 and the q_4-q_3 shortage quantity.)

Observations on Repeated Shortages -- the sample of users provided information on investment coping costs prior to 1976-77 as well as directly after, both of which are observations on shortage coping costs for repeated shortages (see the shaded area in Figure 1).

Clues on Severe Shortages -- the individual users and individual distributor companies (local suppliers) had shortages that would be severe if they were more widespread.

Insights for Other Energy Types -- since the 1976-77 experience included capacity shortages with little warning as well as energy shortages with larger warning, there are insights on shortage impacts for electric power and other types of energy shortages.

As quickly determined, the 1976-77 natural gas shortage is a particularly good case-study -- it can guide development of methodology and it can provide valuable calibration of parameters in shortage-cost estimation models.

MANY PERSPECTIVES ON SHORTAGE COSTS

The perspectives shown across the top of Figure 2 have two important classifications:

- First, classification of the affected parties' (losses by four different groups)
  1. Producers -- the production cost increases on the part of both direct- and indirect-energy users
  2. Employees -- the welfare loss of employees who are laid off by producers (the direct-and indirect-energy users)
  3. Consumers -- the final demand which has lower utility because of product unavailability

4. General public that suffer macro-economic effects -- the employees and resources that are underutilized because of economic multiplier impacts

- Second, classification of stages in the sequence of impacts (the four stages in ripple effects)
  1. Direct-energy user (a producer and the employees he lays off)
  2. Indirect-energy user (a producer and the employees he lays off)
  3. Final demand (the consumers who must wait for products or use substitutes)
  4. Macro-economic effects (the multiplier and inflation from reduced employee income and reduced availability of products)

The first classification is important in determining the final incidence of shortage costs while the second is important in guiding the analyst's quantitative assessment of shortage costs.

The matrix in Figure 2 shows how the initial effects on the left margin eventually generate costs and produce the ripple effects that can make shortage costs very large. It is helpful for a clearer understanding of the relationship between the four groups and the four stages described above and it will be particularly helpful in understanding the 1976-77 natural gas shortage scenario.

It is important to review each item in Figure 2. First, each of the six columns represent initial effects at the direct-user level and the ripple effects that show up at various points in the production-consumption cycle, as indicated below:

1. Direct User -- These are all costs that originate at the direct user point in the production-consumption cycle whether or not they are passed on by the direct user.

2. Indirect User -- These are costs similar to those for the direct user, but they are over and above the costs passed on from the direct user.

3. Employee Wage Loss -- These are costs (hardships) that accrue to employees, but are not reflected in his employer's cost; e.g., a worker who loses a month of wages because of his employer's sales loss has a cost over and above the employer's cost (identified in columns 1 and 2, Figure 2).

4. Employee Working Conditions -- in an energy shortage, workers might be uncomfortable in temperatures of 50 degrees or less.

5. Final Demand -- a loss for the final consumer who waits or switches to an inferior product because the production of his first choice product is interrupted by an energy shortage; again, this cost is over and above the producer's loss from the foregone sale.

6. Macro-economic Effects -- the typical multiplier effect starts with the employee or stockholder income loss; reduced purchases cause lower production which reduces other wages, thereby introducing the multiplier effect. Unavailable products also initiate a multiplier effect and inflation potential. If the economy is particularly weak, the multiplier effect is even greater.

The above is a brief review of the stages and the affected parties in the "ripple effects" from shortages.

The two initial impacts on the direct user -- shortage coping costs and shortage impact costs -- that can initiate ripple effects are sub-divided into the categories shown on the left-hand side of Figure 2.

The boxes in the center of Figure 2 indicate whether or not the entire ripple effect can, or cannot be, measured by extra cost originating at the direct user level. For example, fuel substitution costs in Lines 1-6 might be passed on to, say, final consumers in Column 5, but the entire magnitude of costs can be fairly accurately measured at the direct user level in Column 1.

The initial effects caused by a shortage can be discussed most easily in four parts with appropriate subdivisions as follows:

1. Adjusting to the specific energy shortage:
    a. Cost of fuel substitution capability;
    b. Cost of substitute fuel; and
    c. Inventory drawdown.

2. Investment to cope with future shortages:
    a. Greater fuel substitution capability; and
    b. Larger fuel and product inventories or modification of the production process.

3. Losses from production cutback beyond coping capacity:
    a. Layoffs that reduce employee income;
    b. Delayed production that requires overtime later; and
    c. Losses in sales that create unrecoverable cost to business-as-usual producers and create extra cost to product users who must substitute products.

4. Sacrifice in comfort and convenience:

   a. Residential cutback in temperature setting; and

   b. Worker conditions within industrial and commercial establishments.

All of the above effects are conditions for which there is a significant willingness-to-pay to avoid them. Just because some conditions are a coping process that reduces impact, they shouldn't be overlooked. Some of the largest costs (willingness-to-pay) are in the coping process. Even conservation of energy that can "reduce shortages" has a cost which may be larger than the savings in energy outlays -- i.e., a net cost for undertaking the conservation that "reduces the shortage".

The expenditures for coping in Item 2 should not be totally assigned to a specific shortage. The fuel substitution in a specific instance utilizes equipment and capacity that serves many shortages. Likewise, the new capacity added after a shortage (after an increase in expectation of future shortages) is a cost that should be amortized over multiple shortages; see glossary for definitions.

Some natural gas users, for example, have permanently shifted to electricity to avoid shortages. Any gas shortage after a permanent fuel switch will not be accompanied by reduced economic activity; however, the extra cost of electricity under business-as-usual should be attributed to the shortage (i.e., amortized over appropriate shortage quantities).

Whereas the above categories are useful for discussing types of impact, they should be re-arranged as shown in Rows 1-12 and Columns 4 and 5 in Figure 2 when developing estimates. In other words, sacrifice 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 1-12. This rearrangement helps in many ways, including better understanding of the ripple effects.

Impact categories 1-12 in Figure 2 can be regrouped according to the degree to which they can be measured at various points in the previous classification of stages:

Stage 1: Costs that show up at the direct-user level

1. Permanent Fuel Substitution
    a. Cost of capability -- Line 2
    b. Cost of fuel -- Line 3
2. Temporary Fuel Substitution
    a. Cost of capability -- Line 5
    b. Cost of fuel -- Line 6
3. Changed Production
    a. Modification for coping -- Line 11

Stage 2: Costs from reduced economic activity or adjustments by indirect-users (i.e., the users of product from, or suppliers of products to, the direct energy user)

1. Use of inventories (build-up in inventories) -- Line 9
2. Delayed production (because of direct user supply interruption) that is made up later at extra cost -- Line 8
3. Lost production for the same reason as 2b. -- Line 8

Stage 3: Impacts on Consumers (i.e., final demand that cannot be satisfied)

1. Delayed consumption -- stemming from Line 7
2. Substitute products -- stemming from Line 12
3. Permanent reduction in consumption including energy -- Line 12

Stage 4: Impacts that result from the multiplier effects

1. Income multiplier -- initiated at Line 12
2. Multiplier because of a weak economy -- initiated at Line 12

Note that employee impacts can be calculated from the above production losses in Stages 1 and 2.

The four stages have significant implications for developing a framework for evaluating shortages. For example, the direct energy user can be surveyed for an opinion on the impacts (from a pending shortage) that are confined to Stage 1, but the indirect users and final demand sectors cannot be easily questioned about shortages that will reach Stages 2-4. Interviews for the 1976-77 gas shortage case study provide limited insights on the second and third stages.

MANY DIFFERENCES BETWEEN SINGLE AND REPEATED SHORTAGES

The crucial use of the concept "with and without a shortage(s)" depends on understanding differences between costs associated with a single shortage and those associated with repeated shortages.

Most post-shortage analyses involve a single shortage that actually occurred (probability = 1.0) under specified conditions. Most pre-shortage analyses involve a range of severity, a probability distribution, and many different conditions. In essence, coping processes, whether government or private user, focus on repeated shortages.

Whereas shortage impacts (costs of effects that occur in spite of the coping process) can be identified with a specific shortage, most coping costs cannot. In Figure 2, parts A, B-1, C-2 and D-1 are coping costs that must be amortized over all shortages. The proper amortization for estimating impacts from a specific shortage is discussed later, but a few general comments are given below:

Investments to better cope with possible future energy shortages are a significant cost -- they are a cost undertaken to protect against more severe future shortage impact costs. They are overlooked in most shortage evaluations because they are in place before the shortage or they occur after the shortage. These investments include (1) greater fuel substitution capability, (2) changes in the production process, and (3) larger inventories -- Lines 10 and 12. The energy user sample in the case study provides valuable information on shortage coping costs as well as on shortage impact costs.

Production cutbacks are the most widely recognized shortage impact costs; however, they are seldom evaluated from the perspective of reduced employee income, greater employer costs, and losses to consumers of products. Production effects can be temporary or permanent, but the employer cost can be significant in both cases.

Whereas voluntary energy cutbacks in a shortage might prevent much greater costs than without them, they still constitute an important effect. An evaluation of actions that will reduce shortage should include all effects for which there is a willingness-to-pay to avoid them. For example, many employers in the survey of the 1976-77 natural gas shortage (Ref. 14) report that workers voluntarily sacrificed comfort rather than stop production and interrupt wages.

MANY CONDITIONS CAN CAUSE LARGE SHORTAGE COSTS

There are many conditions (besides a large percentage curtailment) that can cause large shortage costs. Figure 3 is designed to show (1) the typical relation between shortage costs and percentage curtailment and (2) the twelve major parameters that can shift this relationship.

If all shortages affected the same users in the same areas under the same shortage preparations, the "shortage cost-shortage level" relationship would be easy to establish. Unfortunately, shortage types and frequency are constantly evolving and indicated in the Chapter 3 discussion of shortage scenarios. The severity of shortages is discussed below.

For analysis of shortage levels in the case-study users were divided into the following three probability categories:

Category A, Non-curtailable: Residential and other small and high-priority users whose curtailment couldn't be monitored and can't easily be assigned an "allocation" q_6 in Figure 6.

Category B, Seldom curtailed: The intermediate group where the largest shortage impacts occur.

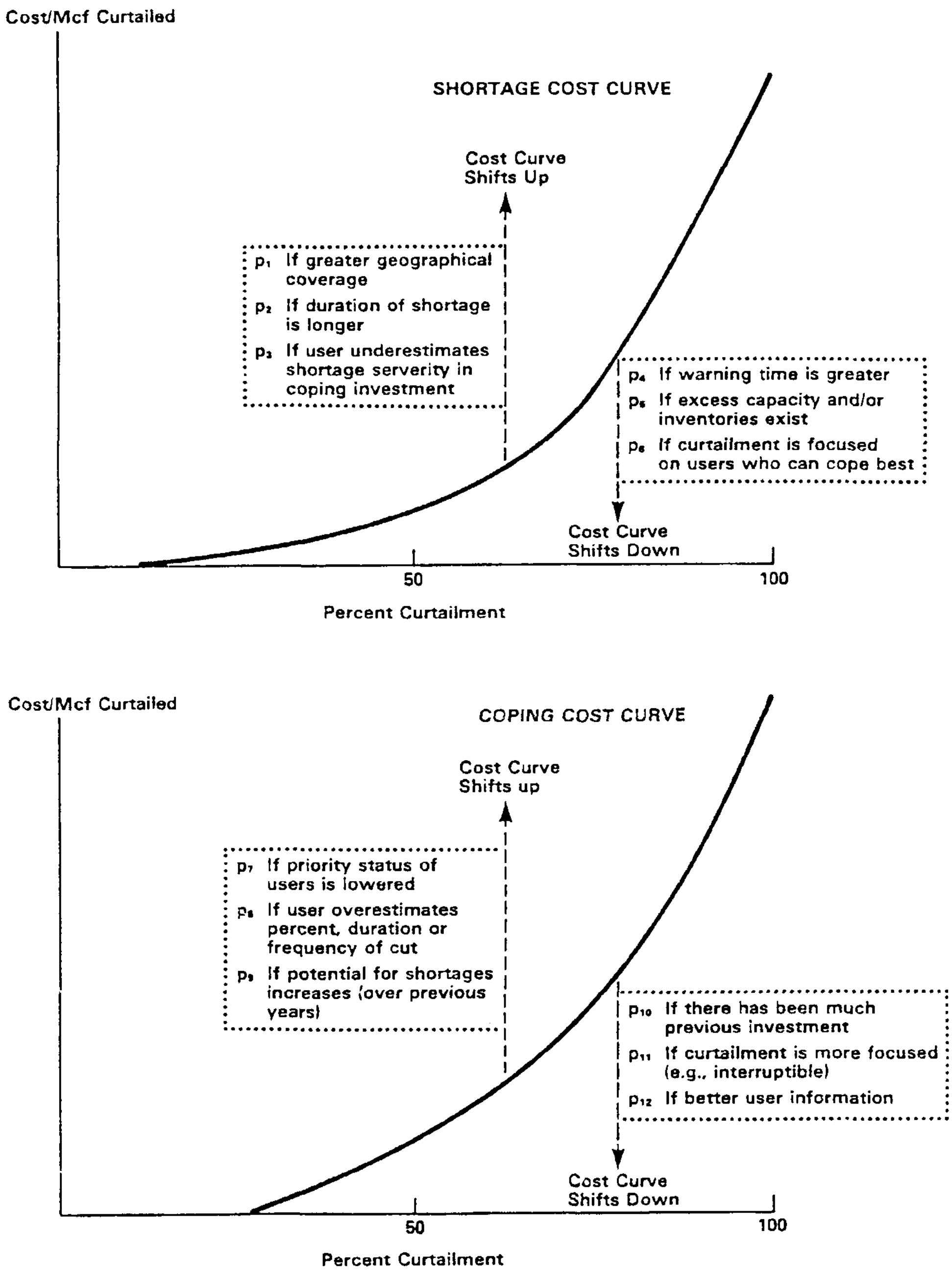


FIGURE 3. PARAMETERS THAT AFFECT SHORTAGE COSTS

Category C, Substitutable: Includes large boiler use which is often curtailed 100% from November 1 through March 31 and includes other uses where shortage impact costs are largely confined to a generally small 5-15% extra cost of a substitute fuel.

It would have been desirable to have more gradation in the "probability of curtailment", but this is difficult as is easily seen by the diverse priority categories shown in Tables 1 and 4.

SUMMARY

This chapter has presented the background and perspective for analyzing energy shortages. A classification of shortage according to type and level was discussed. By type, a shortage is either a capacity or energy shortage and should be analyzed as a single shortage or a series of repeated shortages, as delineated in this report. By level, a shortage can be small or severe. Cost estimates must include shortage coping costs as well as shortage impact coping costs.

The impact and coping costs from a shortage were shown to arise from initial effects such as fuel substitution, delayed production, changed production, or lost sales. The sequence in effects across the various groups in the economy was described; groups that were analyzed included direct and indirect energy users, employees, consumers, and the macro economy. This classification is important to (1) determine the final incidence of shortage costs, (2) guide the analyst in making quantitative assessments of shortage costs, and (3) avoid double counting of costs.

Descriptions of the 1976-77 shortage include shortfall in Mcf and comparison between shortfall and normal gas usage. Descriptions also include specification of whether users are perennially or very rarely curtailed.

TABLE 1 - CURTAILMENTS BY OHIO GAS SUPPLIERS

(Percent Curtailment During January and February, 1977)

	Jan. Cut	Peak Period[a]	Feb. Cut	Winter Energy Allocation[b] (Bcf)
East Ohio Gas Co.		1/17 to 2/8 (23 days)		
Category A				
1. Residential and commercial less than 50 Mcf peak day				165
Category B				
2. Large commercial and firm industrial requirements				
a) plant protection				23
b) commercial 50 Mcf peak day				
c) firm industrial 170 Mcf peak day		100		4
d) firm industrial 300 Mcf peak day	10	100	10	23
e) all other feedstock process	10	100	10	
Category C				
3. Small boiler with substitute fuel	10	100	100	24
4-9. Larger boiler and interruptible	10	100	100	5
				245
Columbia Gas of Ohio		1/16-20 1/27-2/1 (11 days)		
Category A				
1. Residential and human needs				157
Category B				
2. Commercial and industrial 200 to 999 Mcf/month	10	(Jan.10)	30	10
3. Large commercial	50	100	85	
4. Large industrial non-sub	50	100	85	
Category C				
5. Large industrial substitutable	100	100	100	84
6. Large industrial boiler	100	100	100	15
				166
Cincinnati Gas & Electric		1/27-2/1 (6 days)		
Category A				
1. Domestic				39
Category B				
2. Non-domestic 50 Mcf/D		100	30	7
3. Non-domestic 50 Mcf/D	20	100	80	8
Category C				
4. Special contracts	100	100	100	13
				67
Dayton Power & Light Co.		1/27-2/9 (14 days)		
Category A				
1. Domestic				38
Category B				
2. Non-domestic				
a) small 50 Mcf/D		100		9
b) large commercial	40	100	50	2
c) large industrial	40	100	50	2
Category C				
d) boiler use/interruptible	100	100	100	5
				56

[a]The cutoff is only to plant protection (generally 5-15% of allocation)
[b]Normal winter allocation (Nov. 1 - March 31) ; see further explanation on next page

b (cont'd) It is important to understand why January and February are specified for shortages, but a "winter energy allocation" is given in the last column. A supplier has an official (base period) winter allocation -- November 1 through March 31. However, the supplier can change the allocation at any time by stating that he will supply only a percentage of the winter allocation. A supplier usually re-interprets the scheduled winter allocation in terms of a percentage allocation of the winter, as indicated in Figure A-1. Therefore, data was available for January and February, 1977, and they were selected for the gas study because they represented the largest curtailments for an interesting length of time -- namely, the months of January and February.

TABLE 2 - CURTAILMENTS BY KENTUCKY GAS SUPPLIERS
(Percent Curtailment During January and February, 1977)

	Jan. Cut	Peak Period[a]	Feb. Cut	Winter Energy Allocation[b] (Bcf)
Columbia Gas of Kentucky		2/1 to 28 (28 days)		
Category A				
1. Residential and human needs				16.0
Category B				
2. Remaining commercial (small)			35	
3. Small industrial		100	50	1.00
4. a) Large commercial	40		75	1.30
b) Industrial non-sub	55	100	55	1.60
Category C				
5. Industrial sub	100		100	.87
6. Industrial Boiler	100		100	2.40
Total				23.1
Louisville Gas & Electric Co.		1/27-2/1 (6 days)		
Category A				
• Residential				30.0
Category B				
• Small industrial and commercial				3.5
• Fort Knox non-domestic	40		67	1.8
• G1, G-1A, G2, industrial process	40	100	67	18.0
Category C				
• G8 large space heat	100		100	2.7
• G6 large boiler	100		100	5.9
Total				61.9
West Kentucky Gas Co.		1/24-19 (5 days)		
Category A				
1. Residential				9.7
Category B				
2. Light industrial				3.7
3. Large commercial				.5
4. Large commercial and mostly small industrial		50-100	50	1.4
5. Industrial and commercial	55	100	100	4.8
Category C				
6. Boiler	100		100	2.7
Total				23.75
Union Light, Heat		1/27-2/1 (6 days)		
Category A				
1. Domestic				
Category B				
2. Non-domestic < 50		100		
3. Non-domestic > 50		100	80	
Category C				
4. Special contracts	70	100	100	

[a] The cutoff is only to plant protection (generally 5-15% of allocation)
[b] Normal winter allocation (Nov. 1 - March 31)

TABLE 3 - CURTAILMENTS BY ALABAMA GAS SUPPLIERS
(Percent Curtailment During Jan. - Feb. 1977)

	Jan. Cut	Peak Period[a]	Feb. Cut	Winter Energy Allocation[b] (Bcf)
Alabama Gas Corporation		1/18-2/22 (36 days)		
Category A				
1. Residential and Small Comm.				13.8
Category B				
2. Large Commercial and firm requirements up to 300 Mcf/day (priorities 283	0	100	0	1.8
3. Industrial	90	100	50	8.7
a) 300-1500 Mcf/day	90	100	50	
Category C				
b) 1500-3000 Mcf/day	90	100	50	
c) 3000 Mcf/day	90	100	50	
Total				24.3
Southern Natural Gas. Co.		1/18-2/22 (36 days)		
Category A				
1. Residential and Small Commercial up to 50 Mcf/day				4.2
Category B				
2. Large Commercial 50 Mcf/day	90	100	50	0.12
3. And firm industrial up to 300 Mcf/day				
4. Industrial requirements				
a) 300-1500 Mcf/day	100	100	100	6.52
Category C				
b. 1500-3000 Mcf/day	100	100	100	
c. 3000 Mcf/day	100	100	100	
d. 3000-19999 Mcf/day	100	100	100	
e) 10000 Mcf/day	100	100	100	
Total				10.84
United Gas Pipeline Co.		1/10-2/15 (35 days)		
Category A				
1. Residential and Small Commercial (feedstock)				4.2 0.2
Category B				
2. Large Commercials and Firm Industrials	80	100	80	5.5
Category C				
3. Industrial Customers All as in II.3 above	80	100	80	5.3
Total				15.2
Alabama-Tennessee Gas Co.		2/18-2/28 (11 days)		
Category A				
1. Residential and Small Comm.				
Category B				
2. Large Commercials & Industrial	60	100	40	
3. Industrial Customers All as in II.3. above	100	100	100	

[a] The cutoff is only to plant protection (generally 5-15% of allocation)
[b] Normal winter allocation (Nov. 1 - March 31)

TABLE 4 - CURTAILMENTS BY TENNESSEE GAS SUPPLIERS

(Percent Curtailment During January and February, 1977)

		Jan. Cut	Peak Period[a]	Feb. Cut	Winter Energy Allocation[b] (Bcf)
	East Tennessee Natural Gas Co. Serves 30% of Tenn.		1/18-3/1 (42 days)		
Category A					
	Priority 1		0		
Category B	2 50 Mcf/day		40		
	3		c/		
	4		c/		
	5		c/		
	6		100		
	7		100		
	8		100		
	9		100		
	Total				40.4
	Chattanooga Gas Company		1/18-2/22 (35 days)		
Category A					
	Priority 8 - (household, firm)				
	Priority 7 - (schools, Hosp., firm)				
Category B					
	6		40		
	5		100		
	4		100		
	3		100		
Category C					
	2 - Boilers 300 Mcf/day		100		
	1 - All interruptible		100		
	Total				18.2
	Texas Gas Transmission Co.				
Category A					
	1				
Category B					
	2				
	3				
	4				
Category C					
	5				
	6				
	7				
	8	100		100	
	9	100		100	
	Total				41.9
	United Cities Gas Co.		1/18-3/1 (42 days)		
Category A					
	Priority 1				
Category B					
	2		40		
Category C					
	3		100		
	4		100		
	5		100		
	6		100		
	7		100		
	8		100		
	9		100		
	Total				7.5

[a] The cutoff is only to plant protection (generally 5-15% of allocation)
[b] Normal winter allocation (Nov. 1 - March 31.)
[c] No customers.

CHAPTER 2

COMPREHENSIVE ESTIMATES OF COSTS PER MCF SHORTFALL

The most useful measure of shortage cost is the cost per unit of shortfall; among other things, this cost measure can be compared easily with market value and incremental cost of energy -- a comparison that immediately gives a clue to the value and the possibility of avoiding the shortage through incremental supply.

Comprehensive estimates implies that we must include every shortage impact for which there is a willingness-to-pay to avoid it; it also implies a concerted effort to comprehend the causes of shortage costs so that better coping can be identified. This chapter presents estimates of all impacts and the Chapter 5 methodology presents clues to causes of extensive shortage costs.

Comprehensive estimates require careful analysis of four stages in shortage impacts and careful estimates of mutually exclusive shortage costs (willingness-to-pay) in four groups. The four stages and four groups are inter-related as shown in Figure 4. Basically, the four stages represent increasing analytical difficulties in developing shortage cost estimates; the four groups represent the final evidence of all shortage costs (the willingness-to-pay). A forthcoming methodology report (60) will have more clarification on stages and final incidence for shortage costs.

Both the four groups and the four stages are represented across the top of Figure 4, as explained below:

Stage 1:	Direct energy user (e.g., stell mill)	Group 1 Group 2	Producers Employees
Stage 2:	Indirect energy user (e.g., auto mfg.)	Group 1 Group 2	Producers Employees
Stage 3:	Consumer (e.g., final demand for autos)	Group 3	Consumers
Stage 4:	Macro-effects (e.g., inflation)	Group 4	General public

Whereas the four stages pertain only to shortage impact costs, the four groups are indirectly affected by coping costs also. However, all the costs for small shortages can be measured within Group 1 (producers), as shown by Items A-J.

The arrows indicate the causal flow. For example, delayed production in the first row, first column, influences Items G,K,H,I, and J. There is feedback from consumer and macro impacts as indicated by the influence on Item H (lost production).

Shortage coping costs are enticed by costs in delayed and lost production. The methodology in Chapter 5 explains the complex relationship between coping and impact costs (see glossary for definitions).

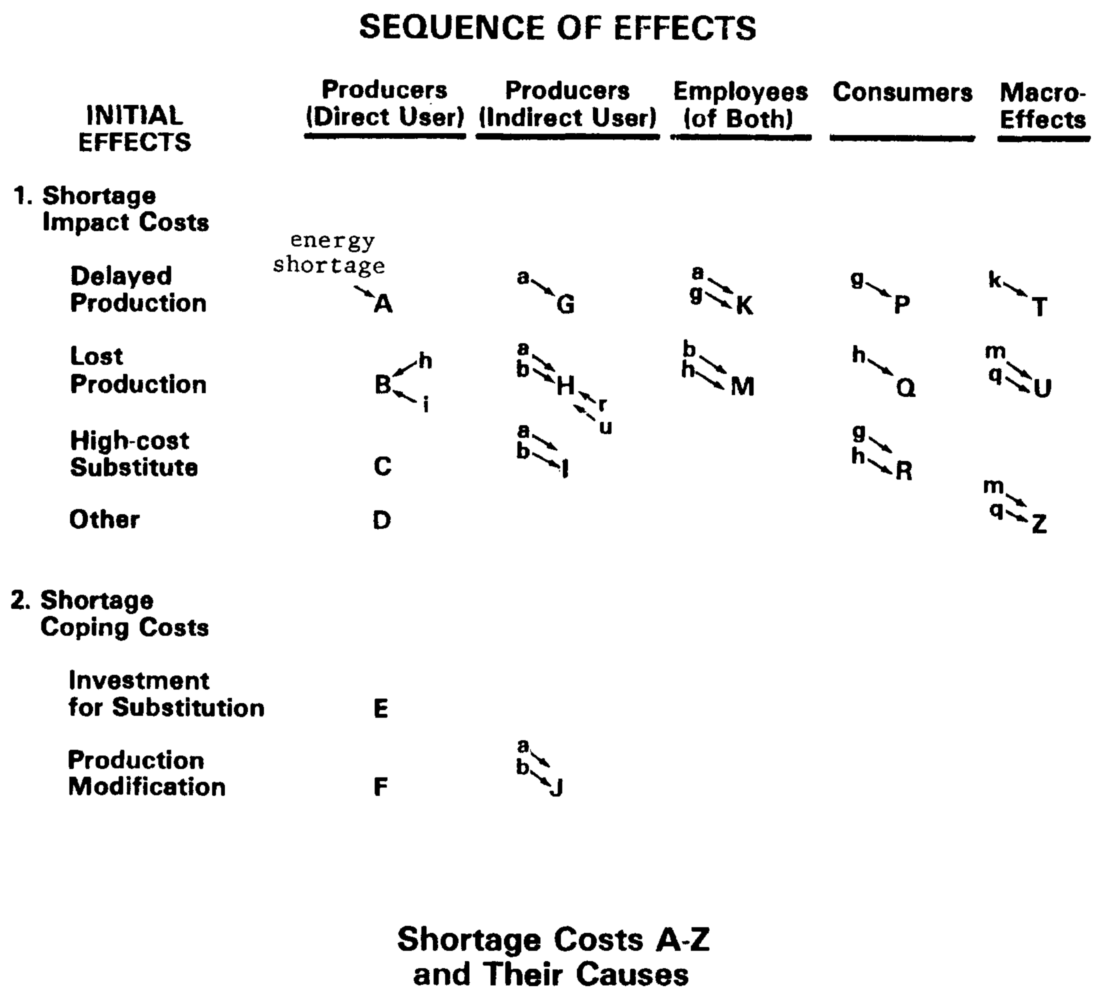


FIGURE 4: INTER-RELATIONSHIP AMONG FOUR STAGES AND FOUR GROUPS

NUMERICAL MEASURES -- WILLINGNESS-TO-PAY

Numerical measures are required in order to sum the many shortage costs and, hopefully, understand total impacts. The willingness-to-pay concept is required to avoid the many dangers for double counting -- double counting between direct users and indirect users and double counting among producers, employees and consumers.

Figure 10 (page 59) is designed to show the important consideration of passed-on costs in the business decision to cope with shortages; it also shows the need to avoid double counting when summarizing costs. It represents only shortage impact costs; shortage coping costs are discussed later.

Every dollar of efficiency loss is a dollar that someone in our society would be willing-to-pay to avoid the loss. The losses represented by shaded areas are drawn to scale for the 1976-77 natural gas shortage. These losses are defined below.

1. Direct-User

   Area A: Unrecovered costs due to loss in sales. Every dollar of unrecovered cost is a dollar of willingness-to-pay (by the direct-user or, if passed on as part of Area E in Figure 10, by the indirect user).

   Area B: Extra costs due to maintaining production. The producer can avoid lost sales, but only by using more expensive substitute fuel, by using overtime to make up delayed production, or by inefficiency from maintaining production under reduced natural gas use.

2. Indirect-User

Area C: Unrecovered cost analogous to Area A.

Area D: Extra costs analogous to Area B, but includes extra cost of either transporting the product from a different supplier or using inferior substitute products.

Area E: Costs passed on by the direct-user. These affect the decision to continue buying from the affected direct-user, but shouldn't be counted a second time in a willingness-to-pay measure.

As quickly seen, practically all shortage impact costs in the 1976-77 natural gas shortage could be identified at the direct-user stage in the sequence of shortage impacts.

The losses by final demand are not shown in Figure 8 or in the above outline because they are so small relative to the direct user's losses.

Investments to cope with future shortages -- shortage coping costs -- constitute a significant willingness-to-pay to avoid shortages. It doesn't matter that a user can avoid more than a dollar of impact costs from <u>spending</u> a dollar of coping costs. He would be just as willing-to-pay to avoid the shortage(s) for which he is preparing to cope better.

Coping costs are reported in the last sub-part of this chapter. The concepts and theory are not presented until the Chapter 5 methodology. Shortage coping cost(s) prior to and just after the 1976-77 natural gas shortage were easy to report, but they are very difficult to assign to any specific shortage, as discussed in Chapter 5.

SHORTAGE IMPACT COSTS: 1976-1977

All shortage impact costs in the 1976-77 natural gas shortage are shown in Tables 5 and 6. Estimates as well as discussions of shortage impact costs and shortage coping costs are separated to differentiate clearly between the two.

Methodology used in developing Table 5 estimates as well as methodology for applying these estimates to other shortages is discussed in Chapter 5; only empirical estimates are presented in this sub-chapter.

Consumer impacts and macro-economic effects are not shown in Table 5 because they are an insignificant addition to costs generated in Stage 1 -- the direct-user in Column 1 of Figure 2.

TABLE 5

SHORTAGE IMPACT COSTS/MCF: 1976-77 GAS SHORTAGE

	Row	Substitutable Direct Users (total) (1)	Non-Substitutable Direct Users: Direct Users (2)	Indirect Users (3)	Employees (4)	Total
A. Capacity Shortage[a/]	1					
1. Unrecovered costs	2	$ .00	$22.00	$ .00	$4.50	$26.50
2. Extra costs	3					
a. Fuel	4	.71	.80	.00	.00	.80
b. Makeup	5	.60	23.00	3.70	.00	26.70
c. Inefficiency	6					
d. Damage	7	.00	.45	.00	.00	.45
3. Total	9	1.31	46.25	3.70	4.50	54.45
B. Energy Shortage[b/]	11					
1. Unrecovered cost	12	.00	1.93	.00	.03	1.96
2. Extra costs	13					
a. Fuel	14	.66	.95	.00	.00	.95
b. Makeup	15	.88	2.40	.00	.00	2.40
c. Inefficiency	16					
d. Damage	17	.00	.00	.00	.00	.00
3. Total	18	1.54	5.28	.00	.03	5.31

[a/] January and February "Allocation Minus Supply" during peak-day curtailment: see Item C in Figure 6, for example; if the January-February allocation was 40% of the base allocation and plant protection allowed 10%, the curtailment was 30% of the base allocation.

[b/] "Base Allocation Minus Supply" during January and February 1977.

TABLE 6

SHORTAGE COPING COSTS/MCF: 1976-77

	Direct Users	
	Substitutable	Non-Substitutable
A. Prior to 1976-77 shortage		
° Cost/Mcf	Not Relevant [a/]	
° Average substitution capacity	100%	48%
° Cost/User	Not Relevant [a/]	$101,000
B. During & immediately after 1976-77 shortage		
° Cost/Mcf	0.0	$1.40
° Average increase in substitution capability	0.0	17%[b/]
° Cost/User		$ 39,000
° Sub-part for larger duration		

[a/] Most substitutable users had in-place coping for 10-20 years, and therefore, costs are not meaningful.

[b/] An average decrease in the percent of non-substitutable natural gas.

SHORTAGE COPING COSTS FOLLOWING THE SHORTAGE: 1976-77

Shortage coping costs increased because of the 1976-77 natural gas shortage; some users discovered that shortage impact costs were greater than expected and they increased their coping capability. Other users decided that future shortages were more probable than previously thought and they increased their coping capability.

Sample data provides insights on coping costs prior to the 1976-77 shortage and coping costs just after this shortage. This report does not discuss the justification of coping investment, but merely presents the estimates. However, the basic reason why a specific shortage such as the 1976-77 natural gas curtailment can cause greater investment in coping is reviewed in the Chapter 5 estimation methodology discussion.

SUMMARY

This chapter has presented the necessary concepts for measuring willingness-to-pay and the corresponding numerical estimates for the 1976-77 natural gas shortages. Estimates of shortage coping costs stemming from user decisions to expand fuel substitution after the 1976-77 shortages were also presented.

Costs for capacity shortages were \$54/Mcf compared to \$5/Mcf for energy shortages. Shortage costs for users who are normally curtailed were \$1-\$2/Mcf compared to the \$54 and \$5 for other users reported above.

CHAPTER 3

RISING IMPORTANCE OF ENERGY SHORTAGES: 1976-77 IN CONTEXT

Will shortages increase in frequency and intensity? Will energy shortage impacts become increasingly important in the nationwide cost of goods and services?

The easiest answers start with a description of the 1976-77 natural gas shortage, followed by review of how parameters of that shortage might change for other energy types and future natural gas conditions.

As will be readily apparent, shortages arise from severe weather conditions, from sudden production (supply) loss following a labor strike or accident or equipment failure, from long-term production loss following energy depletion, and from imbalanced load-growth that intensifies weather-sensitive demand.

DEFINITION OF SHORTAGE CONDITION

A shortage exists when consumption at the present market price could be higher or price at the current consumption level could be lower: i.e., either demand exceeds supply or market prices exceed resource costs.

It might not be economically or politically feasible to set prices to clear the market and attract the optimum supply even though this would eliminate shortages. E.g., severe weather can surge demand such that a sufficiently high price to clear the market is undesirable. This will become clear in the following discussion of the 1976-77 natural gas shortage.

The annual production shortage is illustrated in Figure 5. With control on wellhead prices, the positive demand growth rate and negative supply growth rate have created the "annual production shortage" shown in Figure 5 -- a shortage because demand exceeds supply at the market price.

Winter-season energy shortages and peak-day capacity shortages are illustrated in Figure 6. Their explanation is complex because winter season supply includes production (q_1) plus pre-season storage (q_1-q_0) plus inter-region transfers (q_3-q_2), as indicated. Identification of short-run shortages is further complicated because there is a long-run allocation (q_6) and continuing shortages (q_6-q_3) which automatically effect demand (q_6^*). Weather causes demand to vary such that it is not possible to forecast whether demand (q_6^*) will exceed long-run allocation (q_6). In the 1976-77 winter, demand (q_6^*) far exceeded long-run allocation.

Peak-day capacity shortages can occur several times during the winter instead of only the one "t_1-t_2" continuous interval shown in Figure 6. In any case, the peak-day shortage is the accumulated shortfall during all days of plant protection; in Figure 6 it is

(3.1) $$\text{Peak-day shortage} = q_5 - q_3$$

where quantity "q_5-q_3" is the quantity "d-c" in Figure 6 -- the accumulated difference between the consumption rate and the delivery rate, as shown.

Winter season energy shortage can occur in any of the five months, and the total shortage is, in fact,

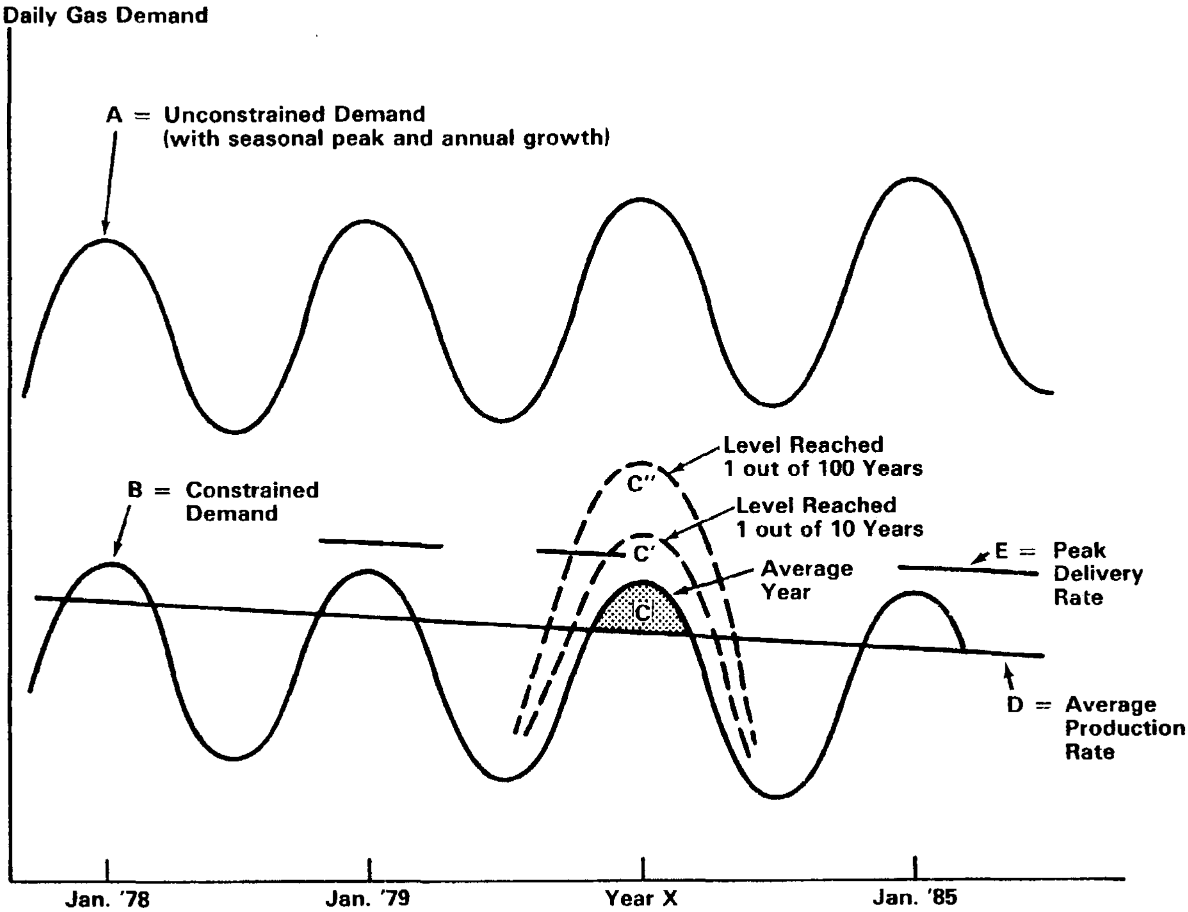


FIGURE 5. ANNUAL PRODUCTION SHORTAGE

(3.2) Winter season shortage = $q_6^* - q_3$

but must be measured as

(3.3) Winter season shortage = $q_6 - q_3$

where demand "q_6^*" can be above or below the base allocation, q_6. In other words, supply can exceed base allocation if, say, weather permits and requires considerable gas transfer as designated by Item E in Figure 6.

For practical reasons, winter season shortage must be defined in terms of base allocation rather than the q_6^* demand (i.e., demand under a system of base allocations and shortages). Stated otherwise, the q_6 base allocation is a known quantity and allows calculation of shortages, but demand q_6^* is not observable even though it is, indeed, the desired base from which to calculate shortages.

The quantities and definitions in the Figure 6 schematic of winter season (short-run) shortages are complex, but they do represent the real world. It is essential to understand the energy shortage conditions of Figure 6 before reviewing the 1976-77 natural gas shortage.

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 curves shown in Figure 3 and repeated in Figure 10. The reader should recall that a simple function relating shortage costs to curtailment level will shift with changes in the 12 parameters listed in Figure 3. The purpose of this section is to establish the values for the 12 parameters and the value for the percentage curtailment (the horizontal axis).

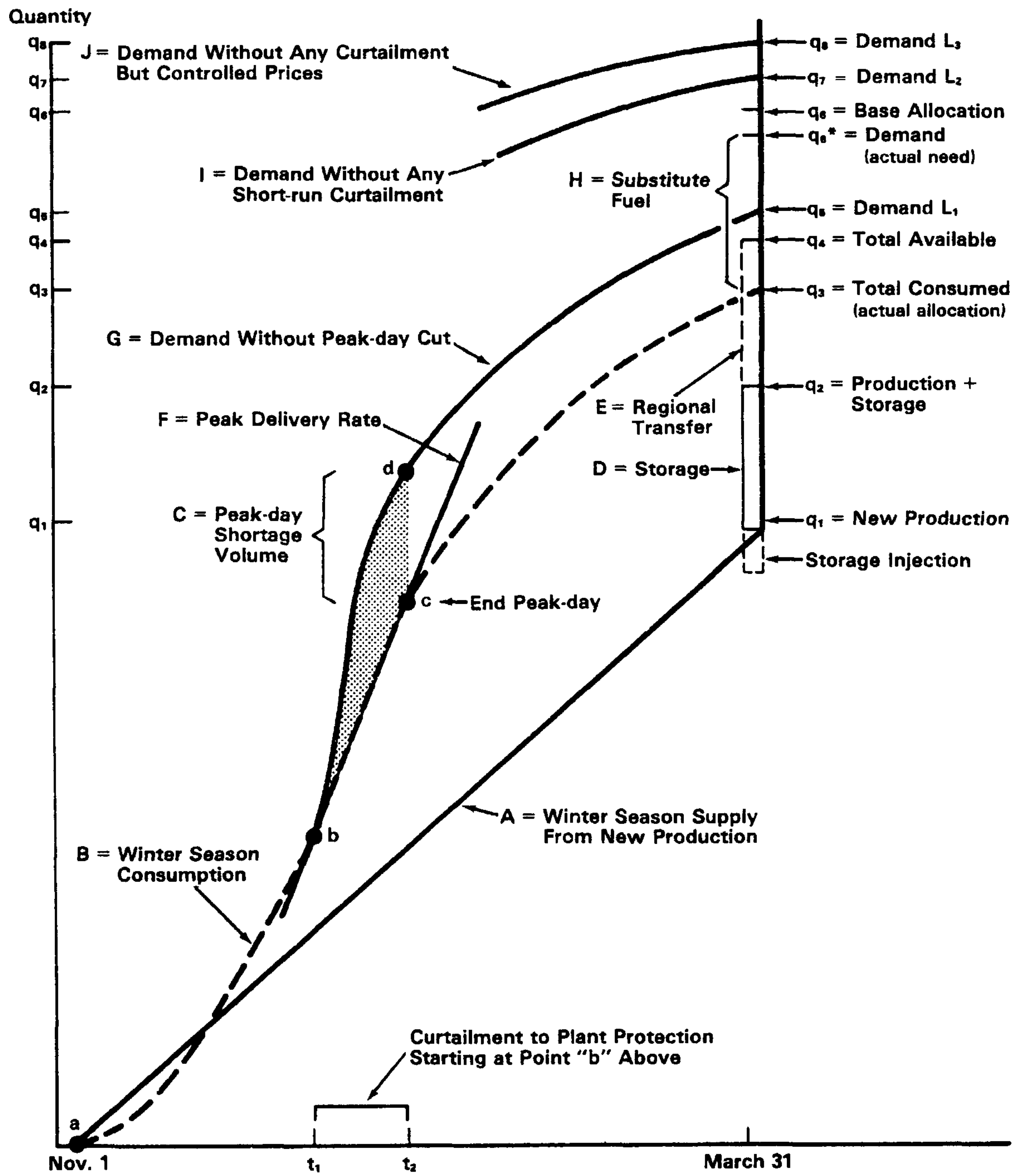


FIGURE 6. WINTER SEASON CAPACITY AND ENERGY SHORTAGE: REGION X

The natural gas curtailments in four example states are summarized in Tables 7 and 8. These four states do not provide four observations for estimating either cost curve shown on Figure 3 because the other 12 parameters vary considerably, as shown in Table 8.

The precision in Table 8 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.

RISING IMPORTANCE OF ENERGY SHORTAGES

Three of the four major reasons for energy shortages seem to be intensifying. The following is a summary.

Energy depletion -- long-term production rates for petroleum and natural gas are decreasing and, consequently, a long-term production decline can create greater annual production shortage. In addition, the isolated ban on nuclear power and the generally long approval time for any electric generation is likely to create electric power shortages.

Unbalanced load growth -- the apparent federal emphasis on residential load growth will create more weather-sensitive demand and, subsequently, create more peak-day and winter season shortages in natural gas.

Sudden production loss -- crippling labor strikes seem more likely than previously, as indicated by the 1977-78 coal-worker strike. As excess capacity in electric generation diminishes, as seems likely with power plant delays, there will be more accident and failure-caused shortages in electric power.

The fourth shortage cause -- abnormally severe weather -- shows no sign of intensifying. However, the above related changes in other causes of energy shortages are sufficient to warrant greater concern for shortage impacts.

Technically, a shortage exists only when market prices cannot adjust to allow market clearance and encourage efficient supply. It is difficult to predict if government policy will tend to control market price to a greater or lesser degree. It appears that government controls will not decrease as domestic oil and gas production decreases; therefore, the factor changes discussed above are likely to produce more shortages in the future.

In any case, shortage impacts are very significant and should be understood better. Besides the major shortage impacts, there is evidence that much of these impacts could be avoided with better allocation during shortages.

SUMMARY

This chapter has defined the very difficult concept of shortage, including explanation of why many commonly-used definitions are erroneous. The shortage definition was illustrated with parameters from the 1976-77 natural gas shortage. The chapter concludes with an explanation of why energy shortages (and good shortage analysis) are likely to become increasingly important.

TABLE 7

1976-77 NATURAL GAS CURTAILMENT

	Line No.	Ohio	Kentucky	Tennessee	Alabama
		- - - - - Billion Cubic Feet - - - - - -			
A. 1976 Total Sales	1	973	180	201	225
B. Nov.-March Allocation					
Non-curtailable[a]	2	440	62	N.R.[c]	68
Non-substitutable	3	160	42	37	23
Substitutable	4	98	16	16	62
C. Jan.-Feb. 1977 energy[a] curtailments		- - - - - Percent Curtailment - - - - -			
Non-curtailable	5	zero	zero	zero	zero
Non-substitutable	6	35%	40%	25%	50%
Substitutable	7	86%	92%	98%	87%
D. Peak-day Curtailment		- - - Days of Plant Protection Curtailment- -			
Non-curtailable	8	none	none	none	none
Non-substitutable[b]	9	6-23 days; Avg.=16	5-28 days; Avg.=9	0-42 days; Ave.=10	10-36 days; Avg.=14
Substitutable	10	N.A.[c]	N.A.	N.A.	N.A.

[a] The three categories of natural gas use are defined on page 14, chapter 1, as follows: Non-curtailable is residential and other small or highest priority users who are never curtailed. Substitutable is all users who have substitute fuel; non-substitutable is all other.

[b] Average across distribution companies.

[c] N.R. = Not reported; N.A. = Not applicable

TABLE 8

TWELVE MODEL PARAMETER VALUES -- 1976-77 GAS SHORTAGE

(See Parameter List in Figure 3)

		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

CHAPTER 4

AVOIDABLE AND UNAVOIDABLE COSTS

The purpose of <u>energy</u> shortage evaluation is twofold: (1) identify ways to reduce shortage costs and (2) establish the practical limit in cost reduction. The latter is very useful in preventing unwarranted expectations and preventing uneconomical government regulators' or private suppliers' actions to improve reliability.

An evaluation of the 1976-77 natural gas shortage is a good opportunity for accomplishing both purposes. The empirical data and theoretical advancement make the practical limits in shortage reduction more obvious. Likewise, the data and theory provide many clues for reducing shortage costs (reaching the limit).

THE AVOIDABLE COSTS WITH BETTER ALLOCATION AND PREPARATION

Opportunities for reducing shortage costs are much more extensive than the intuitively obvious policy of more fuel substitution. In fact, there is too much investment in coping; it is caused by poor information on future shortages and poor allocation schemes during shortages.

In brief, it appears that both impact costs and coping investment cost could be reduced more than 80%. Stated otherwise, the almost $1 Billion cost attributed to 1976-77 shortage in Ohio could have been less than $200 Million if shortage costs would have been understood and appropriate decisions implemented.

The following outline provides a clear delineation of options that should be considered in reducing shortage costs:

1. Reduction (in total shortage quantity)
    a. Greater production and imports, nationwide
    b. Greater storage for meeting weather-sensitive demand
2. Allocation (of a given shortage)
    a. Curtail those users within a system who are least affected
    b. Transfer gas among systems
3. Preparation (for potential shortages)
    a. Better users' coping process
    b. Reliable supplier/government information on potential shortages

This chapter will consider only allocation and preparation; specifically, it will consider a subset of the 12 parameters that can shift the shortage impact cost and shortage cost curves shown in Figure 3. Note, that Item 1 above -- reduction in shortage volume -- is a shift along the horizontal axis of Figure 3.

The reader is reminded again that this research did not focus on policy recommendations; it focused on shortage costs as they exist under present policy. However, the 1976-77 gas shortage provides many clues on shortage cost reduction with better government policy or supplier actions.

A first approximation of the value of better allocation and better preparation is given in Table 9. First, it is an approximation because it is based on clues from only the 1976-77 shortage. Second, it is a guess on which option area is the cheapest; e.g., the 70-30 split for allocation "within" versus "among"

TABLE 9

POTENTIAL REDUCTIONS IN SHORTAGE COSTS: FIRST APPROXIMATION [a/]

	Shortage Impact Costs	Shortage Coping Costs	Total
Better Allocations			(.70)
Within System	.20	.20	
Transfer among systems	.15	.15	
Better Preparation [b/]			(.30)
User coping	.05	.10	
User information		.15	
Total			1.00

a/ Estimates are very rough approximations; they are offered merely as a guide to what programs might be very helpful in reducing shortage costs.

b/ Better preparation includes more substitution for users who have under invested and reduced investment for those who have over invested in substitution capability.

supplier systems differs if the "within" is done first or second. The intent in developing the table was to provide clues on the cost-benefit ratio in various categories of options.

The avoidable costs should, of course, be addressed in order of cost-benefit payoff. Again, this report can only provide clues, so-to-speak. The following clues are valuable for guiding next efforts:

Priority 1: Better supplier/government information. User confusion from government warnings on long-run energy shortages and suppliers' short-run curtailment actions can be greatly reduced. In particular, each shortage like the 1976-77 experience should be followed by clear analysis of the probability of a repeated event.

Priority 2: Within systems allocations. Although the spirit for this could be greatly enhanced by federal action to facilitate inter-system transfers, it still seems second priority. In particular, the very high shortage costs from peak-day curtailments can be greatly reduced by more selected curtailments that avoid costly plant shutdowns.

Priority 3: Inter-system transfers. First, government hindrance should be removed; second, knowledgeable brokers should be available. In short, a good futures market and spot market should be set up.

Priority 4: Individual user coping. This provides considerable opportunity, but it differs so much between with and without implementation of priorities 1 and 3 that it very deservedly is rated fourth.

A forthcoming Jack Faucett Associates report to the federal government will provide more detail on options and priorities.[a]

PRACTICAL LIMITS

The probability distribution underlying any shortage potential does not allow 100% elimination of shortage costs. There are practical limits in reducing both efficiency losses and inequities.

The first realization is that practical limits exist for all three, but particularly the last two, of the following three shortages:

Shortage Type and Major Causes	Potential Reduction
1. Annual production shortages	
a. Price controls (below market clearance)	100%
b. Long-run reduction in production	50%
2. Winter season energy supply shortage	
a. Below-optimum storage	100%
b. Weather variation	90%
3. Peak-day delivery capacity shortages	
a. Improper load growth	100%
b. Inadequate pipe and pumping capacity	20%

Again, the above percentage reductions in current level shortage costs are only a first approximation; consistent with the philosophy of this report, they are presented to guide further investigation.

a/ "Identification and Comparison of Options in Natural Gas Curtailment Priorities."

In one sense, the practical limits are set by weather and resources whereas the opportunities for reducing shortage costs are limited by man's decisions (actions). The above outline is deliberately designed to show opportunities along with the practical limits. The remaining discussion illustrates both limits and opportunities.

There is an annual production shortage because government controls keep well-head prices below the market clearing price. There is no import (or alternate supply such as coal conversion) shortage because prices for gas from these sources are at or above market clearing prices. There is opportunity for 100% reduction in annual production shortages caused by government control.

On the other hand, the annual production "shortage" caused by users who designed consumption for quantities greater than existing, is only partially avoidable. Stated otherwise, the short-run demand curve is more inelastic than the long-run (the long-run demand from which shortage is properly defined).

The storage part of winter season energy shortages are 100% avoidable, as indicated above. The weather caused variation is 90% avoidable; even optimum supply/storage quantities cannot eliminate, say, the 1 out of 100 year condition - a condition that undoubtedly existed in part of Ohio in 1976-77. This does not mean that the Ohio situation couldn't be helped; to the contrary, an optimum policy that could accommodate, say, 1 out of 20-year shortages would greatly reduce shortage costs from a 1 out of 100 year shortage level.

The proper load-growth portion of peak-day curtailment can be eliminated completely, as indicated in Item 3a above. However, there are very few, if any, justifiable increases in nationwide pipeline capacity.

Later studies have a big responsibility for establishing practical limits more clearly. The above clues were presented, in part, to guide these later studies.

SUMMARY

The most important component of shortage costs is the avoidable part. This chapter has carefully outlined the avoidable component and delineated how cost estimation should focus on the avoidable part.

Preliminary estimates indicate that over 50% of many types of shortage costs are unnecessary. Therefore, improved state-of-the-art in shortage cost estimation is important for the nation as well as for isolated shortage situations.

CHAPTER 5

METHODOLOGY FOR ESTIMATING SHORTAGE COSTS

This chapter is a summary of a forthcoming and more detailed methodology report -- Analytical Framework for Evaluating Energy and Capacity Shortage (60). It serves two purposes: first, it explains the process by which empirical estimates were developed for this report; second, it provides a guide and concise summary of the methodology for estimating costs in other shortages. The summary of methodology for very severe shortages (where ripple effects are extensive) is given in Appendix C.

Figure 7 outlines sub-models and furnishes a guide to this chapter. As indicated, it is highly preferable to subdivide methodology for single and repeated shortages because of the much greater complexity in the latter. Among other things, assessment of repeated shortages involves probability distributions of shortages for every year within the planning horizon -- a probability distribution for frequency and for severity.

	Shortage Impact Costs	Shortage Coping Costs
Single Shortage		
small curtailment	First Section	Not Applicable
severe curtailment	Second Section	
Repeated Shortages		
frequency distribution	Third Section	Fourth Section
severity distribution		

Figure 7: Models for Shortage Cost Estimation

It is also highly desirable to subdivide methodology for shortage impact and shortage coping costs. The latter is defined as the cost of any coping action (to help if a shortage occurs) that must be amortized over multiple shortages (for determining the cost-benefit ratio of the coping action). Shortage impact costs are any cost attributable to a specific shortage -- they are the costs over-and-above shortage coping costs.

Coping costs are generally confined only to direct users (and energy suppliers)[1/] whereas impact costs can extend to indirect users and consumers via a complex set of ripple effects; see discussion of 4 stages in Chapter 2.

The first part of each subchapter is the concepts and basic approach; the last part is empirical estimates.

SMALL CURTAILMENT IN A SINGLE SHORTAGE

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

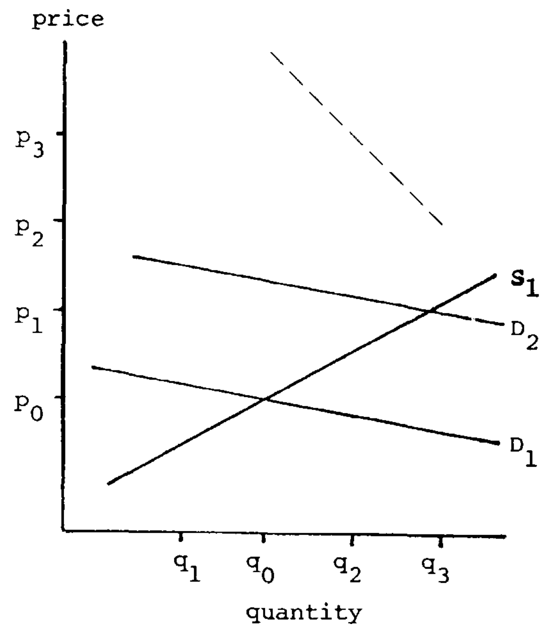
$$(5.1) \quad \text{(Shortage cost)} = \sum_i K_i \left[\text{Appropriate Shortage Quantity} \right]$$

where K_i is cost per unit shortfall and "i" is the ith cost component in the Figure 5 schematic.

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 <u>winter</u> season as described on the following pages.

[1/] Energy suppliers have coping costs when they build in reliability (particulary storage, which reduces short-term shortages). In some cases, supplier coping is much larger than in this case study.

Since shortage quantity is difficult to define in the context of curtailment schemes, it is helpful to delineate different bases from which shortage is measured. The economic definition of shortages for both supply reduction and demand increase is shown to the right.[a/] If the shortage estimates are to help administrative allocation of the available volume for the existing demand, the shortage is "$q_3 - q_1$." If the short-run price is allowed to increase, some users will drop out as shown by the dotted short-run demand curve -- i.e., demand decreases from q_3 for prices above p_2. If price is allowed to reach p_3, for example, shortage quantity under one definition decreases to "$q_2 - q_1$"--the appropriate measure of shortage estimates for guiding administrative rationing for shortage "$q_2 - q_1$." If estimates are to help guide decisions on reliability level, the cost of reliability that is not reflected in the S_1 supply curve must be considered also.



The physical definition of shortage for applying estimated shortage cost/unit is:

$$\text{shortage} = (\text{allocation}) - (\text{supply})$$

where allocation is the agreed-upon allocation in a curtailment plan and does not reflect shifts in demand (e.g., from D_1 to D_2 above).

[a/] Supply reduces to q_1 from the q_0 previous equilibrium, and demand shifts from D_1 to D_2 for reasons such as cold weather.

The physical shortage is measured as specified because it is the quantity that can be obtained when applying shortage cost estimates. The concepts are easier to understand after realizing that residential demand shifts up in cold weather and, consequently, the supply remaining for others decreases -- it decreases below the base-year allocation.

The difference between the economic definition and physical designation is complex, but both must be understood. Cost estimates in this report are based on the physical quantity designation in order to make them useful for estimating cost in other shortages. The economic definition depends on the specific use of the shortage cost estimate and cannot be specified apriori. However, the above illustration indicates the approach for a definition.

Peak-day capacity shortages can occur several times during the winter instead of only one "$t_1 - t_2$" continuous shortage period shown in Figure 6 (page 34). In any case, the peak-day shortage volume is the accumulated additional shortfall during plant protection days as shown in Figure 6 (page 34) and Equation 5.2.

$$\text{(5.2)} \qquad \text{peak-day shortage} = q_5 - q_3$$

where quantity "$q_5 - q_3$" is the quantity "d - c" in Figure 6 -- i.e., the accumulated difference between the consumption rate and the delivery rate, as shown by the shaded area.

Winter season energy shortages can occur in any of the five months, and the total shortage is defined in Figure 6 as:

(5.3) actual winter shortage = $q_6^* - q_3$

but must be measured as

(5.4) observable winter shortage = $q_6 - q_3$

where demand "q_6^*" can be above or below the q_6 base allocation. Supply as well as demand can exceed base allocation if weather permits (and makes it desirable for) considerable gas transfer within Item E in Figure 6.

For practical reasons, winter season shortages must be defined in terms of base allocation rather than the q_6^* demand (i.e., demand under a system of base allocations and affected by weather). 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 base from which shortages and associated shortage costs are initiated.

Quantities and definitions in the Figure 6 schematic of winter season (short-run) shortages are complex. Nevertheless, given the above definitions and explanation of "single shortage", we can now define "small cutback" (the level of cutback in the Figure 12 horizontal axis for which the methodology in this chapter is applicable).

A small shortage is a winter season in which (1) shortage impact costs are virtually all generated at, and possibly confined to, the first stage in the 4-stage ripple effect depicted in Figure 2 and (2) shortage coping costs are not increased because user expectations do not change enough to generate greater coping investments. The change in user expectations and the subsequent investment in greater coping capacity are better discussed in the next section.

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

Figure 8 is drawn to show small costs beyond the direct user[a]; there can be many specific reasons why costs beyond the direct user are small. The general reason is that the energy shortage is not intense (i.e., it is a small percentage cut or of a short duration).

If sales are lost, direct-user impact is "unrecovered costs" shown as Area A in Figure 8. These are both capital and labor costs -- the latter includes continuing salaries in order to avoid losing employees in a layoff during interrupted production. Unrecovered costs could easily be 50 percent of the market value of sales lost in a shortage, as indicated in Figure 8.

If the indirect user can obtain the same product (the same product as the direct-users output) from another supplier with little extra transportation or can use a substitute product with little sacrifice, his loss will be small, as indicated by shaded areas C and D in Figure 8. That is, it will be small even when the direct user loses sales. Indirect users can obtain an alternative supplier or product more easily if the energy shortage is local.

[a] See App. C for shortages which cause large costs beyond the direct user.

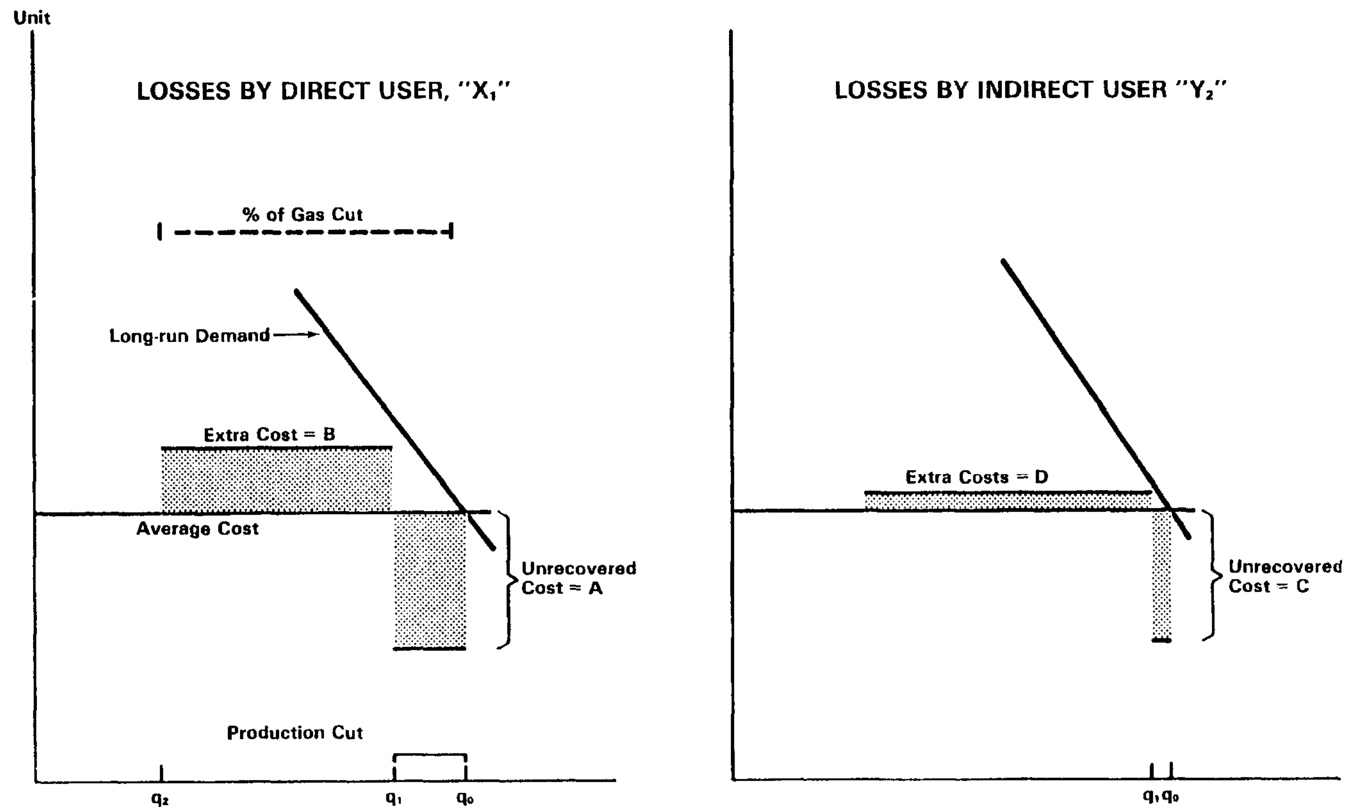


FIGURE 8: LOSSES BY DIRECT AND INDIRECT GAS USERS

If the direct user maintains production, his "extra costs" are at least 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 8. For example, a 50% energy cut would generally affect 50% or less of production.

When the direct user maintains sales, there are only small effects on indirect users, as indicated by shaded area D in Figure 8.

There are several reasons why no significant additional impacts exist beyond the direct-user in a small shortage.

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.

The Table 10 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 10. They are representative of typical values for the six parameters shown in the upper part of Figure 3. Chapter 3 gives more detail on the parameter values.

As shown in Table 10, 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 is unavailable and measures of energy curtailed must be used.

Of the following two coping processes, only the second 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 Item 1 is insignificant because the incidence of a "small shortage" does not cause the user to increase preparedness; the explanation is given in Figure 9.

TABLE 10 - 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)	$L_3=K_3$ (ΔSeles) $=K^*_3$ (ΔMcf)	
Makeup Costs [b/]	$L_4=K_4$ (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}=.80	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.

[c] Makeup and efficiency are combined.

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 9. The MV' marginal value of substitution capacity is:

$$\text{(5.5)} \qquad MV'_Q = P_Q \left[\text{Shortage Impact Cost} \right]_Q$$

where MV' is the incremental value of having substitution capacity of "$Q + \triangle Q$", 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 9.

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 9. 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 section, the important investment decisions perspective in Figure 9 will be utilized and explained further in discussing severe shortages.

Table 10 does not present coefficients for estimating shortage coping costs. These costs are negligible for a small shortage because users don't re-evaluate their shortage expectations for the reasons stated above. The model and empirical estimates in Table 10 will become clearer after discussion of severe shortages in the next subchapter.

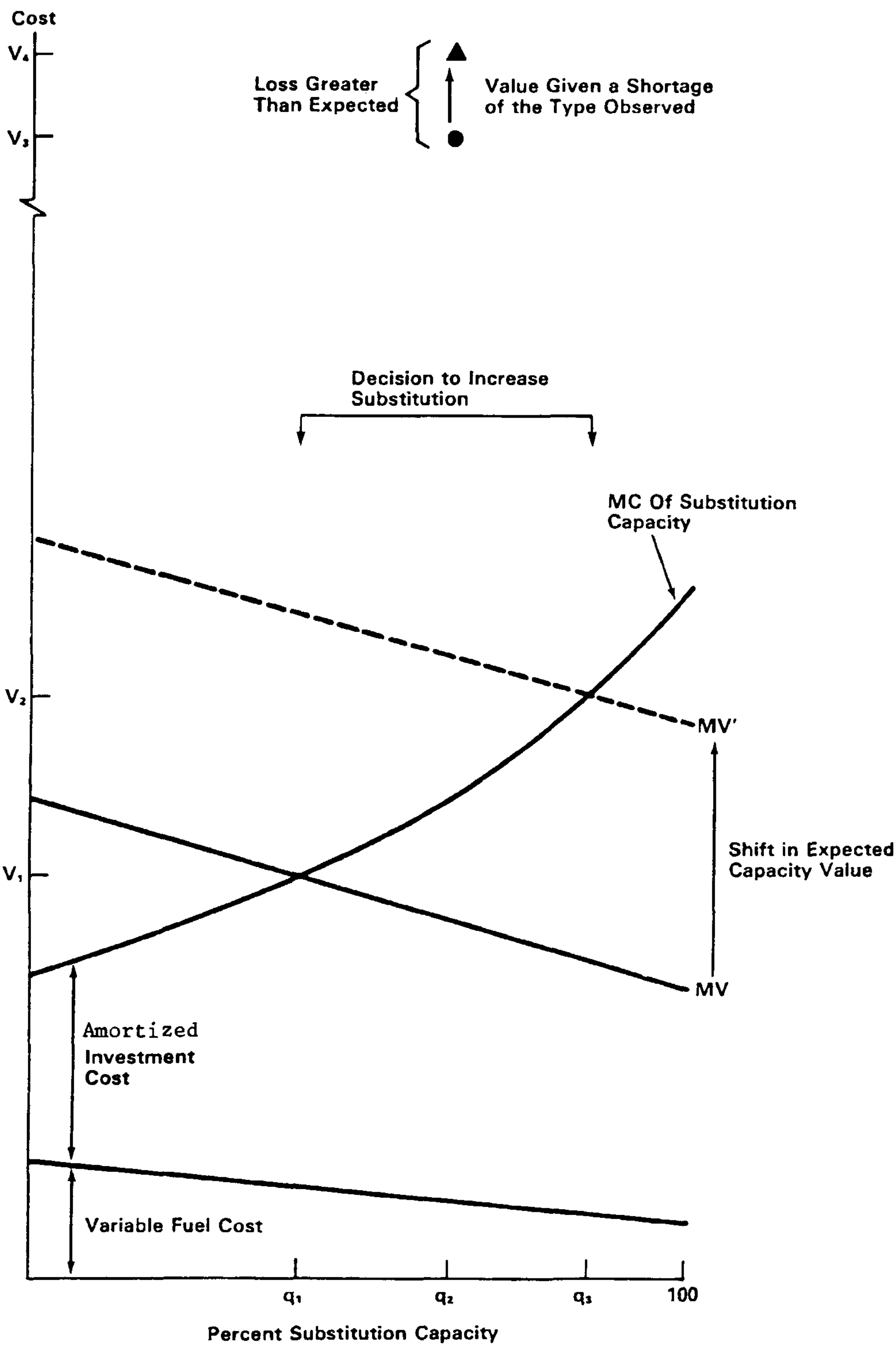


FIGURE 9. DECISION ON SUBSTITUTION CAPACITY AFTER A SHORTAGE

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 10 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 10) are larger than the extra costs from continued or delayed production (Areas B and D in Figure 10). Modifications of input-output analysis seem the best way to estimate effects from extensive loss in sales.

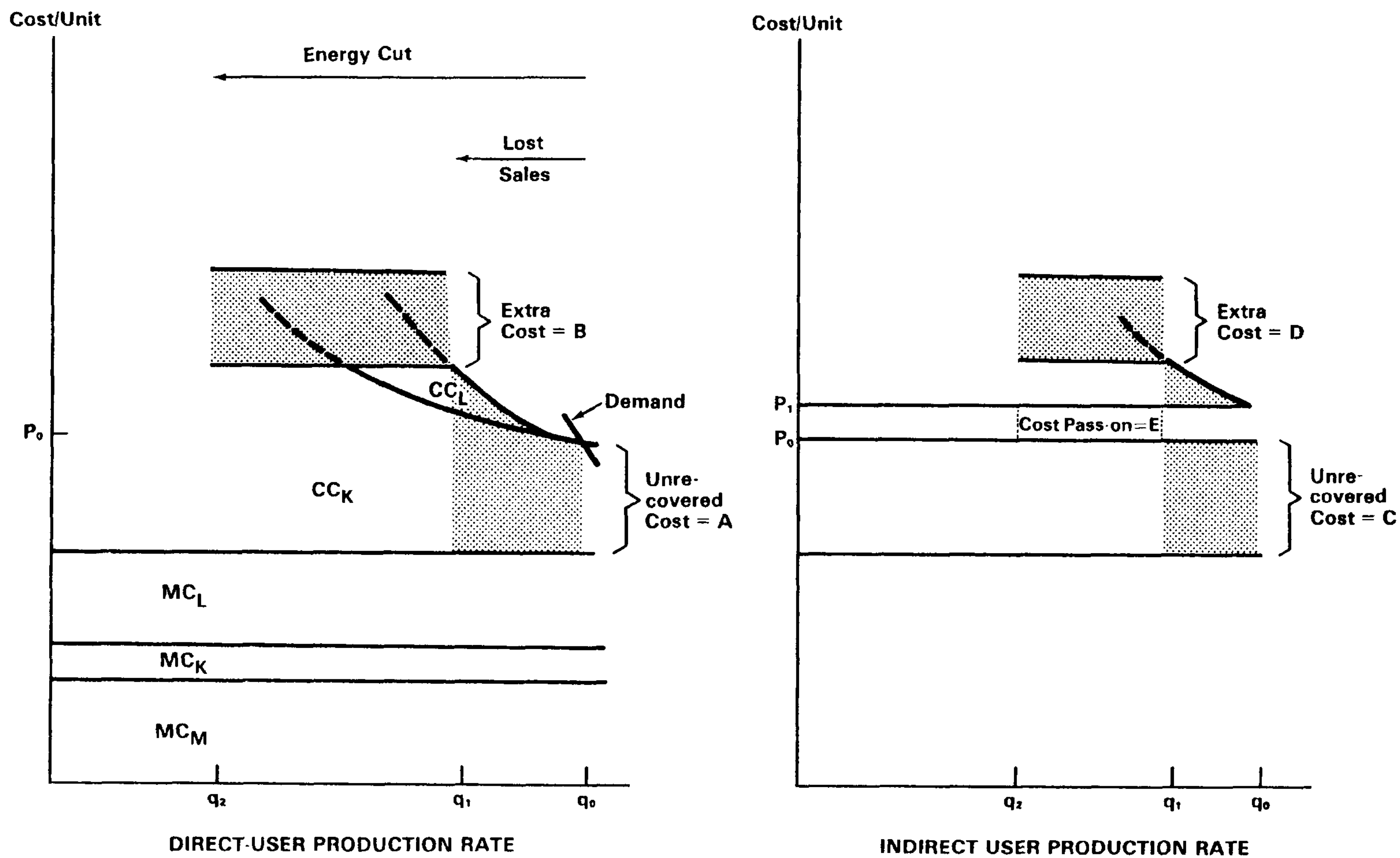


FIGURE 10. DIRECT AND INDIRECT USER COSTS

Figures 10 and 11 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 10 basically resembles Figure 8, 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, as shown on Figure 10.

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

1. Variable cost (at the margin)
   - Marginal cost of materials, MC_M
   - Marginal cost of capital, MC_K
   - Marginal cost of labor, MC_L

2. Fixed costs (for given production level)
   - Common cost of capital, CC_K
   - 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 10. 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 11 context below.

The shortage impact sequence and producer/consumer decisions can be outlined using Figure 11 as follows:

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

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

III 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 and again, the direct user incurs Area F loss from unrecovered costs.

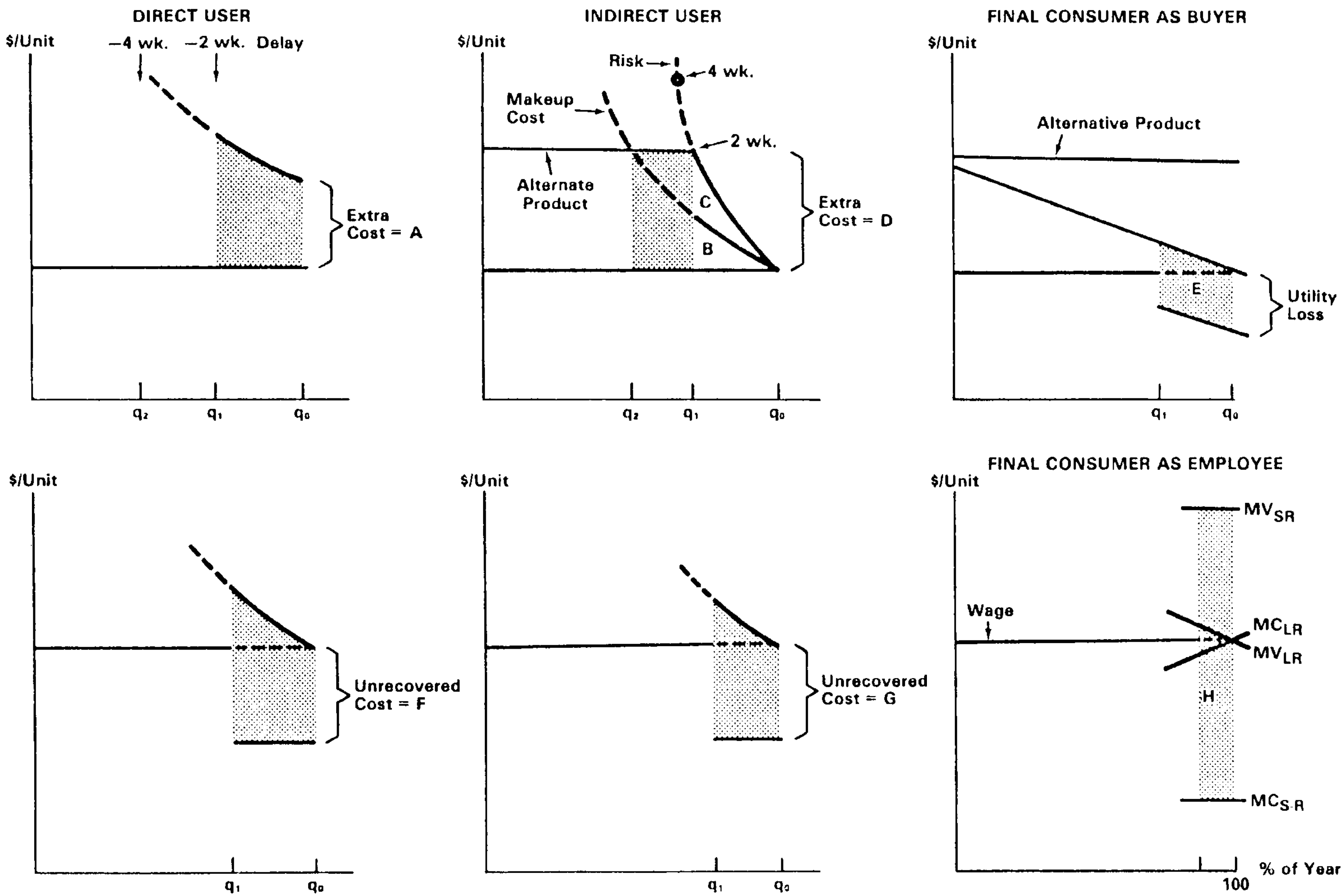


FIGURE 11. COST OF (1) DELAYS, (2) SALES LOSS, (3) EMPLOYEE INCOME

IV Indirect users will incur either the extra cost (Areas B, C, and D) or the unrecovered costs (Area G).

V 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.

VI Employees will incur the Area H loss because a short-run surprise layoff with an income cut has more loss from wage interruption than leisure gain from work interruption.

VII Reduced employee income and lower consumer purchases can trigger the economic multiplier effect (See Figure 1, Row 13, Column 6) which then causes sale loss and unrecovered costs in Areas F and G.

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.

DIFFERENCES IN COSTS BETWEEN DIRECT AND INDIRECT USERS

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 (see next subchapter).

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

Direct User	Indirect User
1. Substitute fuel ° Greater cost per unit ° Less desirable fuel	1. Substitute product or supplier ° Greater transportation ° 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 ° Cold working conditions ° Using less energy ° Changing 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 10) 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_1 at q_o in Figure 10)

2. Increment to fixed-cost/unit as sales are reduced (see the increase in cost CC_K as "q" drops below q_o in Figure 10)

3. The implicit labor cost when employees quit during layoffs (see cost CC_L as "q" reduces in Figure 10)

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 of Ref. 60.

The above steps help us to review the six parameters that shift the shortage impact curve -- the six parameters shown in Figure 3 -- as shown below.

Step 1:	Restrict volume by sector	Parameter 2 -- The larger the shortage 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 capacity to increase inventories, and, thereby, reduce impacts as Step 1 will accomplish.

		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 that 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.

Parameters 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 discussion, in a forthcoming report.

REPEATED SHORTAGES: IMPACT COSTS

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

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 3.

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 re-evaluation of expectations about the underlying distribution of shortages, thereby giving the analyst 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.

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 a complete elimination of shortages -- i.e., not all significant shortage impacts shown in Figure 12 are eliminated.

2. Lower actual probability but not necessarily lower user expectations -- the expectations leading to shortage coping costs in the lower parts of Figure 12.

3. Lower shortage impact costs by improved allocations without necessarily reducing overall shortage quantity (see the 12 factors that can shift shortage costs listed in Figure 3).

Because of these complexities, this subchapter focuses only on the additional methodology required beyond that for a single shortage. There are two major additions:

1. the discounted value of probable future shortages (in contrast to an actual present shortage in analysis of a single shortage) and

2. the sum of shortage coping costs and shortage impact costs (in contrast to impact costs only in analysis of a single shortage).

The additional methodology will be presented in detail in a forthcoming report and is summarized below.

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

$$\text{(5.6)} \qquad \text{Shortage Cost} = \sum_{t=1}^{M} (1+r)^{-t} \left[\sum_{L=0}^{100\%} P_L \, (IC + CC)_L \right]_t$$

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 in Figure 3 are redrawn in Figure 12 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 12, the expected costs are C_1 and C_2 for an implied set of values for the 12 parameters listed in Figure 3 -- the 12 parameters for the 1976-77 natural gas shortage are given in Chapter 3.

The "with and without" situation for repeated shortages can be illustrated in the Figure 12 schematic as follows:

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 12.

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).

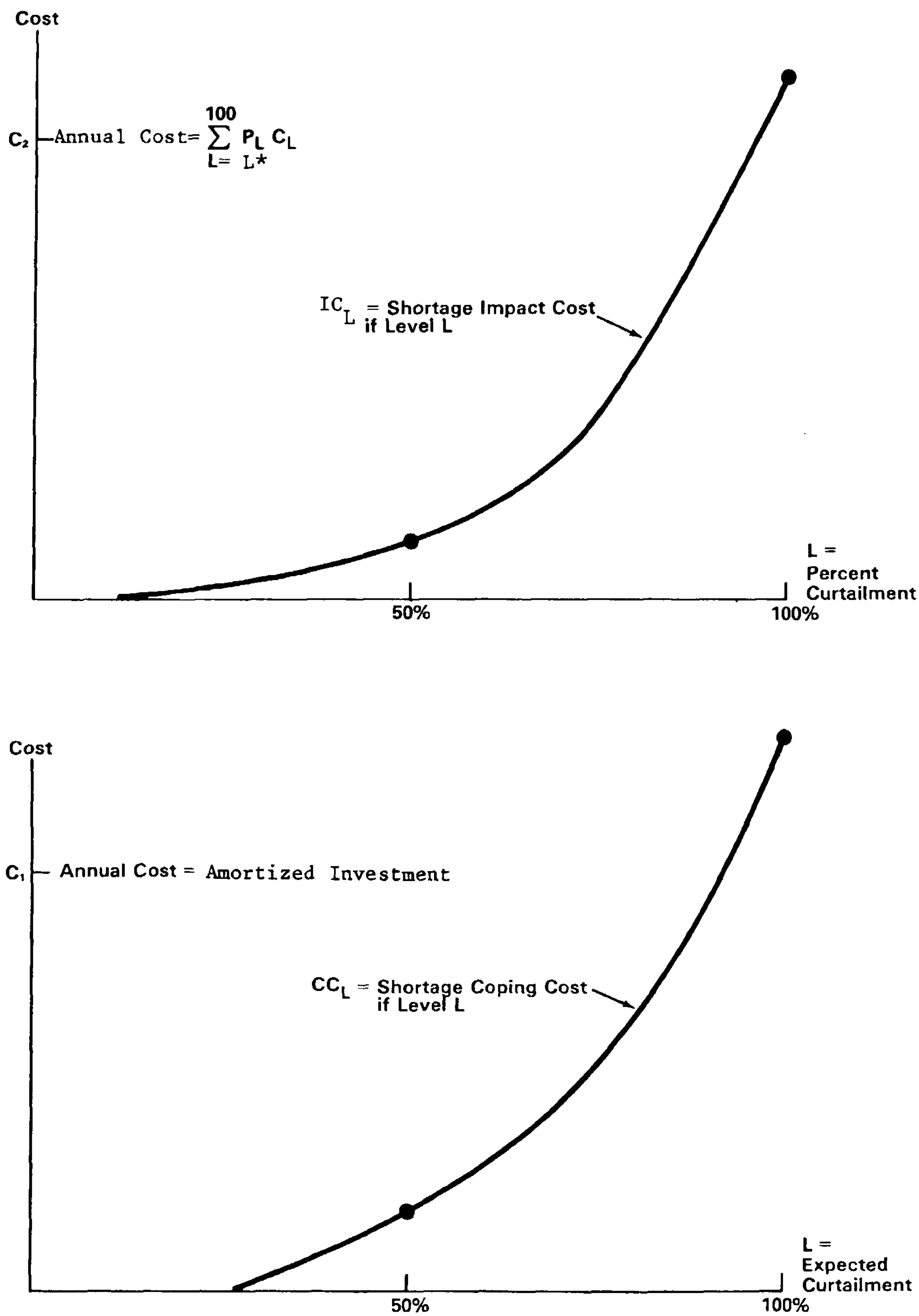


FIGURE 12. AGGREGATE CURVES AND EXPECTED ANNUAL COSTS[a/]

[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 shortage impact certainly illustrates the need for updating shortage impact evaluation parameters after each shortage -- each shortage that can significantly change user expectations and the cost analyst estimates of the 12 parameters in Figure 3.

COPING COSTS

Coping costs are not analyzed for single shortages; coping costs are defined as any coping process for which the cost must be analyzed 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 in coping costs (60).

Figure 13 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 13 can increase.

2. Curtailment loss -- e.g., The V_4 shortage impact cost for a shortage severity of q_2 in Figure 13 could be less or greater than his prior estimate of V_3.

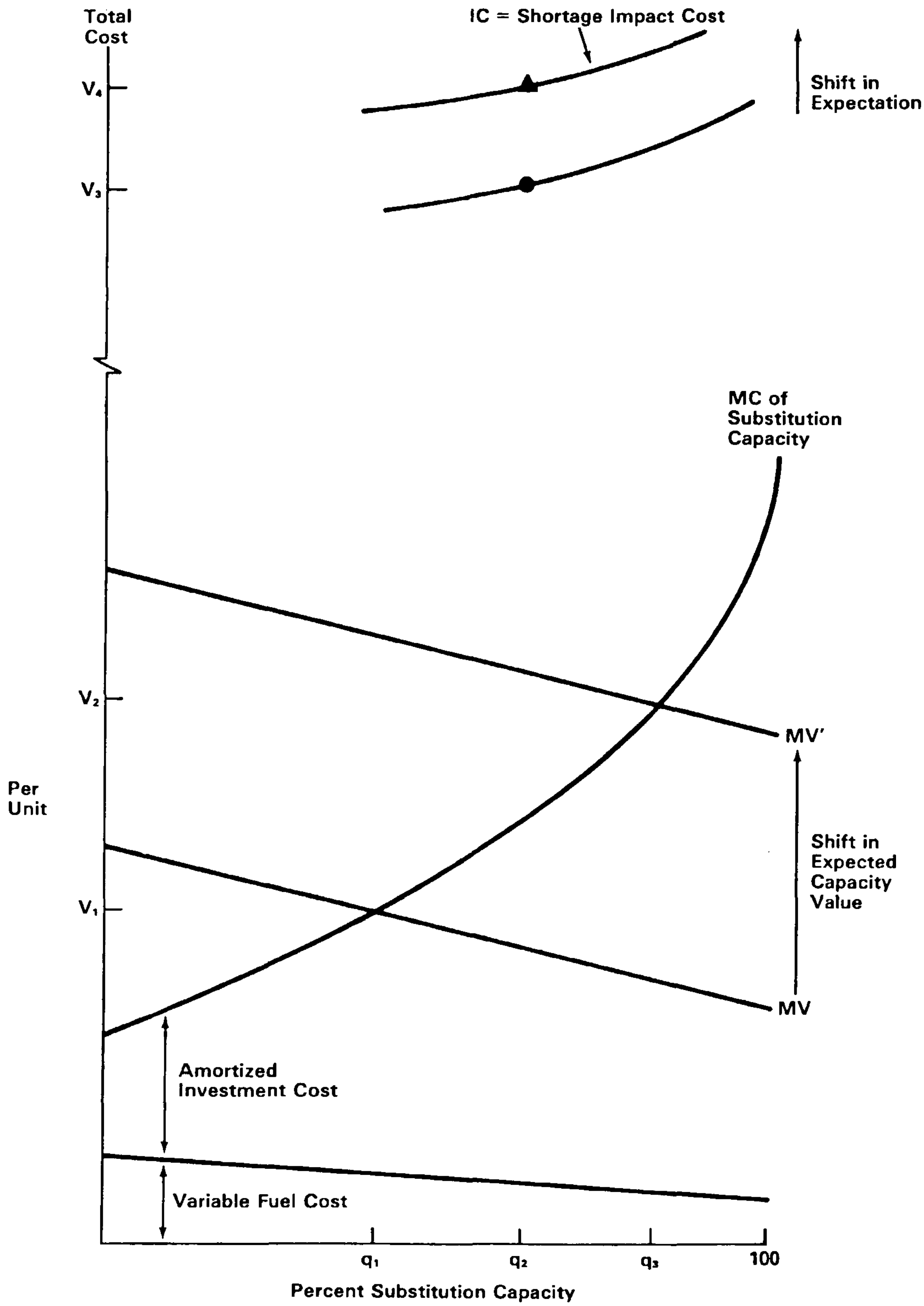


FIGURE 13. DECISION ON SUBSTITUTION CAPACITY AFTER EACH SHORTAGE

As shown in Figure 13, 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 13 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 13.

APPLICATION TO ELECTRICITY

This subchapter is only an introduction in adapting a methodology to fit both natural gas and electricity.

Although the energy 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 and analogous to implicit energy limits when electric power plants are curtailed by referendum or whatever.

There are 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. The electric power supplier can provide cheaper coping solutions than the user in some cases; therefore, the coping cost function must include supplier as well as user actions and costs in electric power.

3. 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.

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

The new methodology has the following principal advantages: it can be applied directly for obtaining a first approximation; 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.

SUMMARY

This chapter summarizes the methodology used in the case study of the 1976-77 gas shortage. It shows how the methodology can be applied for estimating other shortage costs. It also shows the relationship between shortage impacts in natural gas and electricity.

The crucial distinction between estimation of shortage costs for a single shortage and for a probability distribution of shortages is also provided. The methodology is designed to aid decisions--i.e., the decisions of private suppliers, private users, and government regulators of energy.

CHAPTER 6

DIFFERENCES IN IMPACTS

Important impact differences should be identified by both geographic regions and economic sectors, as indicated in the lower part of Fig. 14. Unfortunately, there are many possible subdivisions as indicated below:

1. Geographic Region
   a. Supplier service area -- interstate service area or distribution company service area
   b. Government jurisdiction -- DOE region, state, county, metropolitan area
   c. Weather patterns
2. Economic sector
   a. SIC categories
   b. Gas curtailment priority categories
   c. Amount of previous gas curtailment experience

There are some useful observations from the 1976-77 natural gas shortage experience. Geographically, the greatest homogeneity is in the weather pattern area because peak-day shortages, in particular, are weather related. The state is probably the regional specification of greatest interest. The best data on shortage levels is by distribution company (category 1.a), but these are not easily blown up to state level unless all of the several major distributors in each state are analyzed.

	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 , D						
2. Cost of fuel	4 , S						
B. Temporary Fuel Substitution	5 C,	• Yes	• N.S.	• Insig.		• Count in Column 1	• Insig.
1. Cost of capability	6 , D						
2. Cost of fuel	7 , S						
C. Delayed Production	8	• Yes		• Temporary Income Loss		• Possible Delay	• Possible Multiplier
1. Makeup cost	9 I, S		• Yes				
2. More inventory cost	10 C, D		• Insig.				
D. Changed Production	11					• Cost counted in Column 1, 2	
1. Modification for coping	12 C, D	• Yes		• Uncertain		• Extra cost counted in Columns 1, 2	
2. Lost sales	13 I, S	• Under-util.	• Sub Trans. • Sub Prod. • Under-util.	• Lost Income		• Sub Product • Do without	• Likely Multiplier
• SPECIAL SUB-PARTS	14						
E. Most affected geographical area	15						
F. Most affected energy sector	16						

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

FIGURE 14. NATIONAL ESTIMATES WITH REGIONAL AND SECTOR BREAKOUTS

In this report, the only regional analysis is for states; sample data were collected under a confidentiality agreement that prevents disclosure below the state level. However, we can reveal that data by distribution company would be more meaningful because of wide differences among distributors within a state. More comments are available in the first subchapter along with discussion of estimates from other studies.

For economic sectors, the obviously best data are for individual users. User differences are more related to previous gas curtailment (category 2c) than to generic type of industry (category 2a). Research for this report did not verify findings of significant differences among economic sectors, as reported in previous studies (10, 13, 18). This is discussed further in the second subchapter.

Gas curtailment priority level (Item 2.b) is meaningful within a distribution company, but has little meaning across companies even in the same state (see Tables 1-4 for review of wide differences in priority classifications).

The next subchapters provide empirical estimates and further comments on shortage impact variation by geographic region and economic sector.

SPECIAL GEOGRAPHIC REGIONS

The 1976-77 gas shortage provides two sets of empirical information: (1) differences among the four sample states -- Ohio, Kentucky, Tennessee, and Alabama and (2) differences between the sample states and the rest of the nation.

Basically, geographic variation can arise from three sources:

1. Weather patterns -- see degree-day differences in Table 12

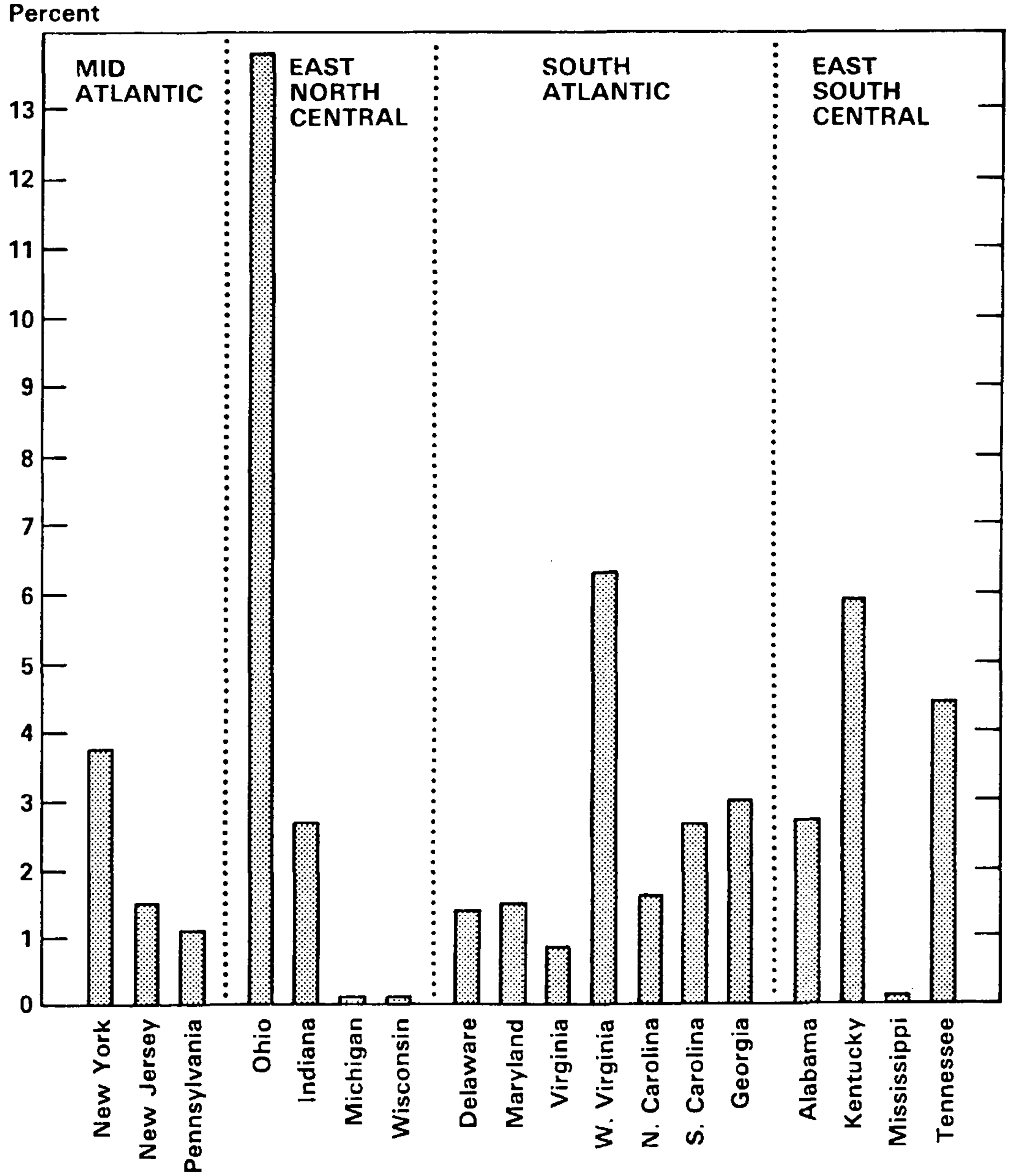
2. Curtailment plans -- see differences among companies in Tables 1-4

3. Industry differences -- e.g., industries with temporary or permanent weak conditions could be concentrated geographically

The only available data for this report is the four sample states shown in Table 11 of the next section. Figure 15 shows several other states as reported in a different study (18).

It appears that estimates of geographic differences reported in other studies mainly reflect different shortage levels which, in turn, were caused by weather patterns. There were temporary industry conditions which contributed to geographic differences, but they cannot be summarized reliably from available data.

Data for this study indicate that the absolute and relative shortage impacts shown in Figure 15 are misleading overestimates. On the one hand, they represent peak-impact levels without any data on duration of impact. On the other hand, there is evidence that impacts, particularly in Ohio, were much smaller than those shown. Due to lengthy interviews with natural gas users, estimates for this report are more carefully developed than those in previous studies.



SOURCE: Department of Commerce, DIBA, Natural Gas Action Group, INDUSTRIAL SITUATION REPORTS, Washington, D.C., 1977, also Ref. 18, p 15.

FIGURE 15. PERCENT OF STATE WORKFORCE OFF THE JOB DUE TO NATURAL GAS CURTAILMENTS AT PEAK.

SPECIAL ECONOMIC SECTORS

There is virtually no useful information by economic sector from this 1976-77 case study: first, the largest differences among sectors were caused by weather patterns that hit sector concentrations or they were caused by inventory/sales conditions that were more a function of time than of sector characteristics. Second, the largest difference among user impacts was caused more by amount of prior experience than by sector type.

The sector differences shown in Table 11 were taken from other studies of the 1976-77 natural gas shortage (17, 18). There is no indication in research for this report that these differences were other than special circumstances described above.

There might be long-run differences in shortage impacts among economic sectors. This report can only point out that many observed differences like those shown in Table 11 are temporary conditions caused by inventory/sales positions or weather patterns.

TABLE 11

INDUSTRY VARIATIONS IN SHORTAGE IMPACTS

PART A: ESTIMATES FROM REF 17 AND REF 18, EXHIBIT II-9

Industry	Total U.S. Employment (000)	Unemployment Due to Gas Crisis (000)	Unemployed % Due to Gas Crisis (%)
Textiles	975.0	24.0	2.5
Nitrogenous Fertilizers	9.4	NA[2]	NA[2]
Glass Containers	73.1	11.5	15.7
Flat, Pressed, and Blown Glass	66.8	10.0	15.0
Brick and Structural Tile	24.1	NA[3]	NA[3]
Mineral Wool	19.5	4.6	23.6
Blast Furnaces and Steel Mills	445.0	NA[4]	NA[4]
Motor Vehicle Parts and Accessories	800.0	100.0	12.5
Gypsum Products	10.5	1.3	12.1

PART B: CONCLUSIONS FROM REF 17, PP 9 AND 10

Group 1 -- Industries heavily impacted by severe winter weather and fuel curtailment:

SIC 22 Textiles
SIC 2873 Nitrogenous fertilizers (ammonia)
SIC 3221 Glass containers
SIC 3229 Pressed and blown glass and
11 Flat glass
SIC 3251 Brick and structural clay tile
SIC 3296 Mineral wool
SIC 3312 Blast furnaces and steel mills
SIC 3351 Copper rolling, drawing, and extruding
SIC 3711 Motor vehicles and passenger car bodies
SIC 3714 Motor vehicle parts and accessories

TABLE 11 Continued

Group 2 -- Industries moderately impacted by severe winter weather and fuel curtailment:

SIC 2511	Wood household furniture, except upholstered
SIC 30794	Plastic packaging and shipping containers
SIC 3275	Gypsum products
SIC 3631	
32, 33	Major household appliances
39	

Group 3 -- Industries slightly impacted by severe winter weather and fuel curtailment:

SIC 2011	Meatpacking plants
SIC 2033	Canned fruits and vegetables
32	Canned specialties
SIC 2037	Frozen foods (outside of Florida)
SIC 2046	Wet corn milling
SIC 2051	Bakeries
SIC 2062	Cane sugar refining
SIC 2063	Beet sugar
SIC 2075	Soybean oil mills
SIC 2082	Malt beverages
SIC 2086	Soft drinks
SIC 23	Apparel
SIC 2421	Sawmills and planing mills
SIC 2611	Pulp, paper, and paperboard
21, 31	
SIC 2653	Fibre boxes
SIC 2752	Commercial printing, lithographic
SIC 28	Chemicals (except nitrogenous fertilizers)
SIC 3011	Tires and inner tubes
SIC 3211	Flat glass
SIC 3241	Cement, hydraulic
SIC 3331	Primary smelting and refining of copper
SIC 3353	Aluminum mill products
54, 55	
SIC 3357	Copper wire mills
SIC 3523	Farm Machinery
SIC 3573	Computers
SIC 3662	Television receivers

Group 4 -- Heavy gas-consuming industries not covered in OBRA telephone survey:

SIC 3321	Gray iron foundries
SIC 3462	Iron and steel forgings
SIC 2821	Plastics materials and resins
SIC 3341	Secondard nonferrous metals
SIC 3295	Minerals, ground or treated
SIC 3274	Lime

FOUR STATES IN SAMPLE DATA

The four states were selected as useful case studies. They came from quite different weather patterns, as shown in Table 12.

The most useful summary statistics are given in Table 13. There is no reliable data for attributing the state differences to any factors.

TABLE 12

Degree-Day Deviations

Part A: Regional degree-day deviation from normal 1976-77 (Ref 61)

REGION	NOV.	DEC.	JAN.	FEB.	MAR.	TOTAL WINTER HEATING SEASON	SAMPLE STATES
East Coast	+26.4%	+11.7%	+28.9%	- 1.8%	-28.6%	+ 7.9%	
Great Lakes	+25.1%	+22.7%	+30.3%	+ 1.1%	-23.8%	+11.7%	Ohio
Midwest	+16.7%	+ 7.6%	+22.6%	-11.8%	-25.3%	+ 3.1%	Ky
West Coast	-22.0%	+ 4.1%	+ 7.2%	-11.7%	+ 6.0%	- 1.9%	
Southeast	+47.9%	+13.8%	+54.6%	+10.1%	-33.1%	+21.0%	Tenn, Al
U.S.	+22.8%	+13.3%	+28.3%	- 2.5%	-25.4%	+ 8.1%	

Part B: National degree-day deviation from normal (Ref 62)

WINTER	NOV.	DEC.	JAN.	FEB.	MAR.	TOTAL WINTER	PERCENT ABOVE OR BELOW A NORMAL WINTER
1971-72	547	721	946	791	600	3,605	- 3.8%
1972-73	612	855	883	735	456	3,541	- 5.5%
1973-74	475	805	830	773	551	3,434	- 8.3%
1974-75	536	796	825	738	695	3,590	- 4.2%
1975-76	459	811	1,009	616	522	3,417	- 8.8%
1976-77	666	977	1,240	765	509	4,157	+11.0%

NOTE: A normal winter has 3,746 degree days. Degree days are a measure of the deficit in the temperature below a reference point of 65 degrees Fahrenheit.

TABLE 13

SHORTAGE COST VARIATION AMONG STATES

PART A: SHORTAGE COSTS

		$ per Mcf (and State total $ in Millions)				
		Producers a/	Employees a/	Consumers g/	Macro g/ Effects	Total
Shortage Impact Costs						
Ohio:	$/Mcf	$13.00	1.20	Insig	Insig	14.20
	(Total in mil)	(839)	(77)			(916)
Ky:	$/Mcf	11.00	.08	"	"	11.08
	(Total in mil)	(155)	(1)			(156)
Al:	$/Mcf	18.00	.30	"	"	18.30
	(Total in mil)	(514)	(9)			(523)
Tenn:	$/Mcf	2.40	.01	"	"	2.41
	(Total in mil)	(28)	(0)			(28)
Shortage Coping Costs b/						
Ohio	$/Mcf	2.44				
	(Total in mil)	(75)				
Ky	$/Mcf	3.12				
	(Total in mil)	(26)				
Al:	$/Mcf	1.53				
	(Total in mil)	(8.6)				
Tenn:	$/Mcf	.61				
	(Total in mil)	(4.3)				

PART B: SHORTAGE LEVELS AND ACTUAL JAN.-FEB. 1977 CONSUMPTION (STATE TOTALS)

		Jan-Feb Use (10^6 Mcf)	Jan-Feb Shortage (10^6 Mcf) Energy c/	Capacity d/
Ohio:	Cat B f/	33.3	17.6	13.1
	Cat C	5.4	33.8	e
Ky:	Cat B	8.6	5.8	2.4
	Cat C	.5	5.9	e
Al:	Cat B	2.2	2.2	4.8
	Cat C	3.2	21.6	e
Tenn:	Cat B	9.2	3.1	2.5
	Cat C	.1	6.3	e

a/ The total cost in parentheses is the $/Mcf times the shortage in Mcf.

b/ $/Mcf estimates are for Category B users only: i.e., non-substitutable uses, as defined in the glossary.

c/ See "$q_6 - q_3$" in Figure 6

d/ See "$q_5 - q_3$" or segment "d-c" in Figure 6

e/ Not applicable

f/ Cat B and Cat C are non-substitutable and substitutable as defined on pp. 13-15.

g/ The impact on final consumers and the macro effects were very small in this localized shortage.

CHAPTER 7

CONCLUSIONS FROM THIS STUDY

The careful coordination of empirical analysis and theoretical development has produced many valuable conclusions. The 1976-77 natural gas shortage was particularly good for both providing observations on shortage costs and for illustrating the need for careful shortage assessment.

The major findings are listed below under three categories: (A) Empirical estimates of shortage costs, (B) Concepts-theory-models, and (C) Observations on cost-effective changes for more reliable energy supply.

A. Empirical Estimates of Shortage Costs

1. Shortage impact costs (e.g., cost of substitute fuel and lost production) were $12.94/Mcf shortfall in the 1976-77 gas shortage (in addition, investment costs for better coping were large enough that they substantially increase total shortage cost over the impact cost).

2. Shortage impact costs are often much smaller than intuitive and first-approximation results indicate; however, they are smaller because of intricate shortage coping processes which, themselves, constitute another significant shortage cost.

3. Shortage coping costs can be as large as shortage impact costs in many shortage scenarios and, therefore, must certainly be included in any shortage assessment.

4. The shortage impact costs were mainly in the short-duration capacity curtailment even though the latter was only one-fifth of the shortfall volume in the 1976-77 shortage.

5. Over 80% of shortage costs could be avoided; stated otherwise, the sum of shortage impact and shortage coping costs could be reduced by over 80%.

6. The largest factor in shortage impact variation among users is the degree of previous shortage experience; there isn't nearly as much variation among industry sectors as there is variation between users with little and those with considerable experience in coping with shortages.

7. No previous shortage impact study has been found to incorporate the breadth of impacts and the care in avoiding overestimates that is required for decision on supply reliability. They have not developed adequate theory nor gathered necessary empirical data.

8. The present state-of-the-art is unacceptable as evidenced by conflicting estimates in many shortage situations -- estimates that often differ more than ten-fold; this is clearly an unacceptable condition if shortage cost estimates are to guide private decisions and government policy.

B. Concepts-Theory-Models

1. A formal single comprehensive model for all shortage cost estimation is infeasible -- it would require a macro-economic model that would invariably be developed from business-as-usual data; a model from such data simply cannot predict effects of rare events; the intricate coping processes that greatly reduce shortage costs require special models; a set of special sub-models plus calibration of parameters so as to fit conditions surrounding each shortage scenario is the proper analytical framework for shortage cost assessment.

2. Sub-models for shortage cost estimation should be delineated as follows:
   a. Annual production shortage -- a coping cost in the required permanent fuel switch
   b. Winter season energy shortage -- an impact cost and a coping cost
   c. Peak-day capacity shortage -- an impact cost and a coping cost

   The two short-run shortages, in "b" and "c" must be rigorously defined, as indicated in Figure 6.

3. The final incidence of shortage costs should be developed for four groups:
   a. Producers
   b. Employees
   c. Consumers
   d. Macro-effects (general public)

4. Impacts should be evaluated at four stages in ripple effects:

   Stage 1: Direct energy user as a producer (includes employees)

   Stage 2: Indirect-energy user as a producer (includes employees)

   Stage 3: Final demand

   Stage 4: General public subjected to macro-economic effects

5. The theory and submodels outlined in Chapter 5 and in the forthcoming methodology report (60) are sound; they provide the best basis for model improvement and provide good first-approximation models in their present form.

6. The concept of measuring shortage costs as "the willingness-to-pay" to avoid shortage impacts is sound and it is essential for accurate public policy and private decision analysis.

7. A similar methodology can be used for both natural gas and electric power shortages, even though there are major differences in the supply/shortage characteristics; see last part of Chapter 6.

8. Shortage cost estimation should be oriented to the level and type of shortage as follows:

   a. Small curtailment in a single shortage. A simpler methodology can be used because nearly all shortage costs originate at Stage 1.

   b. Unlimited curtailment in a single shortage. This requires a more complex model such as modified input-output analysis, like that described in App. C.

c. Unlimited curtailment in repeated shortages. This requires the complex shortage impact model described in "b" above as well as a complex model for shortage coping costs as described in App. C.

C. Observations on Cost-Effective Changes in Supply Reliability

1. The 80% avoidable costs (nationwide average of almost $5 billion/year) can be attained by relatively simple changes. There is need for cooperation among government controls, supplier allocations, and user preparation, but this certainly can be accomplished.

2. The ranking of major improvement in supply reliability (including curtailment) appears to be as follows:
   a. Better supplier/government information for users
   b. Better allocations within supplier systems
   c. Easier transfers of energy among supplier systems
   d. Improved user coping processes

3. The rising importance of energy shortages and the growing publicity on shortages make it imperative to establish practical limits in minimizing shortage costs and make it imperative to reach this limit expeditiously.

4. Appropriate reliability in energy supply can be established with carefully determined engineering cost functions plus carefully determined shortage cost functions; the shortage cost estimation models presented in this report add the

essential accuracy that previously has been missing in shortage cost estimation and supply reliability determination.

5. Energy shortages can be studied under the same cost-benefit framework for most policy analysis, but there is need for more rigor than in previous studies; the avoidance of double counting with the willingness-to-pay concept and assurance of comprehensive analysis with the "certified public accounting" concept greatly facilitate reliable cost-benefit analysis.

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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), on pp. 13-15, Chapter 1.

Coping Cost -- See shortage coping cost.

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.

Mcf -- Thousand cubic feet of natural gas.

MMBTU -- Million BTU's; the approximate amount of BTU's in an Mcf of natural gas.

Peak-day Capacity Shortage -- The inability of gas suppliers to transport sufficient gas through pipes even if gas supply would be 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 Costs -- 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.

Appendix A

Simple Examples to Illustrate Calculations

This appendix shows the calculations performed on confidential data and shows a simple example of how to avoid double counting of impacts. The examples are hypothetical in order to simplify discussion and protect confidential data.

AVOIDING DOUBLE COUNTING

It is important to understand how and when some shortage costs are passed from direct-energy user to indirect-users and, sometimes, passed on to consumers (final demand). Many shortage cost estimation methods can incorporate much double counting among the stages in ripple effects and among the shortage costs accruing to the four groups -- producers, employees, consumers, and general public. Stages and affected groups cannot be understood until the "pass-through" of added cost is delineated carefully. The following example and counter-example in the importance of ripple effects are 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 E would pay $2 to avoid waiting for the delayed production of 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+3+1) <u>cannot</u> be estimated without considering all four groups; this is regardless of whether costs from any stage are, or are not, passed on (an equity issue).

Now, assume the following plausible scenario as another example in considering four different groups in estimating "willingness-to-pay" to avoid an energy shortage:

$11 Initial cost -- Energy user A incur $10 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 uninterrupted wages and the interrupted plus overtime wages.

$0 Additional cost -- Indirect user B does not incur any extra cost beyond the $10 passed on by A, but he passes all $10 on 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 at User A in Stage 1, on the $10 passed on to indirect user B, or on the $10 extra cost paid by consumer C.

The counter example illustrates that it is not always necessary to consider all stages in achieving a complete shortage impact accounting.

It is important to note that most data on the 1976-77 natural gas shortage was collected from direct-users. Even though most costs could be identified at Stage 1 -- the direct-user -- it does not mean that no costs were passed on. The question of passed-on costs was not an issue in the research for this report -- only the total shortage cost per unit of shortfall, regardless of final incidence -- was an issue.

ANALYSIS OF CONFIDENTIAL DATA

This hypothetical example explains, in 6 steps, how data for a specific user contributes to the total shortage cost estimate. At the same time, it shows how the estimated shortage cost can be used to predict the shortage impact for a typical energy user.

Step 1: Energy use (normal and curtailed)

Since all shortage cost estimates are normalized on energy curtailment, the precise energy cutback must be delineated. Since energy use in a shortage period might be grossly misspecified in an interview, it is desirable to specify total normal energy use for the shortage period (and other reference periods). The shortage (and normal consumption) data would look like Table A.1.

Step 2: Shortage costs as reported by users

The shortage costs during the shortage period were obtained in a form shown in Table A.2 (see the questionnaire in App. B for greater detail). All information was obtained from the direct user because the shortage was not so severe that costs beyond the direct user (and his employees) were dominant.

Step 3: Separation of energy and capacity shortages

The separation of energy and capacity shortages, as well as impacts from the same, is shown in Figure A.1. The important point is that a capacity shortage curtailment is over and above the energy shortage curtailment, as shown in the Figure and in the Table A.2 specification for the peak. The same point is illustrated in the following discussion of cost per MMBTU shortage.

Step 4: Calculate shortage cost/Mcf shortfall

Since estimates of shortage cost will be used by applying them to another shortfall, it is desirable to calculate shortage costs per energy shortage unit. As shown in Table A.3, the sample observations are summed and, then, cost/Mcf is calculated. No observations for interruptible users are shown (Column 2, Table A.3), but the calculations are the same as for non-interruptible users in Column 1, Table A.3.

TABLE A.1

ENERGY SHORTAGE & NORMAL ENERGY USE
(Hypothetical for illustration)

	Row	Normal Use (1)	Shortage: Specification (2)	Shortage: Volume (3)
Sample Observation 1				
Annual	1	100		
Peak-season (Nov. 1-Mar. 31)	2	60	10%	6[a/]
Shortage period				
. E.g., Energy cut in Jan. & Feb.	3	40	25%	10[b/]
. E.g., Cut to plant protection for 6 days	4	4	95%	2.8[c/]
Sample Observation 2				
Annual	1	100		
Peak Season	2	60	10%	6[d/]
Shortage period				
. Energy	3	80	25%	20[e/]
. Cut to Plant protection	4	2	85%	1.2[f/]

Total sample: Winter energy = 10 + 20 = 30

Peak-day = 2.8 + 1.2 = 4.0

Source: Hypothetical example designed for simplest illustration of data collected from users.

a/ 60 x .10 = 6

b/ 40 x .25 = 10

c/ 4 x (.95-.25) = 2.8

d/ 60 x .10 = 6

e/ 80 x .25 = 20

f/ 2 x (.85-.25) = 1.2

TABLE A.2

COSTS TO AFFECTED GROUPS

	Row	Total Loss	% During Peak-day Cuts
Sample Observation 1			
Production (Group 1)			
Unrecovered cost from lost sales	1	$ 100	80%
Extra cost from less efficiency	2	50	80%
Indirect user loss from extra or unrecovered cost	3	30	80%
Employee loss from wage loss (Group 2)	4	20	80%
Consumers and Group 4	5	not shown	
Observation Total	6	200	80%
Sample Observation 2			
Production (Group 1)			
Unrecovered cost from lost sales	11	0	50%
Extra cost from less efficiency	12	100	50%
Indirect user loss from extra or unrecovered cost	13	0	50%
Employee loss from wage loss (Group 2)	14	0	50%
Consumers and Group 4	15	not shown	
Observation Total	16	100	50%
Sample Total	21	300	70% [a]

[a] .70=2/3(.80)+1/3(.50)

Source: Hypothetical example designed for simple illustration of data collected from users.

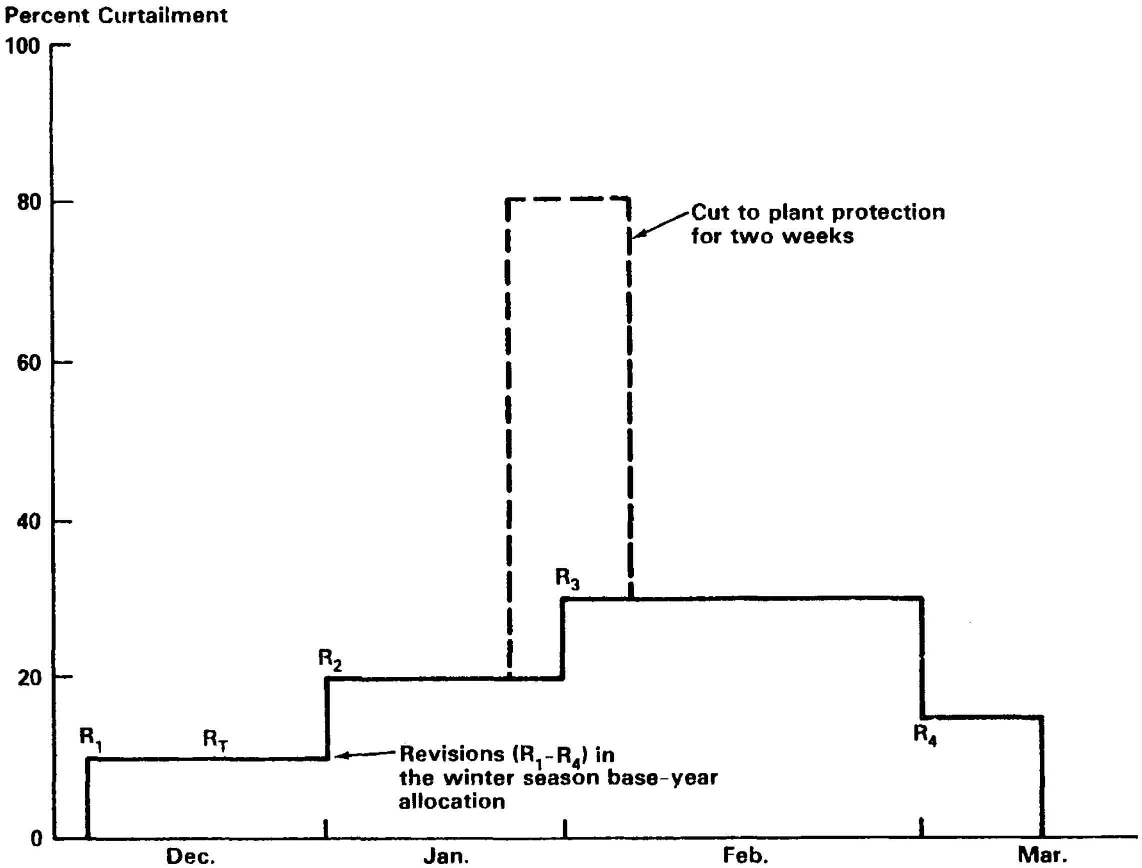

FIGURE A.1 ENERGY AND CAPACITY CURTAILMENT

TABLE A.3

SHORTAGE COST PER MCF

	Non-Interruptible Users	Interruptible Users
Peak-day curtailment	\$52/Mcf = 210 ÷ 4.0	No Examples Shown
Winter-season curtailment	\$3/Mcf = 90 ÷ 30	

Source: Costs from Table A.2 and Mcf shortfall from Table A.1

Step 5: Improve estimates by using sales loss and increased production

The cost of lost sales, for example, involves two parts, as follows:

Part 1. Loss in sales per Mcf shortfall

Part 2: Dollar loss per dollar of lost sales

If the sales loss were known, the error in part 1 can be eliminated. Hence, estimates in table 10 provide an option in using estimates. Since good shortage cost estimation methodology is just now being developed, this report shows two sets of coefficients in order to provide maximum insight. The hypothetical example in this appendix does not include Step 5, but the procedure is straightforward.

APPENDIX B

QUESTIONNAIRE FOR SAMPLE DATA

The important contribution of this project was detailed data collection along with theoretical advancement for energy shortage evaluation. This contribution was accomplished by extensive and carefully designed empirical questions.

The questionnaire in Table B.1 evolved from many changes as interviewing results became available. It was necessary for research staff to conduct both personal and telephone interviews. It was impossible to expect natural gas users to complete the questionnaire without benefit of careful explanation by the project staff.

User information was generally supplied by a combination of opinions from plant managers, chief engineers, and customer representatives.

TABLE B.1

GAS USER QUESTIONNAIRE

(All Information will be Confidential; No Individual Response Will be Revealed)

1. Was the January-February, 1977 gas curtailment the most severe gas shortage you have had?______________________________

2. If you purchase gas under more than one priority class, provide the information described below:

   a. List the priority classes for your gas purchases in Column A, starting with boiler use as the lowest class.

   b. Specify the dates or days you were cut to plant protection here____ and, in Column B below, specify the percent cutback in the January and February, 1977 allocations.

   c. Give the volume for each priority class in Column C, specify the long-run allocation for Nov. 1 - Mar. 31.

Col. A. Priority Class	Col. B % Cutback Jan. 1977	Col. B % Cutback Feb. 1977	Col. C Base Period Annual Gas Allocation	Col. D Maximum Curtailment w/o Prod.Cut	Col. E Effect of 100% Curtailment to Plant Maint.
o					
o					
o					

   d. In Column D above, specify the percent curtailment you could accept before cutting production and, in Column E, specify the percent of production loss if gas were curtailed 100% (except for plant maintenance) in each priority class under which you purchase gas.

TABLE B.1 Continued

e. If January or February allocations differ from the one-twelfth of the annual gas allocation, indicate the percentage of annual use:

January = ________ %   February = ________%

3. Did you lay off employees or reduce production during the January-February, 1977 severe gas curtailment (do not include reductions for weather or other non-gas shortage factors)?

a. Layoffs:____________   Average No. of Days:____________

b. Production loss was sometimes greater than layoffs indicate because employees were retained to avoid layoffs, because of poor conditions; or because desired extra production was impossible. Please indicate the total reduction in production below.

January ________ % reduction from desired level.

February ______ % reduction from desired level.

c. What % of January and February losses were within the plant protection cutback? ________%

Calculate: 1. Sales value of decreased production = $_____.

2. Wages lost permanently by employees = $_____.

3. Employer cost to make up _____% of January and February production loss later = $_____.

d. What is your estimate of the loss your customers incurred to buy products elsewhere? ________%

TABLE B.1 Continued

e. By what percentage, if any, do January and February production differ from average monthly production? ________%.

f. What is the cost of shutdown and startup over and above the "time-and-one-half" for labor? Equivalent to the cost of ____ days of production.

4. Do you schedule annual plant maintenance or otherwise plan for reduced production in January-February each year in order to reduce effects of gas shortages that might occur at this time? ____; if yes, what is your planned reduction in production? ________.

5. Amount of fuel substitution and cost of substitution:

a. What percentage of your non-substitutable load (critical gas) in January, 1977 have you changed to substitutable? ______%

b. What was the cost of installing equipment and procedures for the capability to substitute, broken down as follows:

$____ for ____% pre-1977 substitution.

$____ for ____% increase in substitution.

$____ for greater storage or other ways to reduce impact at the maximum percent substitution.

c. What substitutes did you use in January-February, 1977 (please identify substitute in Column 1 and provide information in Columns 2-4 for each substitute)?

TABLE B.1 Continued

Col. 1 Type of Substitute	Col. 2 Quantity or % of Mcf Equivalent	Col. 3 Priority Class in Which Used	Col. 4 % Cost Increase Over Natural Gas
o			
o			
o			
Total			

d. What percent of your January-February allocation would you have used if available? _____%

e. What are the advantages, if any, of using natural gas over alternate fuels besides price? Equivalent to _____% of the price of natural gas.

6. Cost of rebuilding inventories:

a. What is the extra cost/unit of building up inventories that are reduced when production drops below sales? _____% (e.g., is it equal to the "time-and-one-half" for wage costs?)

b. Do gas curtailments cause you to increase inventories over what they would be if there were no gas curtailments? _______. If yes, what is the increase in inventories in terms of percent of monthly sales? ________%

7. What is the cost of any plant damages that occurred because of the gas curtailment? $__________.

TABLE B.1 Continued

8. SIC classification of your company__________: or description of business ____

____

9. Company size:

   a. Number of employees______________________________

   b. Annual sales___________________________________

10. Inventories that help reduce impact of gas shortages.

   a. By what percent were customers orders and inventories above or below the annual average during the January-February, 1977 shortage? _______ %

      Orders were __________ % (above) (below) normal during January-February.

      Inventories were __________ % (above) (below) normal at the onset.

   b. How many days can you generally continue to satisfy orders if production is stopped completely? __________ days.

   c. What percent of your customer orders were affected because inventories and production were inadequate to meet orders:

      __________% of January and February interruption in production were lost completely = $__________ sales.

      __________% of January and February sales were delayed on average of __________ days.

   d. How long did it take to rebuild inventories?

TABLE B.1 Continued

11. Did you have production cuts, or at least danger of same, because your sources of supply were curtailed by gas cutoffs?__________.

    a. How did the severity of this problem compare to your shortage of energy?

    b. What extra costs did you incur because of having to buy supplies and parts from other than regular sources?

APPENDIX C

EXTENSION OF METHODOLOGY FOR SEVERE SHORTAGES

The 1976-77 natural gas shortage was severe in many states. However, extensive ripple effects throughout the national economy were avoided because the shortage did not cover the entire nation and did not reach as severe levels as it might some day. The following discussion summarizes the approach for really severe shortages (wide geographic area and large percentage curtailment).

INTRODUCTION

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 Figures 1 and 2.

The approach suggested in this appendix is for a single shortage; the general approach is summarized in Chapter 5.

This appendix focuses on shortage impact costs since shortage coping costs should really be related to repeated shortages. A forthcoming report will deal with shortages (60).

The methodologies in this appendix 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.

Several 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 new 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 for shortage analysis is a multiregional inter-industry intertemporal activity analysis model; the long title contains almost a complete description of its form and structure. The basic assumption is that each produces a variety of possible activities, each of which takes inputs to produce outputs. As normally modeled, such activities are linear --i.e., there are constant returns to scale in production because outputs are proportional to inputs. The inputs come from other industries, possibly via transportation activities from other regions, or from stocks; product outputs 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. 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 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

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

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 C-1 the demand schedule is

$$p = a - bq \quad . \qquad \text{C-1}$$

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

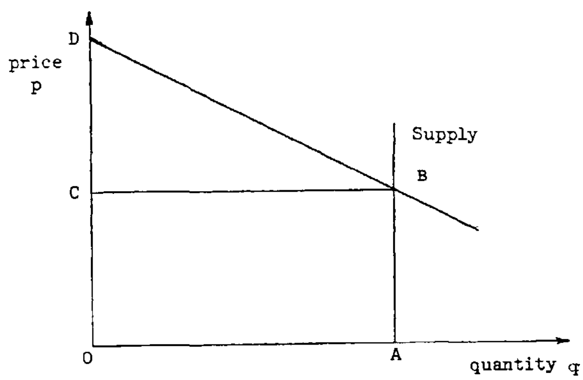

Figure C-1. Consumers' Surplus

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

$$\frac{dV}{dL} = V'(L) = w. \qquad \text{(C-1)}$$

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

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

which, by Taylor series expansion gives approximately

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

Suppose the elasticity of labor supply is η

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

Then

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

---

[*]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,

$$\frac{C}{2wL} = L/2\alpha^2. \qquad \text{(C-7)}$$

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

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

$$\frac{C}{nwL} = L/2\ \frac{\alpha^2 \eta}{n-1} \qquad \text{(C-9)}$$

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 overstated 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

$$\sum_{t=1}^{T} py_t \qquad \text{(C-10)}$$

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; 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 $\underset{\sim}{a}_j$),

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

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

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

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

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[2]/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.

$$p_{mi} > p_{ci} > p_{ei} \quad \text{and} \quad e_i = m_i = 0 \; , \; y_i > 0 \quad , \tag{C-13}$$

or

$$p_{mi} = p_{ci} > p_{ei} \quad \text{and} \quad e_i = y_i = 0 \; , \; m_i > 0 \quad , \tag{C-14}$$

or

$$p_{ei} = p_{ci} < p_{mi} \quad \text{and} \quad m_i = 0 \; , \; e_i > 0 \; , \; y_i > 0 \quad . \tag{C-15}$$

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: $\underset{\sim}{x} \leqq \bar{\underset{\sim}{x}}$ (C-16)
2. Transport capacity constraints: $\underset{\sim}{m} \cdot \underset{\sim}{w} \leqq \bar{M}$ (C-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: $\underset{\sim}{m}^r \leqq \bar{\underset{\sim}{m}}^r$ (C-18)
(e.g., imports from region r are limited by regional capacity.)
4. Factor availability: $B\underset{\sim}{x} \leqq \underset{\sim}{k}$ (C-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: $\underset{\sim}{c}\, , \underset{\sim}{e}\, , \underset{\sim}{m}\, , \underset{\sim}{y}\, , \underset{\sim}{x} \geqq 0$. (C-20)

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

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

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

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

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

$$\underset{\sim}{p}_m^s = \underset{\sim}{p}_o^s + \underset{\sim}{t}^s \tag{C-24}$$

$$\underset{\sim}{p}_e^r = \underset{\sim}{p}_o^r - \underset{\sim}{t}^r \ , \tag{C-25}$$

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

$$Y^n = \text{Max} \sum_{t=1}^{T} Y_t \tag{C-26}$$

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

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

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

The net availability is the supply at date "t" <u>less</u> 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

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

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 C.2.

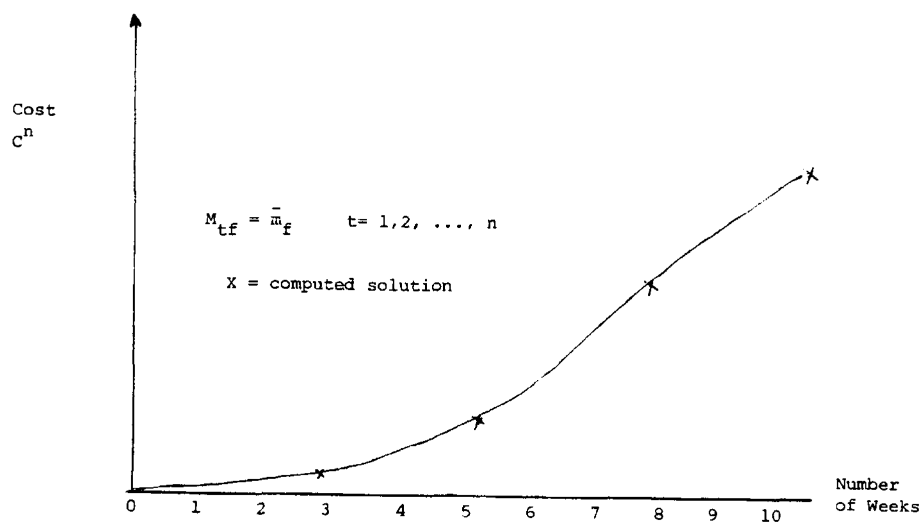

Figure C-2 Costs of Shortage as Function of Duration

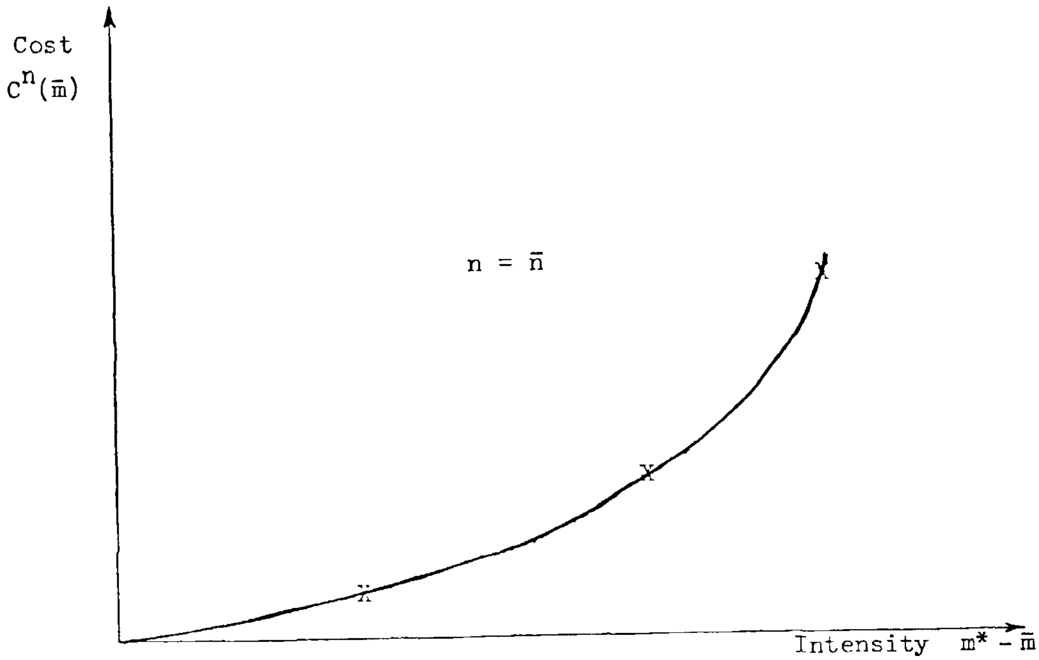

Figure C.3 Costs of Shortage as Function of Intensity

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 C-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 C-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 C-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 $\underset{\sim}{x}$:

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

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

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

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

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

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

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.