ENERGY LABORATORY

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

ANALYSIS QUALITY REPORT ON THE EIA ANNUAL REPORT TO CONGRESS 1978, VOLUME III: COAL SUPPLY

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MIT Energy Laboratory Report No. MIT-EL 81-017

April 1981

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Energy Laboratory

Energy Model Analysis Program

Analysis Quality Report
on the
EIA Annual Report to Congress 1978, Volume III:
Coal Supply

by

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Submitted to
Office of Analysis Oversight and Access
Office of Applied Analysis
Energy Information Administration
Department of Energy

January 1980 (draft)

April 1981 (final)

MIT-EL 81-017

This research was supported by the Department of Energy under MIT-DOE Institutional Agreement No. EX-76A-01-2295.

NOTICE

ACKNOWLEDGMENTS

The material in this report draws heavily on an evaluation of the Coal and Electric Utilities Model documentation reported in Goldman et al. [1979], and on the Energy Model Analysis Program indepth evaluation of that model reported in EMAP[1980]. We acknowledge the contributions and support of Neil Goldman, James Gruhl, Michael Manove, and Fred Schweppe. We also acknowledge the comments and substantive contributions of George Lady, Susan Shaw, and John Herbert, all of the EIA Office of Analysis Oversight and Access. Finally, we are seriously in debt to Mr. Peter Heron for editorial assistance in preparing and publishing this report.

ABSTRACT

The Energy Information Administration (EIA) is charged by Congress to prepare an Annual Report to Congress (ARC) which includes projections of energy supplies, consumption and prices, as well as the relation of energy to other economic activity. As an aid to users of ARC, the EIA Office of Analysis Oversight and Access (OAOA) is preparing "Analysis Quality Reports" on particular components of the energy information analysis system used in developing the ARC-78 projections. This report focuses on the Coal Supply Module used for the midterm projections of the ARC-78. The Coal Supply Module is part of the EIA's National Coal Model. The review and analysis presented here is based upon the MIT Energy Model Analysis Program's (EMAP) evaluation of the documentation and implementation of the Coal Supply Module sponsored by OAOA, and an indepth evaluation of a related model--the ICF Coal and Electric Utilities Model--which also employs the EIA Coal Supply Module. The indepth evaluation has been sponsored by the Electric Power Research Institute.

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1. INTRODUCTION

The Energy Information Administration (EIA) is charged by Congress to prepare and submit an Annual Report to Congress (ARC). In particular, EIA is directed to prepare "..projections of energy production, consumption and prices, in addition to their economic and other related consequences" (EIA[1979,p. xvii]). An important objective of the Annual Report is to organize and interpret factual materials to improve understanding of the nation's energy-related condition, and to project future developments in the short, medium and long term. The EIA Annual Reports are thus an important national resource for improving, understanding, and providing background for the development and interpretation of national energy policy.

ARC's mandate to present short, medium and long term projections requires that an information analysis system be developed and used to organize factual and analytical information, and to support developing projections. Users of the ARC must be assured that such systems exist, are understood by energy analysts in general, and have been evaluated and found to represent good scientific practice for the purposes of the ARC.

The EIA has developed or sponsored components of such an energy information analysis system. In preparing the ARC projections, many of these component systems have been used. Likewise, EIA is developing and applying procedures and guidelines for documentation and evaluation of these information analysis systems. A survey of these various activities is provided in Wood [1981].

The EIA Office of Analysis Oversight and Access (OAOA) is responsible for the review and evaluation of the ARC. As a means of combining its responsibilities, OAOA has developed the concept of the "Analysis Quality

Report." The purpose of these reports is to support users of the ARC by organizing and presenting evaluative materials relating to particular information analysis systems used in preparing ARC projections. A distinguishing feature of the "Analysis Quality Reports" is that they are explicitly intended for users of the ARC, not just for the community of energy analysts familiar with the EIA's modeling systems.

The Energy Model Analysis Program (EMAP) of the MIT Energy Laboratory has been conducting documentation and model evaluation projects for EIA and other sponsors bearing on the Coal Supply Module employed in the preparation of ARC-78 midterm projections. EMAP was therefore contracted by OAOA "to prepare a report, using the results of any such validation projects in addressing the quality and usefulness of the projections of coal production for the years 1985, 1990 and 1995 given in the EIA Annual Report to Congress 1978, Volume III" (OAOA [1979]).

This "Analysis Quality Report" for the midterm coal supply projections used in the 1978 Annual Report to Congress (ARC-78) is organized as follows. In Chapter 2 we summarize the materials employed in the evaluation, and present a summary of how the coal supply module fits into the larger information analysis system employed in the ARC-78. In Chapter 3, the results of a verification analysis on the implementation and application of the Coal Supply Module are presented. Chapter 4 presents a validation analysis of the data, logical and mathematical structure of the Coal Supply Module, and Chapter 5 presents results from an empirical investigation of the sensitivity of projection results to uncertainties in the Coal Supply Module data and structure.

2. DESCRIPTION OF THE COAL SUPPLY MODULE IN THE NATIONAL COAL MODEL, AND ITS USE IN ARC-78

The energy information analysis system underlying the midterm projection of ARC-78 is the EIA Midterm Energy Forecasting System (MEFS). The MEFS includes as one component the National Coal Model which in turn includes a Coal Supply Module. In this chapter we first identify those aspects of the ARC-78 which reflect the NCM Coal Supply Module, the documentation of the Coal Supply Module (CSM), and relevant evaluation studies. Then a summary description of the CSM is presented, supported by a more technical description in Appendix A, and followed by a description of how the outputs of CSM are transformed and used as inputs to the Midterm Energy Market Model (MEMM), the integrating model which combines the various modules into a system for generating the ARC-78 projections.

2.1 Review of Materials

This "Analysis Quality Report" focuses upon the Coal Supply Module (CSM) of the National Coal Model as used in developing midterm projections in ARC-78. The main place in which the analysis based on the CSM is represented in ARC-78 is in Chapter 9 of Volume III, entitled "Coal Supply." In this chapter, EIA provides some historical perspectives and short-term projections. However, it is the section on mid-term projections for the years 1985, 1990, and 1995 which concern us here. Projections are made in ARC-78 concerning production quantities and prices for coal, by region/mine type and by region/coal type (designated by sulfur content). In addition, the results of sensitivity tests are reported; these tests altered the price of imported oil, coal transportation costs, and production of western coal. The data presented in Chapter 9 of ARC-78 Volume III are supported in greater detail in Supplement One to Volume III. In particular, Series C Tables 16 and 17 provided the less aggregated data upon which Tables 9.2 and 9.3 were based. In the next section of this report, we present results of a verification and error correction of the Coal Supply Module, and suggest how this may alter the projections made by EIA in Chapter 9. In Section 5 of this report, we turn to the sensitivity analysis, and suggest how uncertainty in model results may be affected.

2.2 Summary Description of the Coal Supply Module*

The supply curves employed in the Coal Supply Module (CSM) are based on the coal supply methodology that ICF, Inc. developed in its Coal Supply Analysis for FEA's Project Independence Evaluation System (PIES). A description of the methodology follows.

The coal supply sector of the CSM consists of price sensitive, multi-stepped coal supply curves for each coal type that exists within each supply region. The curves are used to simulate potential production levels available at various prices. Each step of a supply curve represents a different type of mine. The length of each step gives the potential production level for each mine type. The height of each step is called the "minimum acceptable selling price" (known as the "reservation price" in economic terminology) and is based on average variable costs for existing mines and average total costs for new mines.

The supply curves are developed in six major steps. The first step defines appropriate coal supply regions and coal types. In the CSM there are 30 supply regions, aggregated into 12 regions as shown in Table 2-1.

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*Adapted from Goldman [1980]

Table 2-1

ARC-78 COAL SUPPLY REGIONS

Northern Appalachia

Pennsylvania
Ohio
Maryland
West Virginia, North

Southern Appalachia

Alabama

East North Great Plains

North Dakota
South Dakota
East Montana

Central West

Iowa
Missouri
Kansas
Arkansas
Oklahoma

Rocky Mountains

Colorado, South
Utah

Northwest

Washington

Central Appalachia

West Virginia, South
Virigina
East Kentucky
Tennessee*

Midwest

West Kentucky
Illinois
Indiana

West North Great Plains

Western Montana
Wyoming
Northern Colorado

Gulf

Texas

Southwest

Arizona
New Mexico*

Alaska

Alaska

---

*Minor problems exist in these regions, in that parts of the states fall into other jurisdictions. See Section 4.1.2.

The model recognizes five heat (BTU) content and eight sulfur content categories, including two special sulfur levels designed specifically to allow for deep cleaning to meet either the New Source Performance Standard (less than .60 pounds of sulfur per million BTUs) or State Implementation Plans (a one percent sulfur emission limitation for existing sources). All bituminous coals receive a standard level of washing. The supply regions and the coal types form the basis for allocating the Bureau of Mines (BOM) Demonstrated Reserve Base into regional coal type categories.

The second step estimates future output from existing mines (using existing production data and expected mine closings) by region and coal type. The third step determines the minimum acceptable selling price for the future output of these existing mines. For such mines capital has been sunk so the minimum acceptable selling price covers only variable costs, i.e., revenues must cover variable operating expenses. The first steps on each supply curve represent coal production from existing mines.

The fourth step analyzes demonstrated reserves that have not yet been developed. The model allocates these uncommitted reserves by region and coal type to hypothetical model mine type categories, defined in terms of overburden ratio and mine size for surface mines and in terms of seam thickness, seam depth, and mine size for deep mines. For a given mine type, region, and coal type the assigned stock of reserves is then translated into a potential production flow (annual production level) using mine lifetime and recovery factor parameters.

The fifth step estimates the minimum acceptable selling price (MASP) for each mine type in each region. This is the price that provides for the recovery and return on invested capital in addition to covering operating costs. At a given mine, it is the minimum price a coal producer would accept for his product and still operate profitably in the long run. The MASP is estimated using engineering mine-costing algorithms as a function of key reserve characteristics (i.e., overburden ratio, mine size, seam thickness, and seam depth).

The last step arrays the mine types in each region for each coal type in order of ascending minimum acceptable selling price, thus generating a step-function supply curve. The height of each step is determined by the MASP (on a per-annual-ton basis) of the associated mine type. The length of each step is determined by the annual potential production level of the mine type.

Estimates of the minimum acceptable selling price per ton of coal for each of approximately 190 hypothetical mine types are developed. This was accomplished by the construction of two "base case" model mines (one surface and one deep) and a matrix of cost adjustment factors for costing changes in key variables. The base case cost models were developed from existing mine cost studies by BOM and TRW and from information obtained by ICF through interviews with mining engineers and coal economists. The cost adjustment factors employed were based on extrapolations of relationships observed in the existing mine cost models and judgments based on consultations with mining engineers. It should be understood that the costing methodology used in the Coal Supply Module does not take into account all possible cost-influencing variables such as roof, floor, water and gas conditions, however the model developers believe that the major influences on mining costs have been captured.

A more technical description of the Coal Supply Module is presented in Appendix A.

2.3 Relation of Coal Supply Module to Midterm Energy Market Model (MEMM)

The basic documentation of the relation between the Coal Supply Module (SCM) of the NCM and the MEMM is Shaw et al. [1979], which also includes a summary description of the CSM/NCM. As noted, the 30 NCM regions are aggregated into 12 MEMM regions and a raw data table is created with the following columns:

- minimum acceptable selling price in dollars per ton, including all direct costs plus severance taxes, reclamation costs, and adjustments for Alaskan production where applicable;
- maximum level of production in millions of tons per year for each step in the supply curve for each type of coal;
- proportion of production from surface mines;
- present value of the intial capital investment in millions of dollars per million tons of coal per year, or dollars per annual ton required between 1977 and the target year to open new mines;
- present value of the deferred capital investment in dollars per ton per year required between 1977 and the target year to open new mines.

The coal raw data tables are then input to the Coal Preprocessor which

- formats the raw data for input to the LP
- converts data units:
    - Production: MMTon/year to MTon/Cal. Day
    - Prices, costs: \$/ton to M\$/MTon
    - Capital costs: MM\$/MMTon/year to MM\$/MTon/Cal. Day
    - Set mine retirement rate = 3.5% for regions 1-4, and calculate mine retirements table in case years.

3. VERIFICATION ANALYSIS OF THE IMPLEMENTATION AND USE OF THE COAL SUPPLY MODULE IN ARC-78

In the preceding sections we have outlined the methodology and general design of the coal supply module of the NCM. At the initial startup of a model evaluation effort, preliminary understanding of the structure and formulation of a model is developed by reading and relying upon available model documentation. An essential next step, however, is to perform an analysis to verify that the methodology indicated in the documentation was actually implemented in the computer code in an error-free fashion. Both the computer code and the documentation must be checked for internal consistency, as well as the accuracy of their relation to each other. We term this process "verification." In this chapter we report on the results of the verification of the Coal Supply Module (CSM) and relate the implications of the verification results to the coal production projections reported in ARC-78.

The verification of the NCM consisted of three basic steps: a comparison of the documentation with the computer code and data files, an analysis of the computer implementation, and an independent reprogramming of the coal production costing portion of the CSM.* This reprogramming utilized a logical sequence different from that in the NCM, and was a very effective verification method; correspondence of the two codes was assured by parallel runs that matched coal supply prices to five decimal places.

During the verification work, the M.I.T. analysts worked first with the computer code as it was received from the modelers. This version of

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*The description here of the verification process and results is based primarily on Goldman et al. [1979].

the code was identified as the Base Case (BC). Analysts uncovered several errors in the Base Case, and also identified a number of other issues relating to understandability of the programming. Many of the errors were then corrected at M.I.T., and the corrected version of the code was identified as the Corrected Base Case (CBC). Sensitivity analysis was performed on both the Base Case and the Corrected Base Case in order to determine the effects of the errors as well as to determine the effects of changes in variables and parameters.

The following is a summary of the more important errors identified during the verification process. None of the errors by itself has been deemed to be of critical importance, although the summation of small factors can sometimes lead to more significant perturbations in results than might be expected. The errors involved the following:

- an incorrect modeling of the deep-cleaning of all metallurgical coals, resulting in the double counting of deep-cleaning costs for certain coal types, and other related problems;
- an incorrect escalation of base-year (1975) price data for existing mines;
- skipping one year of cost escalation between the base year and the case year (1985) in the calculation of real annuity coal prices;
- inappropriate method for approximating treatment of initial capital cost expenditures;
- an incorrect escalation of the property taxes and insurance component of coal mine operating costs;
- an incorrect calculation of base-year Union Welfare Costs for coal mines;
- changing the smallest seam thickness input value in the midst of cost calculations for deep mines;
- improperly allocating more than 100 percent of deferred capital over the lifetime of a mine when the lifetime is not perfectly divisible by four.

Other problems identified include:

- In parts, the Supply Code relates to old code used for the PIES Coal Supply Analysis. Such code may lead to user confusion;
- Because of an undocumented "patch" that exogenously overrides the coal supply curve output for Utah bituminous low-sulfur coal, this particular supply curve should be considered invalid for sensitivity runs involving regeneration of supply curves;
- Real escalation of cost factors is not appropriately accounted for in 1990 and 1995 case-year model runs; and
- The implementation of a change in the general rate of inflation is not at all straightforward and may lead to user confusion.

Those errors that could be corrected without significantly changing the structure of the Coal Supply Module were corrected by the M.I.T. analysts. Such corrections related to the calculations of reserve fractions, coal cleaning costs, property taxes and insurance, definition of base year dollars, depreciation charges, welfare costs, smallest seam thickness, labor costs, allocation of deferred capital, Oklahoma reclamation costs, and escalators for initial capital and existing mine prices.* The implementation of the corrections led to the development of the Corrected Base Case (CBC).

In order to determine the effects that the errors alone had on model results, Base Case output was compared with Corrected Base Case output. The results of this comparison are summarized in Tables 3-1 and 3-2 for two important factors--national coal production amounts and average coal production prices. In these tables, the percentage changes due to the effects of the corrections appear in parentheses. Some of the more interesting and signficant effects of the corrections include:

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*A detailed discussion of the errors and their corrections may be found in Goldman et al. [1979].

Table 3-1

NATIONAL COAL PRODUCTION (MM TONS)

	1985	1990	1995
Metallurgical			
BC	153.49	154.33	164.01
CBC	163.57 (+6.6%)	169.93 (+10.1%)	173.23 (+5.6%)
Low Sulfur			
BC	291.71	466.29	577.21
CBC	284.83 (+2.4%)	459.77 (-1.4%)	623.49 (+8.0%)
Medium Sulfur			
BC	412.13	550.35	664.65
CBC	411.75 (-.09%)	544.92 (-1.0%)	641.73 (-3.4%)
High Sulfur			
BC	260.07	342.63	456.07
CBC	254.90 (-2.0%)	330.45 (-3.6%)	437.12 (-4.2%)
Surface			
BC	598.94	776.73	913.39
CBC	599.68 (-.12%)	779.49 (+.35%)	962.60 (+5.4%)
Deep			
BC	518.44	736.87	948.54
CBC	515.37 (-.59%)	725.58 (-1.5%)	912.97 (-3.9%)
Total			
BC	1117.38	1513.60	1861.93
CBC	1115.05 (-.21%)	1505.07 (-.56%)	1875.57 (+.73%)

BC = Base case of model as transmitted to M.I.T.

CBC = Corrected base case of model after error correction by M.I.T. analysts.

Table 3-2

AVERAGE COAL PRODUCTION PRICES (1978 $/MMBtu)

	1985	1990	1995
Metallurgical			
BC	1.64	1.76	1.85
CBC	1.66 (+1.2%)	1.78 (+1.1%)	1.86 (+.54%)
Low Sulfur			
BC	0.83	0.79	0.83
CBC	0.85 (+2.4%)	0.80 (+1.3%)	0.83 (0.0%)
Medium Sulfur			
BC	0.99	1.03	1.09
CBC	1.02 (+3.0%)	1.07 (+3.9%)	1.11 (+1.8%)
High Sulfur			
BC	1.00	1.18	1.27
CBC	1.04 (+4.0%)	1.23 (+4.2%)	1.33 (+4.7%)
Total			
BC	1.07	1.10	1.15
CBC	1.10 (+2.8%)	1.14 (+3.6%)	1.18 (+2.6%)

BC = Base case of model as transmitted to M.I.T.

CBC = Corrected base case of model after error correction by M.I.T. analysts.

- There is a general increase in surface coal production (a high of 5 percent in CBC-1995) and a general decrease in deep coal production (a high of 4 percent in CBC-1995) for all case years. There are small decreases in total coal production in both 1985 and 1990, and small increases in 1995 (see Table 3-1).
- There is a consistent average coal production price increase of between 2 and 4 percent (Table 3-2).

Rather than examine the implications of the corrections in the abstract, however, the important task for EMAP analysts was to consider the effects of these corrections on the data and projections presented in ARC-78, Volume III. The direct way to accomplish this would have been to re-run the actual ARC-78 scenarios using corrected computer code. This was not feasible for the EMAP team. However, an approximation to the effect of the corrections on ARC-78 could be calculated because the CEUM, which EMAP could run, is a somewhat generalized version of the NCM with updated data. Both the NCM and the CEUM represent a subset of the MEMM; variables endogenous to MEMM are exogenous to NCM and CEUM, the most important being the supplies and prices of fuels competing with coal. Conditional on holding these variables constant, we assume that a change in the data/structure of the CSM has an equal proportional effect upon coal production and prices, whether calculated by NCM, CEUM, or MEMM. Hence, a "first order" estimate of the effect on ARC-78 of implementing the CSM verification corrections may be obtained by examining the change in the CEUM BC/CBC results.

The analysis was performed in the following manner. In ARC-78 Volume III, Tables 9.2 and 9.3, a series of results and projections is presented giving data on coal production for the three case years of 1985, 1990 and 1995. These results are developed for the EIA Series C data (median supply curve -- median demand curve), and are supported by Supplement One to Volume III in Series C Tables 16 and 17. The EIA projections are displayed by region/coal type (sulfur content) and region/mine type. M.I.T. analysts developed for each of these same categories a percentage change factor of the difference between CEUM Base Case and Corrected Base Case results. Then that percentage change factor was applied to each of the results presented in the tables in ARC-78, and a "corrected" EIA figure was calculated. This analysis is presented in Tables 3-3 through 3-8. Tables 3-3 through 3-5 display the correction effects by coal type and region, and the latter tables display the effects by mine type and region.

In the analysis of these data, the first thing to notice is that although individual percentage changes vary widely due to the corrections, the effects tend to cancel as the regions are aggregated. For example, in Table 3-3, metallurgical coal is increased by 17% in the Northern Appalachian region; however the other coal type amounts are decreased, such that the total amount of coal for that region is changed by only 1.01%. This "cancellation" effect is also true when the regional totals are aggregated into the national total. Again looking at Table 3-3, although the regional subtotals were changed due to the corrections by varying amounts in both directions, the National total changed by only 0.1%.

Let us look more closely at the percentage changes due to the verification corrections by sulfur categories, national totals.

National Total	1985	1990	1995
Metallurgical	+6.6%	+10.1%	+5.6%
Low Sulfur	-2.4%	-1.4%	+8.0%
Medium Sulfur	-0.1%	-1.0%	-3.4%
High Sulfur	-2.0%	-3.6%	-4.2%

For the medium and high sulfur categories, the corrections show that for those coal types production was overestimated in ARC-78, an effect that tended to intensify as the years progressed. For the lowest sulfur categories, the trend is not consistent; however, by 1995, in both low sulfur categories, coal production was underestimated in ARC-78. In fact, this underestimation in 1995 of low sulfur coal production more than offset the overestimation of the higher sulfur coals. To rephrase this, the error analysis indicates that if the verification corrections were made on the ARC-78 scenarios, it is likely that the results would show more low sulfur coal production by 1995 and less high sulfur coal production, although the national total for all coals would not change significantly.

Turning to the projections concerning the production of coal by type of mine -- surface or deep -- displayed in ARC-78 Table 9.3, a similar analysis can be performed. In general the error corrections tended not to change the ARC-78 projections concerning surface-mined coal significantly. Looking at Tables 3-6 through 3-8 it is evident that in those regions where surface production of coal was changed a few percentage points due to error corrections, the total amounts involved tended to be small. More significant effects appear in the deep mining production numbers, for example in 1985 in Central Appalachia (+3.2%), in 1985 in the Midwest (-3.3%), in 1990 in Central Appalachia (+5.4%), in 1990 in the Midwest (-4.9%), and in 1990 in the Rocky Mountains (-6.7%). In 1995 the significant changes in deep coal production occur in Northern Appalachia (-7.2%), in Central Appalachia (+5.1%), in the Midwest (-4.4%) and in the Rocky Mountains (-5.6%). The summary table for the National totals is as follows:

National Totals	1985	1990	1995
Surface	no change	+0.4%	+5.4%
Deep	-0.6%	-1.5%	-3.8%

From this summary table it is evident that it is likely that correction of the verification errors in the EIA ARC-78 scenarios for Series C would produce higher figures for coal production from surface mines, and less coal production from deep mines.

In summary, it is evident that the verification corrections do have some effect on the results produced by model runs. Because the analytical exercise performed above on the ARC-78 projections relies on the application of a factor to the EIA data, the "corrected" columns in Tables 3-3 through 3-8 should not be considered exact predictions of what would occur should the verification corrections actually be implemented on the ARC-78 scenarios. However, the likely direction and magnitude of such changes is suggested.

Table 3-3

1985

COAL PRODUCTION (MM TONS) EFFECTS OF CORRECTIONS BY COAL TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA" presents data from ARC-78 Vol. III, Supplement One, Table 17; also summarized in Vol. III, Table 9.2)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Metallurgical	16.658	19.408	1.17	17.69	20.70
Low Sulfur	.282	.202	.72	1.5	1.08
Med. Sulfur	84.383	84.074	.996	72.22	71.93
High Sulfur	73.904	73.504	.995	84.96	84.53
Total	175.227	177.188		176.37	178.24
Cent. App.					
Metallurgical	128.152	135.052	1.053	128.04	142.21
Low Sulfur	18.677	17.367	.929	33.64	31.25
Med. Sulfur	54.337	53.537	.985	70.58	69.52
High Sulfur	12.575	12.575	1.0	15.51	15.51
Total	213.741	218.531		247.76	258.49
South App.					
Metallurgical	4.444	4.744	1.068	4.53	4.84
Low Sulfur	4.080	3.280	.804	.96	.77
Med. Sulfur	12.031	11.951	.993	12.91	12.82
Total	20.555	19.975		18.40	18.43
Midwest					
Low Sulfur	.720	.640	.889	.08	.07
Med. Sulfur	60.695	59.895	.987	54.99	54.28
High Sulfur	167.418	162.652	.972	167.47	162.78
Total	228.834	223.188		222.54	217.13

Table 3-3 (continued)

	BC	CBC	Change Factor	EIA	CEIA
E. No. G. Plns.					
Low Sulfur	1.604	1.604	1.0	5.01	5.01
Med. Sulfur	21.531	21.531	1.0	22.66	22.66
High Sulfur	.341	.341	1.0		
Total	23.476	23.476		27.67	27.67
W. No. G. Plns.					
Low Sulfur	215.766	212.579	.985	145.95	143.76
Med. Sulfur	90.997	92.341	1.015	50.89	51.65
Total	306.762	304.920		196.84	195.41
Central West					
Metallurgical	.243	.303	1.247	.23	.29
Low Sulfur	.480	.400	.833		
Med. Sulfur	1.375	1.647	1.198	.59	.71
High Sulfur	5.828	5.828	1.0	11.1	11.10
Total	7.927	8.178		11.92	12.10
Gulf					
Med. Sulfur	57.717	57.717	1.0	70.21	70.21
Total	57.717	57.717		70.21	70.21
Rocky Mountains					
Metallurgical	3.992	4.063	1.018	4.69	4.77
Low Sulfur	32.074	31.274	.975	24.56	23.95
Med. Sulfur	9.375	9.375	1.0	5.86	5.86
Total	45.441	44.712		35.11	34.58
Southwest					
Low Sulfur	18.022	17.480	.97	3.66	3.55
Med. Sulfur	16.016	16.016	1.0	16.03	16.03
Total	34.038	33.496		19.69	19.58

Table 3-3 (continued)

	BC	CBC	Change Factor	EIA	CEIA
Northwest					
Low Sulfur				.10	.10
Med. Sulfur	3.668	3.668	1.0	6.02	6.02
Total	3.668	3.668		6.12	6.12
National Total					
Metallurgical	153.490	163.571	1.066	155.18	165.42
Low Sulfur	291.705	284.826	.976	215.44	210.27
Med. Sulfur	412.125	411.751	.999	382.93	382.55
High Sulfur	260.066	254.900	.980	279.03	273.45
Total	1117.384	1115.048		1032.58	1031.69

Table 3-4

1990

COAL PRODUCTION (MM TONS)
EFFECTS OF CORRECTIONS BY COAL TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA" presents data from ARC-78 Vol. III, Supplement One, Table 17; also summarized in Vol. III, Table 9.2)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Metallurgical	21.446	27.676	1.287	19.72	25.38
Low Sulfur	.441	.361	.819	1.43	1.17
Med. Sulfur	142.335	139.245	.978	116.04	113.49
High Sulfur	90.246	88.467	.980	110.29	108.08
Total	254.518	255.748		247.48	248.12
Cent. App.					
Metallurgical	123.308	131.929	1.070	134.43	143.84
Low Sulfur	17.916	16.395	.915	30.77	28.15
Med. Sulfur	30.724	31.764	1.034	50.59	52.31
High Sulfur	4.191	4.191	1.0	9.27	9.27
Total	176.140	184.280		225.06	233.57
South App.					
Metallurgical	5.121	5.841	1.141	5.45	6.22
Low Sulfur	5.120	4.560	.891	.96	.86
Med. Sulfur	4.410	4.330	.982	5.96	5.85
Total	14.651	14.731		12.37	12.93
Midwest					
Low Sulfur	1.040	1.040	1.0	.08	.08
Med. Sulfur	72.285	68.125	.942	60.52	57.00
High Sulfur	241.390	232.099	.962	229.86	221.13
Total	314.716	301.265		290.45	278.21

Table 3-4 (continued)

	BC	CBC	Change Factor	EIA	CEIA
E. No. G. Plns.					
Low Sulfur	6.140	5.922	.964	5.58	5.38
Med. Sulfur	23.945	23.945	1.0	26.60	26.60
High Sulfur	.341	.341	1.0		
Total	30.426	30.209		32.18	31.98
W. No. G. Plns.					
Low Sulfur	356.849	357.829	1.003	359.83	360.91
Med. Sulfur	172.600	172.907	1.002	143.44	143.73
Total	529.449	530.736		503.27	504.64
Central West					
Metallurgical	.181	.253	1.398	.23	.32
Low Sulfur	.880	.800	.909		
Med. Sulfur	2.469	3.029	1.227	.59	.72
High Sulfur	6.463	5.350	.828	11.10	9.19
Total	9.993	9.432		11.92	10.23
Gulf					
Med. Sulfur	71.757	71.757	1.0	71.76	71.76
Total	71.757	71.757		71.76	71.76
Rocky Mountains					
Metallurgical	4.228	4.228	1.0	4.69	4.69
Low Sulfur	40.235	37.510	.932	29.75	27.73
Med. Sulfur	9.288	9.288	1.0	6.71	6.71
Total	53.751	51.026		41.15	39.13
Southwest					
Low Sulfur	37.670	35.355	.939	6.83	6.41
Med. Sulfur	16.866	16.866	1.0	16.03	16.03
Total	54.536	52.221		22.86	22.44

Table 3-4 (continued)

	BC	CBC	Change Factor	EIA	CEIA
Northwest					
Low Sulfur				.10	.10
Med. Sulfur	3.668	3.668	1.0	6.02	6.02
Total	3.668	3.668	1.0	6.12	6.12
National Total					
Metallurgical	154.334	169.927	1.101	164.52	181.14
Low Sulfur	466.290	459.771	.986	435.32	429.23
Med. Sulfur	550.347	544.924	.990	504.23	499.19
High Sulfur	342.631	330.448	.964	360.51	347.53
Total	1513.602	1505.069	.994	1464.58	1457.09

Table 3-5

1995

COAL PRODUCTION (MM TONS)
EFFECTS OF CORRECTIONS BY COAL TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA presents data from ARC-78 Vol. III, Supplement One, Table 17; also summarized in Vol. III, Table 9.2)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Metallurgical	28.900	29.860	1.033	25.24	26.10
Low Sulfur	.560	.480	.857	1.40	1.21
Med. Sulfur	198.467	177.255	.893	149.67	133.66
High Sulfur	126.303	121.586	.963	144.02	138.70
Total	354.230	329.181		320.33	299.67
Cent. App.					
Metallurgical	126.865	134.891	1.063	140.35	149.19
Low Sulfur	17.910	16.360	.913	29.37	26.81
Med. Sulfur	19.280	20.160	1.046	42.95	44.93
High Sulfur				6.19	6.19
Total	164.055	171.412		218.86	227.12
South App.					
Metallurgical	6.060	6.060	1.0	6.36	6.36
Low Sulfur	5.520	5.120	.928	.96	.89
Med. Sulfur	1.280	.960	.75	2.45	1.84
Total	12.860	12.140		9.77	9.09
Midwest					
Low Sulfur	1.120	1.120	1.0	.08	.08
Med. Sulfur	78.160	76.020	.973	66.15	64.36
High Sulfur	310.499	296.801	.956	310.87	297.19
Total	389.780	373.942		377.10	361.63

Table 3-5 (continued)

	BC	CBC	Change Factor	EIA	CEIA
E. No. G. Plns.					
Low Sulfur	10.450	10.450	1.0	14.69	14.69
Med. Sulfur	14.624	14.624	1.0	67.01	67.01
High Sulfur	10.303	10.303	1.0		
Total	35.377	35.377		81.70	81.70
W. No. G. Plns.					
Low Sulfur	452.035	501.899	1.11	534.20	592.96
Med. Sulfur	272.410	272.410	1.0	265.15	265.15
Total	724.446	774.309		799.35	858.11
Central West					
Metallurgical	.360	.600	1.667	.29	.48
Low Sulfur	1.040	1.040	1.0		
Med. Sulfur	4.457	5.129	1.15	.67	.77
High Sulfur	8.960	8.425	.940	15.90	14.95
Total	14.817	15.194		16.86	16.20
Gulf					
Med. Sulfur	61.750	61.750	1.0	71.76	71.76
Total	61.750	61.750		71.76	71.76
Rocky Mountains					
Metallurgical	1.820	1.820	1.0	4.69	4.69
Low Sulfur	38.580	37.250	.966	43.67	42.19
Med. Sulfur	10.291	9.491	.922	10.43	9.62
Total	50.692	48.561		58.79	56.50
Southwest					
Low Sulfur	49.994	49.770	.996	15.33	15.27
Med. Sulfur	2.980	2.980	1.0	16.89	16.89
Total	52.974	52.750		32.22	32.16

Table 3-5 (continued)

	BC	CBC	Change Factor	EIA	CEIA
Northwest					
Low Sulfur				.14	.14
Med. Sulfur	.950	.950	1.0	6.49	6.49
Total	.950	.950		6.63	6.63
Alaska					
Low Sulfur				5.70	5.70
National Total					
Metallurgical	164.005	173.231	1.056	176.93	186.84
Low Sulfur	577.209	623.489	1.080	645.53	697.17
Med. Sulfur	664.649	641.729	.966	699.61	675.82
High Sulfur	456.065	437.115	.958	476.98	456.95
Total	1861.929	1875.564		1999.05	2016.78

Table 3-6

1985

COAL PRODUCTION (MM TONS)
EFFECTS OF CORRECTIONS BY MINE TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA" presents data from ARC-78 Vol. III, Supplement One, Table 16; also summarized in Vol. III Table 9.3)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Surface	41.971	42.321	1.008	71.9	72.5
Deep	135.257	133.867	1.012	104.5	105.8
Total	175.227	177.188		176.4	178.3
Cent. App.					
Surface	49.541	49.111	.991	99.9	99.0
Deep	164.200	169.420	1.032	147.9	152.6
Total	213.741	218.531		247.8	251.6
South App.					
Surface	8.393	8.393	1.0	9.9	9.9
Deep	12.162	11.582	.952	8.5	8.1
Total	20.555	19.975		18.4	18.0
Midwest					
Surface	58.724	58.724	1.0	60.3	60.3
Deep	170.110	164.463	.967	162.2	156.8
Total	228.834	223.188		222.5	217.1
E. No. G. Plns.					
Surface	23.476	23.476	1.0	27.7	27.7
Total	23.476	23.476		27.7	27.7

Table 3-6 (continued)

	BC	CBC	Change Factor	EIA	CEIA
W. No. G. Plns.					
Surface	303.125	304.483	1.004	192.4	193.2
Deep	3.637	.437	.12	4.4	.5
Total	306.762	304.920		196.8	193.7
Central West					
Surface	6.361	6.361	1.0	7.1	7.1
Deep	1.566	1.817	1.160	4.9	5.7
Total	7.927	8.178		11.9	12.8
Gulf					
Surface	57.717	57.717	1.0	70.2	70.2
Total	57.717	57.717		70.2	70.2
Rocky Mountains					
Surface	12.956	12.956	1.0	9.0	9.0
Deep	32.485	31.756	.978	26.1	25.5
Total	45.441	44.712		35.1	34.5
Southwest					
Surface	33.008	32.446	.984	15.5	15.3
Deep	1.029	1.029	1.0	4.2	4.2
Total	34.038	33.496		19.7	19.5
Northwest					
Surface	3.668	3.668	1.0	6.0	6.0
Deep				0.1	0.1
Total	3.668	3.668		6.0	6.1
National Total					
Surface	598.939	599.675	1.0	569.8	569.8
Deep	518.445	515.373	.994	462.8	460.1
Total	1117.384	1115.048		1032.6	1029.9

Table 3-7

1990

COAL PRODUCTION (MM TONS) EFFECTS OF CORRECTIONS BY MINE TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA" presents data from ARC-78 Vol. III, Supplement One, Table 16; also summarized in Vol. III, Table 9.3)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Surface	16.272	16.272	1.0	51.0	51.0
Deep	238.246	239.476	1.005	196.5	197.5
Total	254.518	255.748		247.5	248.5
Cent. App.					
Surface	22.936	22.936	1.0	81.4	81.4
Deep	153.204	161.344	1.053	143.6	151.2
Total	176.140	184.280		225.1	232.6
South App.					
Surface	2.797	2.797	1.0	4.8	4.8
Deep	11.854	11.934	1.007	7.6	7.7
Total	14.651	14.731		12.4	12.5
Midwest					
Surface	39.703	39.703	1.0	39.4	39.4
Deep	275.012	261.562	.951	251.1	238.8
Total	314.716	301.265		290.5	278.2
E. No. G. Plns.					
Surface	30.426	30.209	.993	32.2	32.1
Total	30.426	30.209		32.2	32.1

Table 3-7 (continued)

	BC	CBC	Change Factor	EIA	CEIA
W. No. G. Plns.					
Surface	522.614	525.503	1.006	495.6	498.6
Deep	6.835	5.233	.766	7.6	5.8
Total	529.449	530.736		503.3	504.4
Central West					
Surface	2.120	2.120	1.0	7.1	7.1
Deep	7.873	7.312	.929	4.9	4.6
Total	9.993	9.432		11.9	11.7
Gulf					
Surface	71.757	71.757	1.0	71.8	71.8
Total	71.757	71.757		71.8	71.8
Rocky Mountains					
Surface	13.335	13.335	1.0	10.3	10.3
Deep	40.416	37.690	.933	30.9	28.8
Total	53.751	51.026		41.2	39.1
Southwest					
Surface	51.107	51.191	1.002	15.5	15.5
Deep	3.429	1.029	.300	7.3	2.2
Total	54.536	52.221		22.8	17.7
Northwest					
Surface	3.668	3.668	1.0	6.0	6.0
Deep				0.1	0.1
Total	3.668	3.668		6.1	6.1
National Total					
Surface	776.735	779.491	1.004	815.0	818.3
Deep	736.867	725.578	.985	649.6	639.9
Total	1513.602	1505.069		1464.6	1458.2

Table 3-8

1995

COAL PRODUCTION (MM TONS)
EFFECTS OF CORRECTIONS BY MINE TYPE AND REGION ON BASE CASE AND ARC-78 (EIA) DATA

(The column labeled "EIA" presents data from ARC-78 Vol. III, Supplement One, Table 16; also summarized in Vol. III, Table 9.3)

	Base Case	Corrected Base Case	Change Factor	EIA	"Corrected" EIA
North App.					
Surface	4.530	4.530	1.0	45.3	45.3
Deep	349.700	324.651	.928	275.1	255.3
Total	354.230	329.181		320.3	300.6
Cent. App.					
Surface	10.200	9.770	.958	74.1	71.0
Deep	153.855	161.642	1.051	144.8	152.2
Total	164.055	171.412		218.9	223.2
South App.					
Surface				2.3	2.3
Deep	12.860	12.140	.944	7.5	7.1
Total	12.860	12.140		9.8	9.4
Midwest					
Surface	28.500	28.500	1.0	38.3	38.3
Deep	361.280	345.442	.956	338.8	323.9
Total	389.780	373.942		377.1	362.2
E. No. G. Plns.					
Surface	35.377	35.377	1.0	81.7	81.7
Total	35.377	35.377		81.7	81.7

Table 3-8 (continued)

	BC	CBC	Change Factor	EIA	CEIA
W. No. G. Plns.					
Surface	712.445	762.308	1.070	787.3	842.4
Deep	12.001	12.001	1.0	12.0	12.0
Total	724.446	774.309		799.3	854.4
Central West					
Surface				7.1	7.1
Deep	14.817	15.194	1.025	9.8	10.0
Total	14.817	15.194		16.9	17.1
Gulf					
Surface	61.750	61.750	1.0	71.8	71.8
Total	61.750	61.750		71.8	71.8
Rocky Mountains					
Surface	12.661	12.661	1.0	11.6	11.6
Deep	38.030	35.900	.944	47.2	44.6
Total	50.692	48.561		58.8	56.2
Southwest					
Surface	46.974	46.750	.955	16.4	15.7
Deep	6.000	6.000	1.0	15.8	15.8
Total	52.974	52.750		32.2	31.5
Northwest					
Surface	0.950	0.950	1.0	6.5	6.5
Deep				0.1	0.1
Total	0.950	0.950		6.6	6.6
National Total					
Surface	913.387	962.596	1.054	1142.2	1203.9
Deep	948.542	912.968	.962	856.8	824.2
Total	1861.929	1875.564		1999.1	2028.1

4. EVALUATION OF THE COAL SUPPLY MODULE IN THE NATIONAL COAL MODEL AND ITS USE IN ARC-78

4.1 Data

4.1.1 Introduction

In this section we describe the data base underlying the Coal Supply Model used in ARC-78. First we summarize the exogenous variables of the model, both those used in calibrating the model's parameters and data, and those over which the model user has more direct control. We then discuss those variables which were changed between various scenarios in ARC-78. It should be noted that most of the model's variables are not explicitly documented in the ARC-78 materials. It is our understanding that the version of the data base established in ICF [1977] was the data base used for ARC-78, except where explicitly modified. The most important change was the adjustment between the medium and high estimates of geological reserves in which resources of unknown quality are included in the high estimate, but excluded from the medium estimate.

4.1.2 Independent Variables, Data Sources, and Synthetic Data Procedures in the Coal Supply Module of the National Coal Model

The component of the National Coal Model with which we are concerned in this evaluation is the Coal Supply Module used to generate coal supply curves for the MEMM. The documentation of the procedures underlying the supply curves has been summarized above, and the model's detailed mathematical formulation is presented in Appendix A. The data inputs are described in ICF [1977].

To summarize, the procedures used in constructing the coal supply model data base and generating the coal supply curves are as follows:

- Define coal supply regions and coal types: allocate the BOM Demonstrated Reserve Base (BDRB) to regional coal type categories.
- Estimate existing 1980 production and selling price from existing mine capacity by coal type and region.
- Assign BDRB to model mine categories, and convert stocks of reserves into production flows;
- Calculate minimum acceptable selling price for each model mine type; and
- Combine potential production flows and supply prices into supply schedules by region and coal type.

(1) Supply regions and coal types

There are thirty NCM coal supply regions which, with minor exceptions, map into the MEFS supply regions. The NCM supply regions and the NCM/MEFS mapping were presented in Table 2.1. The exceptions are a part of Tennessee in BOM District 13 which is in MEFS Southern Appalachia, and that part of New Mexico in BOM District 17 which is in the MEFS Rockies region. The NCM documentation reports that these exceptions are minor, and that the addition of two NCM regions to deal with this problem was not justified. However, the question remains how the incompatibility is treated in aggregating NCM to MEMM regions. Are MEMM regions redefined in the aggregation so that

- MEFS Central Applachia is overstated,
- MEFS Southern Appalachia is understated,
- MEFS Southwest is overstated,
- MEFS Rockies is understated,

or is an adjustment made to preserve the MEFS definition; if the latter is the case, how is the adjustment made? The documentation does not address this point.

There is a more general question relating to the basis for the original PIES (now MEMM) regions, and the more detailed NCM regions. The NCM regions were developed to account for the "importance of state mining laws and taxes" which require that each supply region include no more than one state. Regions (by or within state) were defined so as to have relatively homogeneous coal types (ICF [1977, p. III-2]). However, there is no formal analysis reported as to the definition of homogeneity, and how this definition was employed in defining regions.

Coal types are defined in the NCM in terms of Btu and sulfur content. Five Btu content levels (on a wet basis) are defined in Table 4.1. Eight sulfur levels are defined in terms of pounds per MMBtu. Sulfur levels were chosen to fit into the classification scheme to meet clean air standards as follows.

- Levels 1 and 2: $\leq$ .6 lbs/MMBtu -- meets the New Source Performance Standards (NSPS)
- Level 3: .61 -.63 lbs/MMBtu -- can be deep cleaned to meet NSPS
- Level 4: .64 -.83 lbs/MMBtu -- approximately 1% sulfur which meets requirements of some state implementation plans (SIPS)
- Level 5: .84 -.92 lbs/MMBtu -- can be deep cleaned to meet 1% sulfur level
- Level 6: .93 -1.67 lbs/MMBtu -- corresponds roughly to the 2% sulfur content level, which is also a break-point for certain SIPS
- Level 7,8: $\geq$ 1.68 lbs/MMBtu -- sulfur content such as to require scrubbing.

While the NCM employs the full detail of coal types in developing coal supply curves by regional coal type, the aggregation for use in MEMM distinguishes low, medium and high sulfur content as follows: (see ARC-78, Vol. III, p. 157)

- Low sulfur = 0-0.67 lbs/MMBtu
- Medium = .67 - 1.68 lbs/MMBtu
- High > 1.68 lbs/MMBtu

Table 4-1

Btu Content Categories and Codes

Millions of Btu's per ton	Code	Approximate Rank of Coal
≥ 26	Z	Bituminous
23-25.99	H	Bituminous
20-22.99	M	Bituminous
15-19.99	S	Sub-bituminous
< 15	L	Lignite

Source: ICF [1977, p. III-5]

This classification obviously does not represent an aggregation of the more detailed NCM classification, and so there is an undocumented adjustment that must have been made in the transition from the aggregation of the NCM supply curves by type to the MEFS classification.

The primary source of reserves data is the BOM Public Reserves Data Tape. This tape provides tonnage by coal beds by county, plus information on the quality of the coal, including heat and sulfur content, for all demonstrated reserves. The total coal tonnage contained on the data tape is similar to, but not exactly the same as, that contained in two BOM publications, "The Reserve Base of U.S. Coal by Sulfur Content 1. The Eastern States" (IC 8680) and "The Reserve Base of U.S. Coal by Sulfur Content 2. The Western States" (IC 8693). The model documentation states that since it was not possible to judge which data source was more accurate, the BOM data tape was used for the model. Table 4-2 presents data from the two sources -- the tape and the publications -- for comparison.*

The comparison of these sources has shown that there are indeed some substantial differences between the tape and the publications. The first issue involves the heat content of the coal. As shown in Table 4-1 and described in the text of ICF[1977](p. III-7) the average Btu content for each of the five heat categories was calculated for the model from the BOM tape. The tape contains dry heat content and a measure of moisture

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*For the purposes of the comparison, some simple data manipulation was performed. Some of the states on the tape data were divided into two sections; where this occurred, the 1977 edition of Coal Data was used to determine which counties were within each BOM district; the totals from the various coal categories for each individual county were then combined to derive the data for that section of the state. Consequently, it was possible to keep the data organized by PIES regions.

Table 4-2

A Comparison of Corresponding Data from the BOM Coal Reserves Data Tape and the 1975 BOM Information Circular

PIES Regions	Tape (10^6 tons)					Publication (million short tons)								
	Bituminous	Sub-bituminous	Lignite	Unknown	Total	Bituminous		Sub-bituminous		Lignite		Total	Total	TOTAL
						Unknown	Assigned	Unknown	Assigned	Unknown	Assigned	Unknown	Assigned	
Northern Appalachia:														
Pennsylvania	21271			2593	23864	2299	21581					2299	21581	23880
Ohio	17753			3319	21072	1872	19205					1872	19205	21077
Maryland	914			115	1029	35	1013					35	1013	1048
W. Virginia, north	12723			8846	21569	2749	17392					2749	17392	20141
Total	52661			14873	67534	6955	59191					6955	59191	66146
Central Appalachia:														
W. Virginia, south	14407			3556	17963	1862	16895					1862	16895	18757
Virgnia	2899			738	3637	245	3267					245	3267	3512
Kentucky, east	7901			5003	12904	2729	10188					2729	10188	12917
Tennessee	751			235	986	88	899					88	899	987
Total	25958			9532	35490	4925	31247					4925	31247	36172
Southern Appalachia:														
Alabama	1704			1278	2982	213	1742			1027	-	1240	1742	2982
Midwest:														
						12201*						12201*		
Illinois	38471			27042	65513	14256	51409					14256	51409	65665
						1290*						1290*		
Indiana	7587			2870	10457	1504	9119					1504	9119	10623
Kentucky, west	7460			5157	12617	2816	9808					2816	9808	12624
Amended Total						16307*						16307*		
Total	53518			35069	88587	18576	70335					18576	70335	88911
Central West:														
Iowa	1044	751		1063	2858	·549	2336					549	2336	2885
Missouri	3678			5773	9451	4081	5406					4801	5406	9487
Kansas	529			843	1372	383	1005					383	1005	1388
Arkansas	430			68	498	42	495			32	-	74	495	569
Oklahoma	834			413	1247	450	844					450	844	1294
Total	6515	751		8160	15426	5506	10086			32	-	5538	10086	15624
Gulf:														
Texas			2828	444	3272					444	2828	444	2828	3272

*Two sets of figures were provided for Illinois and Indiana. The larger number is based on the assumption that coal in the ground is basically equivalent in sulfur content to that already mined. The asterisked number was amended from that assumption by BOM using "...personal knowledge and judgment...". (see BOM IC 8680, p.8)

NOTE: May not total due to rounding

Table 4-2 (Continued)
A Comparison of Corresponding Data from the BOM Coal Reserves Data Tape
and the 1975 BOM Information Circular

PIES Regions	Tape (10^6 tons)					Publication (million short tons)								
	Bituminous	Sub-bituminous	Lignite	Unknown	Total	Bituminous		Sub-bituminous		Lignite		Total Unknown	Total Assigned	TOTAL
						Unknown	Assigned	Unknown	Assigned	Unknown	Assigned			
East Northern Great Plains:														
North Dakota			12576	3412	15988					15	15988	15	15988	16003
South Dakota			200	227	427					1	427	1	427	428
Montana, east			1530	1747	3277			702	-	1464	2111	2166	2111	4277
Total			14306	5386	19692			702	-	1480	18526	2182	18526	20708
Western Northern Great Plains:														
Montana, west	4511	96345		3237	104093	-	1384	-	99212	-	3523	-	104119	104119
Wyoming	9273	39717		4318	53308	22	4502	3038	45774			3060	50276	53336
Colorado, north		659		1537	2196	-	127	606	1592			606	1719	2325
Total	13784	136721		9092	159597	22	6013	3645	146577	-	3523	3667	156113	159780
Rockies:														
Colorado, south	4925			7722	12647	4924	4887	1010	1538			5934	6425	12359
Utah	793	230		2982	4005	478	3564					478	3564	4042
Total	5718	230		10704	16652	5402	8451	1010	1538			6412	9989	16401
Southwest:														
Arizona	329	21		0	350			-	350			-	350	350
New Mexico	4368			0	4368	28	1749	-	2615			28	4364	4392
Total	4697	21		0	4718	28	1749	-	2965			28	4714	4742
Northwest:														
Washington	98	51		1341	1950	22	229	21	1674	2	6	45	1909	1954
Alaska:														
Alaska		2386		6790	9176	-	1201	-	10148		296	-	11645	11645
National Total:	164653	140160	17134	102669	425076	41649	190246	5378	162902	2985	25178	50012	378326	428338

NOTE: May not total due to rounding

content; the Btu content on a wet basis was obtained by multiplying the average dry heat content by one minus the average moisture content. No information is provided on the variance associated with the average Btu content, so we do not know how representative the average is for each heat content in each of the 30 regions.

The classification of coal on the data tape into either the bituminous, subbituminous, or lignite categories was made on the basis of the coal heat content. In contrast to the tape, the publications classify coal on the basis of percent of fixed carbon and volatile matter, as well as heat content (see Table 4-3). Therefore, it is difficult to determine whether the type of coal in each classification is consistent between the tape and the publications. Using the heat value information alone, the treatment appears inconsistent. For example, the tape places coal in the 15-15.99 MMBtu/ton range in the subbituminous class, while the publications' range for subbituminous coal is 21-23 MMBtu/ton (10,500-11,500 Btu/lb).*

A second important point to note regarding the two data sources concerns the allocation of coal of unknown sulfur content. As noted in the model documentation and displayed in Table 4-2, the tape tends to report much more coal of unknown sulfur content than the publications. This difference can be easily seen by comparing the regional totals, where in general the tape reports about twice as much coal of unknown sulfur content as the publications. State totals vary significantly as well. In West Virginia, North for example the tape shows that 41% of the

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*Although the tape provides three categories of bituminous coal, the publication lists only one; therefore for the comparative purposes of Table 4-2, the three tape classes of bituminous coal were aggregated.

Table 4-3

BOM Definitions of Coal Classification

<u>Anthracite</u>	A hard, black lustrous coal having 92 percent or more but less than 98 percent fixed carbon, and 8 percent or less but more than 2 percent volatile matter, on a dry, mineral-matter-free basis.
<u>Semianthracite</u>	A coal intermediate between anthracite and bituminous coal. It is nonagglomerating and contains 86 percent or more but less than 92 percent fixed carbon, and 14 percent or less but more than 8 percent volatile matter, on a dry, mineral-matter-free basis.
<u>Bituminous</u>	A solid, brittle coal relatively high in gaseous constituents and having 69 percent or more but less than 86 percent fixed carbon, and 31 percent or less and more than 14 percent volatile matter, on a dry, mineral-matter-free basis. The calorific value ranges from 10,500 to over 14,000 Btu per pound on a moist, mineral-matter-free basis, but the calorific value does not determine the classification provided the fixed carbon is 69 percent or more; it is commonly agglomerating. Coal of a Btu content in the range of 10,500 to 11,500 per pound, and nonagglomerating, is classified as subbituminous.
<u>Subbituminous</u>	Coal of a rank greater than lignite but less than that of bituminous coal and distinguished from lignite by its black color and its lack of a distinctly woody structure and texture, and from bituminous coal by its loss of moisture and slacking when exposed to weathering. Fixed carbon is less than 69 percent, and volatile matter is more than 31 percent on a dry, mineral-matter-free basis. The calorific value and nonagglomerating characteristic determine the classification provided the fixed carbon is less than 69 percent.
<u>Lignite</u>	A brownish-black coal in which the alteration of vegetal material has proceeded further than peat but not so far as subbituminous coal. The Btu content is less than 8,300 on a moist, mineral-matter-free basis.

Source: BOM Publication IC (8680) pp. 31 & 32 total coal is of unknown sulfur content while the publications show only 13.7% in that category. Other states with pronounced percentage differences are Kansas, North and South Dakota, Northern Colorado, Utah, Washington, and Alaska. This difference in the amount of coal considered to be of unknown sulfur content amounts to a significant quantity at the national level. The tape reports 102,669 x 10^6 tons, while the publications report only 50,012 x 10^6, a difference of over 50 billion tons of coal. Less important, on the tape the coal of unknown sulfur content is not identified by its classification (bituminous, subbituminous, or lignite), but is considered as an unclassified total, while in the publications coal of unknown sulfur content _is_ identified by classification. Thus, the publication reports less unknown coal, but at a greater level of detail.

Another minor disparity between the two data sources is that in many regions the publications show a greater diversity of coal type; for example the tape shows Alaska having only subbituminous reserves, while the publications indicate Alaskan reserves in the bituminous, subbituminous and lignite categories. The publications also list coal in states not indicated on the tape. These states are Georgia, Michigan, North Carolina, and Oregon; this coal is mostly bituminous and amounts to only about an additional 152 million tons (see Table 4-4).

While the details differ between the two data sources, the state and national totals for coal are very similar. The national total in the publications is 3,262 x 10^6 tons larger than that on the tape, a difference of less than one percent between the two sources. Looking just at the total coal quantities, the modelers' choice of the tape over

Table 4-4

Coal Tonnage Figures Not Included

In the BOM Coal Reserves Tape

State	Publication (not listed on tape) (10^6 short tons)							
	Bituminous		Sub-bituminous		Lignite		Unknown	Total
	Unknown	Total	Unknown	Total	Unknown	Total		
Georgia	.17	.50					.17	.50
Michigan	7.03	118.20					7.03	118.20
North Carolina	31.62	31.62					31.62	31.62
Oregon	.00	.46	.00	1.40			.00	1.86

the publications does not appear to be of great consequence. However, to the extent that the other differences between the two data sources are important to the model (particularly the coal heat content and the distribution of coal of unknown sulfur content), that choice could have an impact on model results.

Once the sulfur content was determined from the BOM data tape, it was converted from percentage content to pounds per MMBtu, using the calculated average Btus for the region. Further, sulfur content was adjusted under the assumption that "a standard level of cleaning" was applied to all bituminous coals. Citing the BOM RI 7633 "Sulfur Reduction Potential of Coals in the United States" (RI 7633), the following reduction factors were applied.

- $\geq$ 2.5 lbs/MMBtu -- 35% reduction
- .84 - 2.5 lbs/MMBtu -- 15% reduction
- .61 - .83 lbs/MMBtu -- 5% reduction
- $\leq$ .6 lbs/MMBtu -- 0% reduction

Finally, in the Central West region both bituminous and lignite coals were adjusted by the above sulfur reduction percentages since in that region the subbituminous coals can in fact be beneficiated.

Thus the basis for the allocation of BOM-demonstrated reserves to NCM supply regions and coal types is the BOM Reserves tape classifying coal types by average Btu content, and significantly adjusting sulfur content downward under the assumption of standard cleaning. Reviewing BOM RI 7633, it is difficult to ascertain why the particular percentage reduction factors were employed. The sulfur reduction potential reported there seems to vary substantially by region, and no effort is devoted to developing average or "standard" sulfur reduction estimates. Most importantly, sulfur reduction potential appears to depend upon the yield factor chosen, that is, how much coal is lost during the cleaning process. In general, higher yields are associated with lower sulfur reduction potential. The particular factors chosen by ICF and employed in ARC-78 are nowhere explained in any documentation we have reviewed, and do not appear to be justified by RI 7633.

(2) Estimating 1980 mine capacity

1980 mine capacity is derived based on an estimate of 1975 production capacity by region, coal type and method of mining, to which is applied an estimate of mine closings between 1975 and 1980. 1975 production capacity by region, coal type, and method of mining (surface vs. deep) was estimated by using BOM weekly production reports aggregated to NCM regions, and distributed by heat and sulfur content. The distribution was obtained by use of the FPC's form 423 data for 1974 scaled to be consistent with the national estimate of utility coal shipments in 1975. Characteristics for non-utility coal shipments were based on the BOM's "Bituminous Coal and Lignite Shipments by Ranges of Sulfur Content Calendar 1970" classified by NCM sulfur category and region.

Classification by Btu content was assigned (no source), with coking and export shipments assigned to the Z category (BTU content ≥ 26 million per ton) and the residential/industrial assigned to the H category (23-26 MMBtu per ton). Non-utility coal shipments were scaled up from 1970 to the national estimate in 1975. The estimated distribution by heat and sulfur content was then used to distribute the actual production in each NCM region. If this procedure produced an estimate of production when in fact no reserves for that coal type existed within the region, a stepwise adjustment procedure was applied, in which first the sulfur level was held constant and the Btu content was allowed to increase or decrease by one category. But if this did not resolve the problem, then a similar one-step procedure was made in sulfur content. If the problem still remained, the coal type was changed to that type requiring the fewest "jumps" in heat and sulfur content category.

Finally, regional production was distributed by mining procedure based on the proportion of surface-to-total reserves.

No adjustment was made to account for the condition of capacity significantly exceeding production in 1975, and no documentation is provided to argue the case that the coal industry was producing everywhere at maximum capacity in 1975. Regional depletion rates are based on ICF's estimates of large mine closings by MEFS regions, 1976-1980. The "estimated production losses" for each MEMM region are applied to each NCM region within the MEMM region. The assumption is that small mines had zero depletion in this period.

Summary

The estimated 1980 capacity is based upon a 1975 estimate of production adjusted for retirements between 1975 and 1980. The 1975 production estimate is based on various data sources for 1970-1975, and employs a fixed proportion distribution procedure and various scaling adjustments to achieve the 1975 estimate. The procedures are well documented in the ICF report, but little justification is given, and no information is provided on what the confidence intervals might be for the 1980 estimate of capacity.

(3) 1980 Coal Prices

Estimates of the 1980 coal prices are based upon 1973 average coal prices by NCM region, inflated by the GNP deflator to 1975, and then further inflated to 1980 by undocumented functions of the separate inflation rates for the labor and supply components of coal production factors. A set of fixed factors is applied to distinguish contract from spot coal average coal prices. The documentation develops an argument that 1980 selling prices are a relatively unimportant data input as long as the variable costs of production -- the correct price for existing mines -- do not exceed the estimated selling price.

(4) Allocation of Reserves to Model Mine Types

Given reserves by region and coal type, the next step is to allocate these reserves. NCM documentation describes this process in terms of eight steps.

Step 1: Estimate and remove the reserves committed to existing mines from the demonstrated reserve base. Committed reserves were estimated by assuming that 1980 production rates would continue through 1990, summing these production rates, and then adjusting the cumulative production by a recovery factor. Recovery factors of .8 and .6 were assumed for surface and deep mines, respectively. This procedure assumes that no committed reserves exist beyond 1990 for large mines. The treatment of small mine production is ambiguous, but apparently is assumed to continue indefinitely.

Step. 2: Remove those stripable reserves that are illegal to mine. Arbitrary adjustments are made to the demonstrated reserve base to eliminate coal reserves which are either illegal or impractical to mine, including those under highways, urban areas and parks. The arbitrary adjustment factors are as follows:

- 25% of stripable uncommitted reserves -- Illinois, Indiana, Kentucky (West)
- 15% of stripable uncommitted reserves -- Pennsylvania, Ohio, West Virginia (North and South), Virginia, Kentucky (East), Tennessee, Alabama, Iowa, Missouri, Kansas, Oklahoma, Arkansas.
- 10% of stripable uncommitted reserves in Texas, North Dakota, South Dakota, Montana (East and West), Wyoming, Colorado (North and South), Utah, Arizona, New Mexico, Washington, Alaska.

Step 3: Distribute uncommitted stripable reserves to overburden categories. The NCM has seven categories of overburden ratios (5:1, 10:1, 15:1, 20:1, 25:1, 30:1, and 45:1). Reserves which exceed a 45:1 overburden ratio are assumed uneconomic to mine under any circumstances. The procedure is as follows: The average overburden ratio for coal mined in 1977 by PIES region is taken from earlier PIES documentation. The marginal overburden ratio is assumed to be 15% greater than the 1970 average value, with exceptions in the Central West (2.7%), Eastern Northern Great Plains (7.1%), and Alaska (-4.8%). The estimated upper limit on overburden ratio by region was based on Bureau of Mines information used in estimating the stripable reserves. The uncommitted stripable reserves are allocated to the seven categories falling between the marginal overburden ratio and the maximum overburden ratio, using a uniform distribution. Reserves thus allocated to an overburden ratio greater than 45:1 are assumed to be uneconomic. No documentation of the 15% difference between the 1970 average and the 1980 marginal overburden ratios is provided, nor is any support given for employing the uniform distribution.

Step 4: Distribute the uncommitted stripable reserves to mine size categories. Five mine size categories are employed, including .1, .5, 1.0, 2.0, and 3.0 million tons per year. The distribution is based upon ICF review of the size of mine planned through 1980. The largest planned strip mine within each NCM region sets the upper size for strip mines, except in the West where 90% of the reserves were assigned to the three largest mine sizes. Except for the west, the uniform distribution was employed.

Step 5: Distribute the uncommitted deep reserve to seam thickness categories. Again, the average seam thickness mined in 1970 is used as a starting point for projecting the marginal seam thickness of uncommitted deep reserves, and then distributing uncommitted reserves uniformly between the marginal and minimum seam thickness. In general, 28 inches was taken to be the minimum seam thickness, with exceptions in Wyoming and for several coal types where additional information on distribution is available.

Step 6: Distribute the uncommitted deep reserves to seam depth categories. Here the depth categories and distributions are the same as those used in the PIES coal supply curves: drift, 400, 700, and 1000 feet below the surface. No documentation for the basis of this assumption is provided.

Step 7: Distribute the uncommitted deep reserves to mine size categories. Assignment of reserves to mine size categories reflects the assumption of lower productivity per section shift in thinner seams and the limitation on the number of sections that can be effectively managed. The distribution factors are presented in Table 4-5. No documentation is provided for these distribution factors, nor is any justification given for the truncated uniform distribution employed.

Table 4-5

DISTRIBUTION FACTORS USED TO ASSIGN RESERVES TO MINE SIZE CATEGORIES

Seam Thickness Categories (in inches)	Mine Size Categories (10^6 tons per year) 0.1	0.5	1.0	2.0
≥ 72	.250	.250.	.250	.250
60-71	.334	.333	.333	-
48-59	.334	.333	.333	-
36-47	.500	.500	-	-
26-35	.500	.500	-	-

Source: ICF [1977, Table III-20, p. III-46].

Step 8: Change the stock of reserves into potential production flows. Stocks of reserves were transformed into production flows by assuming a constant mine life and recovery factor for all reserves. Initially, a twenty year mine life was assumed, although in subsequent applications of this model the mine life has been adjusted to thirty years. A recovery factor of .8 for stripable reserves and .6 for deep reserves is assumed. No documentation is provided regarding either the mine life or the recovery factors, and in particular justification is not provided for the assumption that production rates do not vary in terms of any of the coal characteristics data.

The "lumpiness" of the various mine size categories versus reserves is dealt with by disallowing "fractional mines" by redistributing fractional reserves to the next smallest mine size category.

(5) Estimation of Minimum Acceptable Selling Price

The NCM concept of the minimum acceptable selling price is a key concept and variable in the model. This price represents the supply price of coal at which an owner of coal resources will choose to open a mine committed to producing at a constant production rate for a fixed life of the mine.

The NCM supply price for coal is defined as the average revenue per ton (sales/production) required to cover capital costs plus a specified rate of return (nominal 15%, ARC-78), depletion and taxes, and operating costs. The supply price is measured as an annuity reflecting the inflation in deferred capital costs from the date of mine opening, plus inflation in the operating costs. The concept of an annuity price is critically important here since this is the means by which the NCM includes temporal information about future costs in a static LP framework in which a mine opening decision must be made in the case year. Since MEMM involves the same static LP framework, the importance of the annuitized price applies here as well.

The approach to measuring the supply price by mine type and coal characteristic is as follows. Two model mines are defined, including:

- a slope mine producing a million tons per year from a 6 foot coal seam 700 feet below the surface using continuous mining and having unit-train loading facilities, but no cleaning plant.
- an area (surface) mine producing one million tons per year working a 6 foot coal seam with a 10:1 overburden ratio and having unit-train loading facilities but no preparation plant.

The costs of production for these two mines are based on studies by the Bureau of Mines and by TRW, plus interviews with mining engineers and coal economists. The cost characteristics for the two model mines are summarized in an income statement which is presented as Table 4-6. The key features of this income statement are as follows:

- a nominal rate of return on capital of 15% is assumed;
- operating costs are based on estimates of labor costs and costs of power and supplies, and output, all using fixed percentages or cost factors as shown in Table 4-6. These cost factors are constant across regions of the country, mine types, and coal types.

The costs associated with mine types and coal characteristics, other than the model mines, are based on cost adjustment factors developed from the BOM and TRW studies mentioned above. These cost adjustment factors relate the key variables of initial and deferred capital costs, output/man-day, and power and supplies to:

- seam thickness and depth, and annual output for drift and deep mines,
- overburden ratio and annual output for surface mines.

In addition to these production costs, two types of cleaning costs are included as operating expenses: basic cleaning costs and deep cleaning costs. Each of these types of cleaning involves costs and losses. The basic cleaning costs are based on 1971 data from a MITRE study ("The Physical Desulfurization of Coal--Major Considerations for SO_x Emissions Control," June 1971). These costs ($.76 - $1.30) are updated to 1975 prices by assuming that O&M accounts for 45% and capital for 55% of the costs. For basic cleaning, the 76¢ cost is inflated to 1975 dollars; for the deep cleaning options, the $1.30 cost is similarly inflated.

The basic cleaning is assumed to result in losses of 30% of tonnage in the Appalachian regions and 20% in other regions. These percentage losses are based on BOM "coal--bituminous and lignite in 1974," which considered Appalachian and Midwestern cleaning losses. Deep cleaning losses are assumed to involve an additional 10% tonnage reduction.

An important variable in measuring costs is labor productivity. The estimate used in the NCM is based on the 1972-73 average man-days work by MEFS region for deep and strip mines. It is our understanding that no technical progress in the form of changes in labor productivity is included in the ARC-78 application of NCM.

Table 4-6

COSTING SUMMARY OF BASE CASE MODELS
(in thousands of dollars)

	Underground Mine*	Strip Mine**
Initial Capital	$29,300	$17,000
Deferred Capital	11,700	3,200
Present Value, Capital Investment	34,729	19,185
Cash Flow (Includes net profit, depreciation and maximum allowable depletion)	3,537	1,954
Sales***	13,980	7,157
Operating Costs	11,997	5,945
Gross Profit	1,983	1,212
Depletion	991	606
Profit Before Tax	991	606
Federal Income Tax	496	303
Net Profit	496	303
Selling Price ($/Ton)	13.98	7.16
Operating Costs		
Labor	3,120	1,352
Power and Supplies	2,835	1,226
Payroll Overhead (.4 x Labor Cost)	1,248	541
Union Welfare ($.80 x Annual output-strip) ($1.04 x " " -deep)	1,040	800
Royalty ($.20 x Annual output tonnage)	200	200
Licenses ($.10 x Annual output tonnage)	100	100
Indirect Costs (.15 x Labor, supply costs)	818	327
Taxes and Insurance (.02 x Initial capital cost)	586	354
Depreciation (.05 x Initial capital plus deferred capital costs)	2,050	1,045
Total Operating Costs	11,997	5,945
Output/Man day (Tons)	17.3	57.0

Notes to Table 4-6 on next page.

Source: ICF [1977] pp. III-50, 51.

Notes to Table 4-6

* A slope mine producing a million tons per year from a six-foot coal seam 700 feet below the surface using continuous mining and having unit-train loading facilities but no cleaning plant.

** An area mine producing one million tons per year working a six-foot coal seam with a 10:1 overburden ratio and having unit-train loading facilities but no preparation plant.

*** It was assumed that the federal income tax equalled half of the taxable income and that depletion equalled 10 percent of sales up to 50 percent of gross profit. Total sales were estimated using one of the following two equations:

$$\text{Sales} = \frac{(.5\ \text{Operating Costs} + \text{Cash Flow} - \text{Depreciation})}{.55}$$

assuming depletion equalled 10 percent of sales, or

$$\text{Sales} = \text{Operating Costs} + \frac{4(\text{Cash Flow} - \text{Depreciation})}{3}$$

assuming depletion equalled 50 percent of gross profit, depending on which assumption represented the binding constraint for the mine type being considered. In each case, however, it was a necessary condition that cash flow equal the sum of depreciation, depletion, and profit after tax. The minimum acceptable selling prices equals sales divided by the assumed annual output level of the mine being costed.

Source: ICF [1977] pp. III-50, 51.

The model also accounts for state severance taxes in the form of percentage of output price. However, not all severance taxes have been represented for the model in this way. At present, the following percentage costs by NCM region are included:

Kentucky (East and West)	4%
Montana (East and West)	30%
Wyoming	2%
West Virginia	3.85%

ICF [1977, p. III-54] indicates that severance taxes for other states have not been added into the model data base as yet. These include:

Alabama	13.5 ¢/ton
North Dakota	50.0 ¢/ton
Ohio	4.0 ¢/ton
Oklahoma	0.75¢/ton
South Dakota	4% of net profits
Tennessee	20.0 ¢/ton

These taxes are based upon "Coal Outlook," February 16, 1976 (p. 3). Whether changes have occurred or new taxes have been imposed since then is unknown. Also, whether EIA has incorporated those taxes not included in the ICF data base is unknown. None of the supporting documentation to ARC-78 comments upon these issues.

The above description provides the basic structure and information used in developing the costs of coal production. As noted, a distinguishing feature of the NCM is that these costs are integrated into a measure of the supply price of coal by discounting over the life of the mine, and then representing the supply price as an annuitized price. Thus cost streams over the life of the mine are discounted to the date of the mine opening, and annuitized. It is the real annuitized coal price which is taken to be the supply price of coal, and which is the key variable in determining mine openings.

Based on the above discussion, there are two points to keep in mind concerning the real annuity coal price as a measure of the supply price of coal. First, there is a problem with the fact that the deep cleaning option must be treated in the annuitizing process; yet the decision whether or not to deep clean depends upon the cost minimization process in the static linear programming portion of the NCM, a process which uses the real annuity coal price for different mine and coal types as an input. This problem is discussed in the verification section.

Perhaps more fundamentally, the use of the real annuity coal price as the supply price for coal in the NCM means that to compare coal prices with other fuel prices requires that other prices also be represented as annuity prices. Thus,

> "The use of the annuity prices for coal has ramifications throughout the NCM. All variable prices must be annuitized. For the 1980 case all prices (e.g., oil/gas prices, coal transportation costs, and electric utility O&M costs) are assumed to increase at the 5% annual inflation rate."

While we have not examined other fuel supply models, or the electric utility submodel of the MEMM system, it is our impression that the annuitized prices are not used elsewhere in MEMM. We can find no discussion of how this problem of different measures of fuel and variables costs is dealt with. We conclude that there may be a serious incompatibility between the measures of fuel costs in the various models comprising MEFS, complicating the comparison of fuel costs, as well as the interpretation of results.

Summary

In this section we have reviewed the data inputs and outputs of the coal supply portion of the NCM. This review follows closely the documentation in Section III of ICF [1977]. As noted, it is our understanding that this is the data base underlying the coal supply portion of ARC-78. In particular, it is our understanding that the various data extensions and improvements discussed in Appendix E of ICF [1977] are not included in the ARC-78 analysis.

As can be seen, the coal supply data base underlying the NCM is based on relatively little independent source data. The most solid data are the Bureau of Mines demonstrated reserve base, but even here there is a serious question raised by the incompatibility between the published data and those data provided on the BOM demonstrated reserve computer tape, the latter being employed in ARC-78. Beyond that, the model data base is based on many assumptions and synthesized adjustment data and parameters; as noted, it also makes wide use of the uniform distribution when no information is available to distribute a resource in terms of some particular characteristic.

How reliable is this data base? We cannot be certain, nor can we put a direct confidence measure on the data base. However, in Section 5, we report sensitivity results obtained by varying assumptions underlying the NCM data base. The evidence presented there is disquieting with regard to the reliability that may be attached to this data base.

4.1.3 Specific Adaptations of the NCM Data Base in ARC-78

The various scenarios of ARC-78 involve some changes in the coal supply data base between scenarios. Differences may be summarized as follows:

Geologic Reserves: The high scenario here is taken to be 425 billion tons. This estimate is equal to the Bureau of Mines total demonstrated reserve base, undifferentiated by quality. The medium level is 322 billion tons, which is the Bureau of Mines demonstrated reserve base for coal reserves differentiated by heat and sulfur content quality. There is an undocumented process which was required in order to distribute the reserves of unknown quality to appropriate coal type and mine size categories.

Operator Efficiency: The operator efficiency differences were introduced into the ARC-78 analysis. The efficiency factors are treated as constant over time, but they differ by region as follows:

Appalachia	.65
Midwest	.75
West	.85

Limited Western Coal Production: An assumption is made in Scenario D that Great Plains coal production is limited to 394 million tons in 1985 rising to 800 million tons in 1995.

In addition to these scenario differences, the ARC-78 report updates the ICF data on labor costs to reflect the 1978 United Mine Workers wage agreement, and introduces an 8.5% increase to account for an expected real labor cost escalation between 1981 and 1985. In Scenarios B and E labor costs are assumed to increase 26% to account for real escalation between 1981-1990.

In Scenario C, capital costs are based upon 1977 estimates with no real escalation assumed. However, in Scenarios B and E, capital costs are assumed to escalate at 10%.

4.2 Logical and Mathematical Structure

In EMAP [1980], three structural issues relating to the CSM/NCM were identified including (i) treatment of royalties and dynamic rent; (ii) coal production costing; and (iii) the relationship between mine lifetime and coal production rates.* In this section we review these issues in terms of their influence upon ARC-78; in Section 5 we present computational results suggesting the uncertainty introduced by the CSM/NCM treatment of these issues, and the sensitivity of results to plausible changes in structure and underlying data.

4.2.1 Coal Royalties and Rents

In a competitive economy two types of scarcity rents or royalties accrue to the owners of coal reserves: static and dynamic. Static rents occur because of differences in extraction and delivery costs of coal types being mined at a given time. The lower-cost deposits earn a static rent, which is represented by the vertical distance between the corresponding point on the supply curve and the market price. Static rents should not be included as a cost in constructing supply curves.

Dynamic--or intertemporal--rents result from the fact that exploiting a resource at one point in time prevents its exploitation at a future time. The higher the expected future price of coal, the greater is the intertemporal rent. Coal supply curves must reflect the intertemporal rent, because it must be paid to the owners of all currently operating mines, even the marginal mines.

When observable in market data, intertemporal rents appear as a portion of the royalty payments made by mine operators to the owners of mineral rights. However, because mine operators often own the mineral

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*Much of this material is taken, or abstracted from EMAP [1980].

rights, intertemporal rents are frequently implicit and cannot be directly observed. Nevertheless, the price the mine operator receives for coal must cover both implicit and explicit intertemporal rents if the operator is to be willing to work the mine. For this reason, in deriving the supply function intertemporal rents should be imputed whenever they cannot be measured.

There is no imputation of rents in the CSM/NCM, nor in the MEMM underlying the ARC-78 midterm projections. While the CSM has provisions for including royalties in the coal supply cost function, royalty payments are always set at zero in supply regions not dominated by federal coal lands. Thus, the model omits even explicit non-federal royalty payments, while the possibility of imputed rents is not mentioned. In regions dominated by federal lands, royalty payments at federal rates are included. In Manove [1980b] a simple model of the generation of intertemporal rents was constructed and analyzed using NCM data to produce crude estimates of these rents. Ten percent of the mine-mouth price was used as the estimate for rents.

4.2.2 Coal Production Costing

The NCM procedure for calculating costs of potential coal production in any case year is based upon an engineering cost analysis of two "base case" model mines, one surface and one deep.

> A matrix of adjustment factors is used to modify the base-case mine costs as the overburden ratio, seam thickness, seam depth, or mine size changes between model mine types. The base-case cost models were developed from existing mine cost studies by BOM and TRW, and from information obtained through interviews with mining engineers and coal economists. For underground operations the base-case mine was defined as a slope mine producing one million tons per year from a six-foot coal seam 700 feet below the surface using continuous mining and having unit-train loading facilities but no cleaning plant. For surface mining operations the base case was a one million tons per year area mine with a 10:1 overburden ratio and

> having unit train loading facilities but no preparation plant [ICF, 1977, pp. III-47-48].
>
> The actual matrix of cost adjustment factors employed are given in Table 4-7. These factors were developed from examination and comparison of existing mine cost models and consultations with a mining engineer and the BOM Process Evaluation Group in Morgantown, West Virginia. Changes in values for initial capital, deferred capital, and power and supplies resulting from variations in mine-type parameters were substituted directly into the costing equations specified for the base-case calculations. However, the cost effects of changes in output per man day were computed by dividing the adjusted productivity figure into the annual output level assumed for the mine and multiplying the resulting number of man days per year by the average labor cost per man-day estimated from the base cases [ICF, 1977, p. III-50].

The NCM essentially specifies the cost function by coal type analytically, with cost parameters specified exogenously. However, the model does not use an explicit engineering cost function that directly relates average cost (i.e., minimum acceptable real annuity coal price) to a mine's physical variables. Beginning with the matrix of cost adjustment factors (see Table 4-7), real annuity coal prices (RACPs) are determined sequentially in the Supply Code component by component. The underlying cost function is only implicit.

EMAP analysts developed and programmed the analytical formulation of both the NCM's implied engineering cost function for both surface and deep mines and the associated cost elasticities relating real annuity coal prices to each of the physical variables characterizing coal deposition. This was verified by duplicating to five decimal places both the uncorrected and corrected base case calculations of coal supply prices.

Table 4-7

A Matrix of Mining Cost Adjustment Factors for Key Variables

	Initial Capital	Deferred Capital	Output/Manday[1]	Power and Supplies
nderground Mines[2]				
Seam Thickness	+6%/ft. decline in thickness	+6%/ft. decline in thickness	-1.0/TPMD/ft. decline in thickness	+$0.15/ton/ft. decline in thickness
Seam Depth	$500,000/100 ft.	--	--	--
Annual Output	30%/MMTPY	15%/MMTPY	0.5TPMD/0.1MMTPY	100%/MMTPY
Drift Mine	-$6,000,000	-$3,000,000	+10%	--
Conventional Mining	3/	3/	--	--
urface Mines[4]				
Overburden Ratio	$1.20/Ton/UOR	$0.25/Ton/UOR	10%/5UOR	$30,000/UOR
Annual Output:				
Mines ≥ 1.0MMTPY	5/	5/	3TPMD/0.1MMTPY	100%/MMTPY
Mines < 1.0MMTPY	-5%/0.1MMTPY	-5%/0.1MMTPY	3TPMD/0.1MMTPY	100%/MMTPY

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[1] The cost effects of changes in output per manday are calculated by dividing the estimated tons per manday figure for gives mine type into the mine's annual output level to get the total number of mandays per year and then multiplying that figure by the average labor cost per manday (i.e., $53.98 for underground mines and $77.12 for surface mines). Note that output per manday is calculated based on the total number of mandays worked by all classes of mine employe in one year.

[2] Variations for underground mines are calculated from a base case operation which is defined as one million ton per y slope mine working a six foot seam seven hundred feet deep using continuous mining and having unit train loading fac ties, no cleaning plant, and an average output per manday of 17.3 tons.

[3] Initial capital (less the cost of required shafts) and deferred capital investment costs for mines producing less th one million tons per year are assumed to remain constant on a dollars per ton of annual output basis with the capita costs after all other adjustments are made for one million ton mine with the same characteristics. This assumes tha the capital intensity of mines with annual output levels of less than one million tons decreases with size.

[4] Variations in surface mine costs are calculated from a base case mine defined to produce one million tons per year f a six foot seam with a 10:1 overburden ratio using area mining techniques and having unit-train loading facilities b not preparation plant.

[5] The capital costs for surface mines producing over one million tons per year are assumed to experience increasing ec mies of scale with respect to capital costs. To reflect this the incremental capital required for each million ton increase in annual output is assumed to decline ten percent from the capital costs for a one million ton per year op tions. Thus, capital costs for a two million ton per year mine would equal 1.9 times those for a one million ton mi and capital for a three million ton per year operation would equal 2.7 times those for the one million ton mine.

ABBREVIATIONS:
TPMD = tons per manday
MMTPY = million tons per year
UOR = units of overburden ratio.

Source: ICF [1977], p. III-52.

4.2.3 Potential Coal Production Rates and Mine Lifetime*

Given the distribution of coal reserves and mining recovery factors, the key variable determining the level of potential coal production is the mine lifetime. Mine lifetime affects supply in two ways. First, because it is inversely proportional to the rate of extraction from a given parcel of reserves, it determines the intensity with which a parcel of reserves is mined. Second, it affects the unit cost of coal production from a given parcel of reserves. Longer lifetimes lead to lower extraction costs due to lowering annualized capital requirements. However, long lifetimes delay the realization of revenues, thus imposing a "waiting" cost on the operator.

If a given segment of a coal supply curve represents coal extractable from a given parcel of reserves, a change in mine lifetime will affect the length of that segment through its effect on rate of extraction, and the height through its effect on costs. Thus, the effect of mine lifetime on the rate of coal extraction can dramatically alter the supply curve. For example, when a mine lifetime of 20 years is changed to 30 years, each supply curve for coal is contracted along the horizontal axis by 33 percent.

Examples of coal supply curves in Figures 4-1 and 4-2 illustrate this effect. In each case, the change in lifetime causes the supply curves to shift from S to S'. D denotes the demand curves and E and E' denote the old and new market equilibria, respectively. Note that whether the effect of such a change in lifetime on the market equilibrium prices and quantities is substantial depends on the elasticity of supply. In Figure

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*This material is abstracted from EMAP [1980].

Figure 4-1

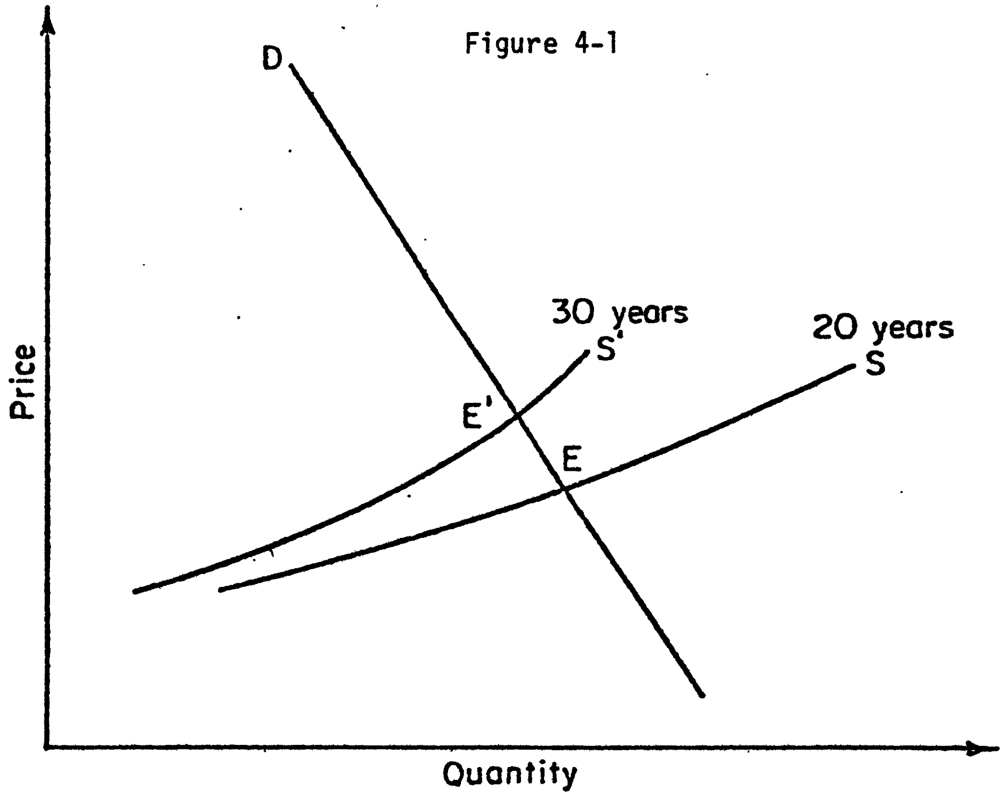
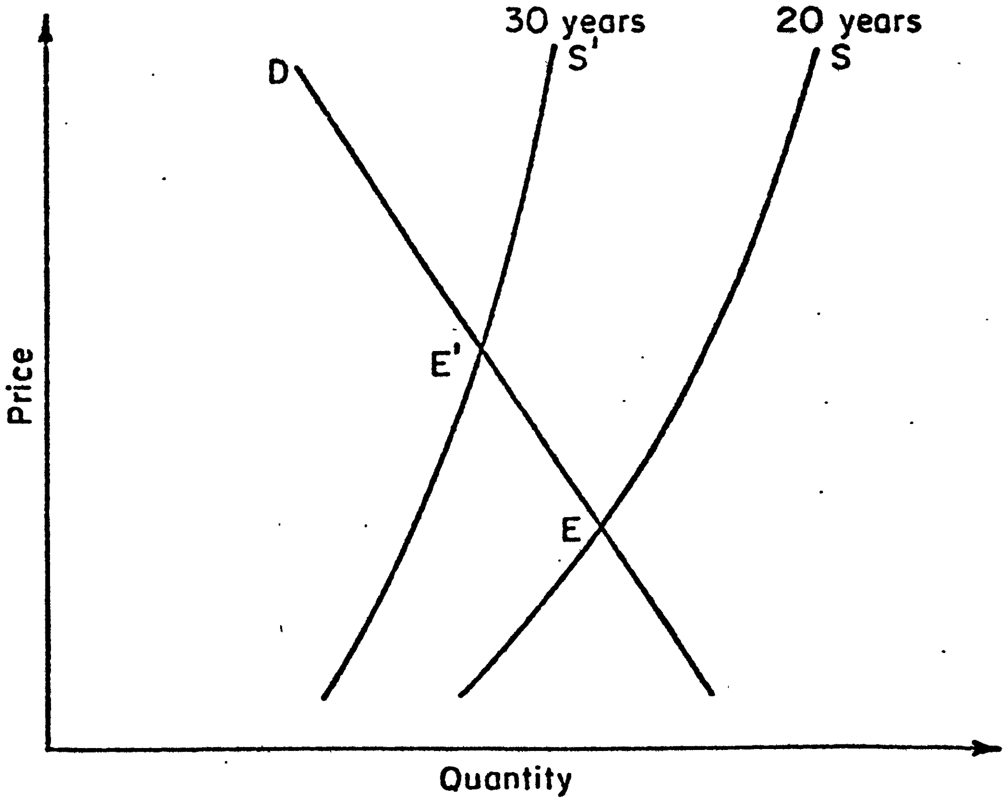


Figure 4-2



4-1, where the supply curves are highly elastic, the shift from a 20- to a 30-year lifetime has little effect on the market equilibrium. However, in Figure 4-2 where the supply curves are inelastic, the effect of the shift is significant.

Because mine lifetime may have a critical influence on coal supply, it is vital to the accuracy of the model results. The CSM/NCM employs a uniform mine lifetime based on the undocumented opinion of mine engineers and on historical data. This lifetime originally was set by the modellers at 20 years, and was then modified to 30 years in later model versions. In the versions of the model considered in this study of ARC-78, the lifetime parameter was set at 30 years.

5. EMPIRICAL ANALYSIS OF KEY UNCERTAINTIES IN DATA AND STRUCTURE

In the previous section several issues relating to the data and logical and mathematical structure of the CSM/NCM were discussed. In this section we report results of some computational experiments investigating the effects upon model results of structural changes, or of plausible changes in the underlying data. In all, five computational experiments are reported including:

-- a change in the coal reserves data based on a random choice from the range of 75% to 150% of the BOM estimates (CDRB),

-- changes in the real escalation for labor costs from +1% to -1% (LABD) and to +3% (LAB3),

-- decrease in mine lifetime from 30 to 20 years (CML20)

-- imposing an estimate of intertemporal rent of 10% in the form of a royalty payment to owners (ROYI)

-- replacing the assumption of a uniform distribution for seam thickness by a truncated lognormal distribution skewed toward the minimum (LOGN).

As in the verification chapter our procedure is to report computational results based on CSM integrated with the ICF CEUM model since we do not have access to the MEMM. Results should be interpreted as only indicative of effects of plausible changes upon ARC-78 results.

Before presenting more detailed results we summarize in Table 5-1 the effects of each change in terms of national coal production and prices, low-sulfur coal production, and coal washing. As the table shows, the effects of these changes in data and structure are mixed, but not trivial. The impact of changes in the real escalation rate for labor are especially dramatic in terms of impact upon coal price. These results also highlight a compositional effect in coal production which occurs whenever the cost share of some input variable varies significantly by

Table 5-1

Effect of Changes in Data and Structure of NCM Upon Selected Variables, 1985

	Production (MMTons) Aggregate	Low-Sulfur	Prices (1978 $/MMBtu)	Coal Washing (MMTons)
CBC	1115.0	284.8	$1.10	17.7

* * * * * * * *

% Change from CBC

CML20	-5%	-5.2%	-2.7%	-67.7%
ROYI	.7	11.8	5.5	-27.2
CDRB	-.1	1.9	-.9	-10.4
LOGN	-.2	3.3	4.6	-9.4
LAB3	2.4	26.4	16.4	-85.9
LABD	-1.0	-6.3	-12.7	11.9

coal type. Note that in LAB3 (LABD) as real wages rise (fall) coal price rises (falls) and both aggregate and low-sulfur production rise (fall). The anomalous rise (fall) in production is due to the fact that labor's cost share in deep mining is greater than in surface mining, and the average BTU content of surface mines that the model chooses is lower than for chosen deep mines. Hence more tons of coal must be produced to obtain a given level of BTU's. In the more detailed results to follow, several of these compositional effects may be observed.

5.1 Sensitivity to Reserve Base (CDRB)*

It was beyond the scope of this project to undertake an investigation of the reliability of the U.S. BOM demonstrated reserve base. It should be noted, however, that a recent report (Major [1979]) undertook a comparison of the demonstrated reserve base estimates between January 1974--the estimates upon which the ICF data base depends (ICF [1977, p. III-6])--and January 1976. The revisions are summarized in Table 5-2 for states having deep or surface reserves exceeding 10 billion tons. While the national totals do not change very much, note that the state distributions do.

In order to examine the effects of uncertainty in the Bureau of Mines reserve base data, a sensitivity run was conducted (CDRB) in which the specified reserve base for each coal type was randomly selected from a uniform distribution whose minimum was 75 percent of the NCM figure and whose maximum was 150 percent of that figure. The confidence interval

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*This and the following sections are abstracted from EMAP [1980].

Table 5-2

COMPARISON OF U.S. BOM DEMONSTRATED RESERVE BASE FOR DEEP AND SURFACE COAL BY LARGE RESERVE STATES: 1974 VS. 1976

	1/1/74		1/1/76		Percent	Percent
	Deep	Surface	Deep	Surface	Deep	Surface
MT	65,165	42,562	70,959	49,610	+9	+17
IL	53,442	12,223	53,128	14,841	< -1	+21
WU	34,378	5,212	33,457	5,149	-3	-1
PA	29,819	1,181	29,303	1,534	-2	+30
WY	27,554	23,674	31,647	23,725	+15	< 1
OH	17,423	3,652	13,091	6,140	-25	+68
CO	14,000	870	12,465	3,791	-11	+335
ND	0	16,003	0	10,145	0	-37
Others	55,454	31,334	52,926	26,426	-5	-16
Total U.S.:	297,235	136,713	296,976	141,361	< 1	+3

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*A state is classified as a "large reserve state" if either Deep or Surface reserves exceed 10 billion tons.

Source: Major [1979]

used in CDRB is based upon an inspection of Table 5-2 and consultation with Professor Richard L. Gordon of Pennsylvania State University.

The results of the CDRB experiment indicate a significant impact upon regional coal productivity and to a lesser extent on prices (see Table 5-3). The production Deviation Indexes are the second highest in 1985 of all runs.*

The results of the CDRB model runs show substantial increases in the production of high-quality coal and in coal with low extraction costs. This is because, on the average, the specified reserves of all types of coal were increased, while overall demand remained unchanged. Therefore, in the model solution, less expensive coal was substituted for more expensive coal, and higher-quality coal was substituted for lower-quality coal. The pattern of percentage changes in production and prices by coal type presented in Table 5-4 bears out these conclusions.

The reader should not attach undue significance to the particular outcome of choosing reserve levels at random from the uniform distribution, since other outcomes would have produced different results. Our purpose here is to provide some indication of what effect uncertainty in basic reserve data might have on ARC-78 results.

**The average Deviation Index is defined as the average change in the absolute value of a quantity (price) between two model runs weighted by the original price (quantity). The measure is unforgiving in that absolute values of differences are accumulated. In this sense it is comparable to similar measures such as the root mean squared difference. For example, consider the value of the index for an aggregation over two regions and a change in quantity between two runs. Assume the original price is 1 in both regions, that the original quantities are 50 and 100 respectively, and that the new quantities are 55 and 95. Then the percentage value of the Deviation Index is 6.67 even though the aggregate quantity is unchanged. The corresponding value for the root mean squared difference measure is 7.07. For our present purposes, there is no inherent basis for preferring one particular measure over another.

Table 5-3

COAL PRODUCTION AND PRICE DEVIATION INDEXES: CDRB vs. CBC

	1985	1990	1995
Coal Production	9.1	14.8	17.7
Coal Price	1.6	3.0	4.4

Table 5-4

PERCENTAGE CHANGE IN NATIONAL COAL PRODUCTION AND PRICES BY COAL TYPE DUE TO CHOOSING RESERVE LEVEL FROM A "PLAUSIBLE" UNIFORM DISTRIBUTION (CDRB vs. CBC)

National Coal Production (MM Tons)	1985	1990	1995
Metallurgical	6.7	4.5	5.9
Low Sulfur	1.9	4.8	8.5
Medium Sulfur	-3.5	-4.3	-5.5
High Sulfur	-1.4	-1.5	-6.0
Deep	-2.1	-1.9	-1.4
Surface	1.6	2.0	1.5
TOTAL	- .1	.1	.1
National Coal Prices ($ MMBtu)	**1985**	**1990**	**1995**
Metallurgical	-4.0	0.0	-3.8
Low Sulfur	0.0	-5.0	-9.6
Medium Sulfur	-2.9	- .9	0.0
High Sulfur	-1.0	-2.4	-2.3
TOTAL	- .9	-2.6	-4.2

5.2 Uniform Versus Lognormal Distribution for Unallocated Reserves

Next we consider a sensitivity experiment to evaluate the potential impact upon model results of a change in the underlying distribution using allocated unclassified reserves to ARC-78 coal types.

As stated previously, the CSM/NCM incorporates no real data on the distribution of reserves by seam thickness. Because CSM/NCM mine-costing algorithms require such data, seam thickness is arbitrarily assumed to be uniformly distributed between the minimum (28 inches) and maximum (72 inches) values for which the Bureau of Mines reports resources. The LOGN sensitivity runs were constructed in order to test the sensitivity of the NCM to the seam thickness distribution. In the LOGN runs, seam thickness is distributed as a truncated log-normal function between the same minimum and maximum as is specified in the Corrected Base Case. The distribution is highly skewed toward the minimum, with the point of truncation being approximately two standard deviations to the right of the mode. It should be noted that because the seam-thickness minima and maxima were not perturbed in the LOGN runs, the output may understate the effect of seam-thickness uncertainty. The LOGN runs are compared with the Corrected Base Case runs in Tables 5-5 and 5-6.

Again, a change in the underlying characterization of the coal reserve data used in ARC-78 leads to significant impacts on the regional distribution of coal production, with lesser impacts on prices. And as with CDRB, the change shifts coal production from inferior to superior coal types and from deep to surface mining.

There are several additional problems with coal reserve data that were not examined via sensitivity runs. For example, data specifying the

Table 5-5

COAL PRODUCTION AND PRICE DEVIATION INDEXES: LOGN vs. CBC

	1985	1990	1995
Coal Production	9.8	15.4	12.3
Coal Price	4.5	2.5	1.5

Table 5-6

PERCENTAGE CHANGE IN NATIONAL COAL PRODUCTION AND PRICES BY COAL TYPE DUE TO ASSUMING A LOGNORMAL DISTRIBUTION FOR SEAM THICKNESS (LOGN vs. CBC)

National Coal Production (MM Tons)	1985	1990	1995
Metallurgical	7.2	6.5	5.8
Low Sulfur	3.5	9.8	2.3
Medium Sulfur	.7	3.3	6.9
High Sulfur	-10.4	-22.5	-13.2
Deep	-5.1	-9.3	-7.3
Surface	3.4	8.6	8.1
TOTAL	- .2	-0.0	.6

National Coal Prices ($ MMBtu)	1985	1990	1995
Metallurgical	2.4	1.1	1.1
Low Sulfur	1.2	-3.8	-2.4
Medium Sulfur	2.9	3.7	-.9
High Sulfur	9.6	5.7	2.3
TOTAL	4.6	.9	-.9

distribution of overburden ratios for surface coal reserves were also estimated in the NCM employing the uniform distribution to distribute resources within the endpoints provided in the BOM data. No computational experiment was conducted relating to the distribution function for overburden ratio.

Another potentially serious problem is the difficulty in deriving data on recoverable reserves from data specifying the reserve base. A 1975 Bureau of Mines publication that presents reserve base data contains the following warning:

> Extreme caution must be exercised in any attempt to translate the underground reserve base into a recoverable reserve figure.... Because of data gaps and inadequacies, it would be very difficult, if not impossible, to accurately quantify the coal unavailable due to multiple beds, thick beds, subsistence considerations, and other factors.

Such warnings by the principal source data organization, coupled with our computational experiments, suggest that extreme caution must be exercised in interpreting ARC-78 results on coal production and prices from the CSM/NCM, or from any other model using these data. This latter point is worth bearing in mind. Any coal supply model, not just the CSM/NCM, must face up to these problems in the quality of the source data.

5.3 Coal Royalties and Rents

To test the potential importance of intertemporal rents on ARC-78 results, a run (ROYI) was made with intertemporal rents set at an estimated 10 percent of coal extraction costs in non-federal regions; royalties in federally dominated regions were left unchanged. The results were compared with the Corrected Base Case model runs for 1985, 1990, and 1995. Differences between the two runs were substantial in each case year.

Introducing estimates of intertemporal rents into coal production costs influences the pattern of production and prices by coal type. Table 5-7 shows that metallurgical production falls in all case years. This is due to the high substitution between these coal types and the fact that metallurgical prices rose relative to low-sulfur prices.

The ROYI market-equilibrium quantities and prices of coal by coal type and supply region were compared to the corresponding CBC values using the Deviation Index (see Tables 5-8 and 5-9). The national average coal price increase was 7.3 percent in 1985 and 6.4 percent in both 1990 and 1995. Coal production changed by an average of 8.8 percent in 1985. On the one hand, coal regions such as Pennsylvania and Ohio decreased production by more than 12 percent in ROYI versus CBC. On the other hand, Western Montana and Colorado South increased coal production by about 23 percent. Coal production by supply region changed by an average of 12.6 percent in 1990 and 10.2 percent in 1995.

As expected, equilibrium prices rise with one exception (low sulfur in 1990) due to changes in the regional shares used to obtain a weighted national average.

Although intertemporal rents should be included in the analysis of the Coal Supply Module, such an analysis is virtually impossible to perform with current structure limitations. Intertemporal rents depend on expectations of the very same future prices that the model is designed to predict. As a result, models including such rents cannot be solved by simple static optimization techniques. The imputation of intertemporal rents together with the solution of the entire model is a dynamic optimization problem, which normally requires the use of dynamic

Table 5-7

PERCENTAGE CHANGE IN NATIONAL COAL PRODUCTION AND PRICES BY COAL TYPE DUE TO INCLUDING AN ESTIMATE OF INTERTEMPORAL RENT IN THE COST OF COAL PRODUCTION (ROYI vs. CBC)

National Coal Production (MM Tons)	1985	1990	1995
Metallurgical	-7.8	-9.8	-8.1
Low Sulfur	11.8	18.5	8.6
Medium Sulfur	-2.2	-2.2	6.9
High Sulfur	-1.5	-10.6	-11.1
Deep	-4.8	-9.0	-8.7
Surface	5.4	11.2	11.9
TOTAL	.7	1.4	1.9

National Coal Prices ($ MMBtu)	1985	1990	1995
Metallurgical	7.2	6.7	8.1
Low Sulfur	1.2	-2.5	1.2
Medium Sulfur	4.9	4.7	0.0
High Sulfur	9.6	8.9	7.5
TOTAL	5.5	1.8	1.7

Table 5-8

COAL PRODUCTION AND PRICE DEVIATION INDEXES: ROYI vs. CBC

	1985	1990	1995
Coal Production	8.8	12.6	10.2
Coal Price	7.3	6.4	6.4

Table 5-9

COAL PRODUCTION PRICES: ROYI vs. CBC

	Coal Prices Aggregate (1978 $/MMBtu)		
	1985	1990	1995
CBC	1.10	1.14	1.18
ROYI	1.16	1.16	1.20
Percent change	+5.5	+1.8	+1.6

programming or an equivalent technique more highly aggregated than the NCM. The rents so calculated could be introduced into the present static version of the NCM as exogenous parameters. As a consistency check, the output of the NCM run with intertemporal rents could then be compared to the output of the more aggregated dynamic model.

Intertemporal rents have a significant role to play in any model focusing on coal, and their omission in the CSM could affect ARC-78 results. This omission in the NCM should be corrected. However, to our knowledge no other supply model of U.S. coal reserves treats the intertemporal rent aspect of production costs.

5.4. Coal Producting Costing*

Examining the analytical cost function and associated cost adjustment factors utilized in the ARC-78 Coal Supply Module of the NCM suggests that an important parameter in the NCM's implicit engineering cost function is the real escalation rate of unit labor costs. This rate is exogenous, and in choosing its value the user/analyst takes into account the fact that the escalation rate implies growth rates for either the rate of growth in labor productivity or in the nominal wage rate. Depending upon which of these rates is taken as given, one determines the other. Thus, if c denotes unit labor cost, w the average wage rate, and v average labor productivity, then $c = w/v$. Therefore, the rate of growth of unit labor costs is the difference between the growth of wage rates and growth of average labor productivity.

In all studies we consider the real escalation rate for labor inputs

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*This section is abstracted from EMAP [1980].

was assumed to be 1 percent/year. However, given the factors underlying such a rate, the assumption that wage rates will grow uniformly 1 percentage point greater than the growth rate of productivity over the next 35 years must be considered highly uncertain. An average unit labor cost escalation of 3 percent/year or -1 percent/year, for example, might be equally plausible. In addition, there is little reason to expect that unit labor cost escalation would be uniform throughout the country. For example, labor market conditions and technological conditions in the West are quite different from those in the East. So, to provide some indication of the impact of unit labor costs on ARC-78 results, two computational experiments were formulated, setting the real escalation rate for unit labor costs at 3 percent/year (LAB3) and -1 percent/year (LABD).

The results of the LAB3 runs indicate that the NCM is quite sensitive to changes in unit labor cost escalation. The Deviation Index shows that equilibrium coal production prices are roughly 25 percent higher in the LAB3 runs than in the Corrected Base Case runs. Solution quantities are about 15 percent smaller. Comparing the LAB3 runs with the Corrected Base Case, Tables 5-10 and 5-11 summarize the most significant results.

For the LABD runs, where labor productivity was assumed to grow 2 percentage points per year more quickly than wage rates, the Deviation Index shows production prices down about 15 percent from the Corrected Base Case, with quantities increased about 10 percent. Comparing the LABD runs with the Corrected Base Case, Tables 5-12 and 5-13 summarize the most signficant results.

Table 5-10

COAL PRODUCTION: LAB3 vs. CBC

	Surface Coal Production (MM Tons)			Deep Coal Production (MM Tons)		
	1985	1990	1995	1985	1990	1995
CBC	600	779	963	515	726	913
LAB3	709	979	1203	433	572	741
Percent change	+ 18	+ 26	+ 25	-16	-21	-19

	Low-Sulfur Coal Production (MM Tons)			Coal Production Detailed (Deviation Index-Percent)		
	1985	1990	1995	1985	1990	1995
CBC	285	460	623	-	-	-
LAB3	360	547	732	-	-	-
Percent change	26	19	18	15	20	19

Table 5-11

COAL PRODUCTION PRICES: LAB3 vs. CBC

	Coal Prices Aggregate (1978 $/MMBtu)			Coal Prices Detailed (Deviation Index-Percent)		
	1985	1990	1995	1985	1990	1995
CBC	1.10	1.14	1.18	-	-	-
LAB3	1.28	1.28	1.38	-	-	-
Percent change	+ 16	+ 12	+ 17	25	24	28

Table 5-12

COAL PRODUCTION: LABD vs. CBC

	Surface Coal Production (MM Tons)			Deep Coal Production (MM Tons)		
	1985	1990	1995	1985	1990	1995
CBC	600	779	963	515	726	913
LABD	561	704	820	543	790	1014
Percent change	-7	-10	-15	+5	+5	+11

	Low-Sulfur Coal Production (MM Tons)			Coal Production Detailed (Deviation Index-Percent)		
	1985	1990	1995	1985	1990	1995
CBC	285	460	623	-	-	-
LABD	267	453	574	-	-	-
Percent change	-6	-1	-8	9	11	13

Table 5-13

COAL PRODUCTION PRICES: LABD vs. CBC

	Coal Prices Aggregate (1978 $/MMBtu)			Coal Prices Detailed (Deviation Index-Percent)		
	1985	1990	1995	1985	1990	1995
CBC	1.10	1.14	1.18	-	-	-
LABD	0.96	1.01	1.05	-	-	-
Percent change	-13	-11	-11	16	15	15

5.5 Potential Coal Production Rates and Mine Lifetime

To form a concrete estimate of the importance of the mine lifetime parameter to ARC-78 projections, a comparison was made of the output of the Corrected Base Case (CBC) version of the model (30-year lifetime) with that of an otherwise identical version with a 20-year mine lifetime (CML20).

This change in the mine lifetime parameter from 30 to 20 years significantly affects the regional distribution of coal production. There is a smaller impact upon regional coal prices. Table 5-14 presents Deviation Indexes for production and prices. The values for the production indexes are the highest of any computational experiment considered in this report.

Table 5-14

COAL PRODUCTION AND PRICE DEVIATION INDEXES: CML20 vs. CBC

	1985	1990	1995
Coal Production	19.2	21.6	20.9
Coal Price	5.3	6.6	7.6

The change also influences the distribution of coal production by coal quality, the primary effect is a significant substitutability from low-sulfur to metallurgical coal. This is the result of a high degree of substitutability between these two coal types and the fact that metallurgical coal prices fall relatively more than low-sulfur prices. Table 5-15 presents these results, together with information on changes in total coal production (very small) and changes in coal prices. The changes in coal prices are, with one exception (low sulfur in 1985 due to changes in coal type and regional mix), consistent with the expectation

Table 5-15

PERCENTAGE CHANGE IN NATIONAL COAL PRODUCTION AND PRICES BY COAL TYPE DUE TO REDUCING THE MINE LIFETIME FROM 30 TO 20 YEARS

National Coal Production (MM Tons)	1985	1990	1995
Metallurgical	7.3	9.2	10.2
Low Sulfur	-5.2	-2.1	-11.5
Medium Sulfur	-1.0	2.7	7.3
High Sulfur	.4	-1.5	-3.0
Deep	-1.8	- .6	2.1
Surface	1.0	2.6	-4.0
TOTAL	.6	1.1	-1.1

National Coal Prices ($ MMBtu)	1985	1990	1995
Metallurgical	-6.0	-7.3	-9.1
Low Sulfur	2.4	-2.5	-2.4
Medium Sulfur	-4.9	-3.7	-2.7
High Sulfur	-3.9	-7.3	-6.8
TOTAL	-2.7	-4.4	-4.2

that costs of production are negatively correlated with mine lifetime, since in the NCM the shorter the mine lifetime, the less capital is required to produce a given quantity of reserves.

These results demonstrate the importance of the mine lifetime parameters and the need for a sound method of determining appropriate values. Several conclusions may be drawn from this analysis. First, mine lifetime should not be assumed uniform. That assumption is no more justifiable than an assumption of uniformity in other mining conditions. Second, the lifetime estimate should not be based on engineering data alone, but should also be treated as an economic variable because of its effect on extraction costs. If mine operators set the lifetime with the intent of minimizing costs, the estimates of optimal (cost-minimizing) lifetimes are appropriate for use in forecasting policy models.

To determine which economic variables affect the optimal mine lifetime and how they affect it, a simple theoretical model of coal extraction was constructed and analyzed (Manove [1980]). The results suggest a surprising hypothesis: The optimal mine lifetime is determined primarily by only two economic variables, the market rate of interest and the capital recoupment period for the mine in question.* Long capital recoupment periods lead to long optimal mine lifetimes, as do low and high interest rates. Intermediate interest rates result in shorter optimal lifetimes.

These results are logical. When a mine is worked over a long period of time, a substantial fraction of the present value of the ultimately extracted reserves is "lost" as a result of discounting future revenues

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*The capital recoupment period is the length of time required to earn net revenues equal to the initial capital investment.

at the market interest rate. If the recoupment period is short (and thus the mine is of high quality), this lost value may be great compared to the initial capital investment. Therefore, there is strong incentive to construct a mine with a short lifetime and high extraction rate. Conversely, if the recoupment period of a mine is long, the value of revenues lost from discounting will be relatively small compared with the cost of the initial capital investment, so there are incentives to construct a mine with a long lifetime.

For very low interest rates, optimal mine lifetime is high because the owner extracts the coal slowly to save on initial capital costs. Over some range, mine lifetime decreases and rate of extraction increases as the interest rate increases. However, as interest rates rise still higher, the present value of any income stream from a mine becomes relatively small compared with initial capital expenditures, so it becomes less desirable to incur high capital expenditures in order to extract the coal more quickly. Thus, as with low interest rates, there is an incentive to reduce initial capital costs, thereby increasing the lifetime of the reserves.

To summarize, the following factors would tend to promote mines with long lifetimes and low rates of extraction by lengthening the recoupment period:

- low quality coal,
- negative mining conditions (bad roofs, thin seams, presence of water or gas, etc.),
- low price of coal, and
- high costs (for labor or other production requirements).

In addition, both very low and very high interest rates would promote long mine lifetimes.

We believe that improving this aspect of the NCM's Coal Supply Module formulation would improve ARC-78 results; at a minimum, the CSM user should be provided with some means to ensure that the assumed mine lifetime for each coal type is consistent with the interest rate, the cost of capital, and the capital recoupment period (the latter determined by the price of coal). One possibility is to reformulate this part of the NCM by making mine lifetime an endogenous variable. Thus, the coal supply functions would be determined simultaneously with utility coal demand and, therefore, with the price of coal. We have not pursued such a formulation in this report, but anticipate that it would be very difficult and would significantly change the operating characteristics of the Coal Supply Module.

A more modest proposal would be to formulate and implement an auxiliary model that included the variables necessary to endogenize the mine lifetime parameter (conditional on the price of coal). Such a model could be used both to estimate the lifetime parameter and to check that the parameter actually used in the model was consistent with the coal prices estimated by the model. We do not necessarily recommend the implementation of the theoretical model outline mentioned above. The issue of the correct formulation for a satisfactory auxiliary model remains a subject for further research.

APPENDIX

APPENDIX A.1 ANALYTICAL FORMULATION OF THE COAL SUPPLY COST FUNCTION AND ASSOCIATED ELASTICITIES*

This appendix presents a detailed and explicit analytical formulation of the corrected version of CSM/NCM's implied engineering cost function and its associated cost elasticities for both surface and deep mines. Note throughout that the minimum acceptable real annuity coal price (described in Appendix A.2) is equivalent to average cost.

A. Definition of Parameters and Variables

RACP = real annuity coal price in case year (1985) dollars per clean ton.

MYR = mine lifetime in years.

ECAP = nominal escalation rate in coal mine capital costs.

EMP = nominal escalation rate for coal mine labor costs.

EPAS = nominal escalation rate for coal mine costs of power and supplies; used in places as a proxy for the general inflation rate.

ROR = nominal after-tax cost of capital (nominal discount rate) for coal producers.

RUT = nominal after-tax cost of capital (nominal discount rate) for electric utilities.

APFAC = annuity price factor; analytically defined both in Appendixes D.1 and F.2; a function of MYR, RUT, and the general inflation rate.

SZ = mine size in millions of raw tons per year; the allowable sizes are 0.1, 0.5, 1.0, 2.0, 3.0, and 4.0, for surface mines and 0.1, 0.5, 1.0, 2.0, and 3.0, for deep mines.

OB = overburden ratio for surface mines; the allowable ratios are 5, 10, 15, 20, 25, 30, and 45.

ST = seam thickness in inches for deep mines; the allowable seam thicknesses are 28, 36, 48, 60, and 72.

DP = seam depth in feet for deep mines; the allowable seam depths are 0, 400, 700, and 1000.

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*This material draws heavily on Goldman [1980].

DR = drift mine switch; equals one when DP=0, and equals zero otherwise.

ICBS75 = initial capital cost for surface model-mine in thousands of base year (1975) dollars.

ICBD75 = initial capital cost for deep model-mine in thousands of base year (1975) dollars.

DCBS75 = total deferred capital cost for a 20-year surface model-mine in thousands of base year (1975) dollars.

DCBD75 = total deferred capital cost for a 20-year deep model-mine in thousands of base year (1975) dollars.

SLAB75 = labor cost in base year (1975) dollars per man-day for surface model-mine.

DLAB75 = labor cost in base year (1975) dollars per man-day for deep model-mine.

TPMDBS = raw tons per man-day for surface model-mine; varies by supply region.

TPMDBD = raw tons per man-day for deep model-mine; varies by supply region.

PSBS75 = power and supplies cost for surface model-mine in thousands of base year (1975) dollars per million raw tons of output.

PSBD75 = power and supplies cost for deep model-mine in thousands of base year (1975) dollars per million raw tons of output.

POW = power cost in thousands of base year (1975) dollars per million raw tons of output; varies by surface or deep mine.

WEL = union welfare cost in base year (1975) dollars per clean ton; varies by supply region.

WPD = union welfare cost in base year (1975) dollars per man-day.

ROY = royalty fee in base year (1975) dollars per clean ton; has a zero value in all supply regions.

LIC = licensing fee in base year (1975) dollars per clean ton.

SEVTR = severance tax rate as a percentage of required revenue (sales); varies by supply region.

SEVT = severance tax charge in base year (1975) dollars per clean ton; varies by supply region.

SEVT$ = severance tax charge in thousands of current dollars per mine year (constant in nominal terms); determined from SEVT; varies by supply region.

FED = Federal royalty tax rate (applies to coal mined on Federal lands) as a percentage of required revenue (sales); varies by surface or deep mine and by supply region.

EINS = exposure insurance charge as a percentage of labor costs; varies by surface or deep mine and by supply region.

AMR = abandoned mine reclamation charge in base year (1975) dollars per clean ton; varies by surface or deep mine and by Btu content level of coal.

BLUNG = insurance charge for Black Lung Disease in base year (1975) dollars per clean ton; varies by surface or deep mine and by BTU content level of coal.

FREC75, VREC75 = fixed and variable reclamation cost, respectively, in base year (1975) dollars per clean ton; varies by overburden ratio and by supply region.

FCL75, VCL75 = fixed and variable basic bituminous cleaning cost, respectively, in base year (1975) dollars per clean ton; varies by surface or deep mine, by sulfur content level of coal, and by Btu content level of coal.

YIELD = clean coal yield fraction in clean tons per raw ton; varies by surface or deep mine, by sulfur content level of coal, by Btu content level of coal, and by supply region.

IC75 = adjusted initial capital cost for any mine in thousands of base year (1975) dollars.

DC75 = adjusted total deferred capital cost for any 20-year mine in thousands of base year (1975) dollars.

TPMD = adjusted raw tons per man-day for any mine.

LAB75 = labor cost in thousands of base year (1975) dollars per year.

PAS75 = adjusted power and supplies cost in thousands of base year (1975) dollars per year.

CF_{JJ} = required annual cash flow, constant in thousands of current dollars per mine year (constant in nominal terms).

$CRF_{ROR,MYR}$ = capital recovery factor for coal producers; a function of ROR and MYR.

PV_{IC} = present value of initial capital cost, in case year dollars, as of beginning of case year (1985).

PV_{DC} = present value of deferred capital costs, in case year dollars, as of beginning case year dollar (1985).

PV_{CAP} = present value of total capital investment of coal producers, in case year dollars, as of beginning of case year (1985).

DCF_{JJ} = fraction of deferred capital spent at the end of each year of a mine's lifetime.

OC_{JJ} = total operating costs in thousands of current dollars per mine year.

LAB_{JJ} = labor cost in thousands of current dollars per mine year.

PAS_{JJ} = power and supplies cost in thousands of current dollars per mine year.

DEP_{JJ} = annual depreciation charge--total nominal capital costs divided by the mine lifetime.

PO_{JJ} = payroll overhead cost in thousands of current dollars per mine year.

WC_{JJ} = total union welfare cost in thousands of current dollars per mine year.

RF_{JJ}, LF_{JJ} = royalty and licensing cost, respectively, in thousands of current dollars per mine year.

IDC_{JJ} = indirect cost in thousands of current dollars per mine year.

TAI_{JJ} = property taxes and insurance cost in thousands of current dollars per mine year.

RR_{JJ} = total required revenue (sales) in thousands of current dollars per mine year.

$DEPL_{JJ}$ = annual depletion allowance either as a percentage of required revenue or as a percentage of gross profit.

GP_{JJ} = gross profit in thousands of current dollars per mine year.

JJ = counter on mine years.

B. Cost Adjustment Factors

1. Surface Mines

(a) For $SZ \geq 1$: (Note that Equations (1) & (2) are only valid for $SZ \leq 10.5$)

$$IC75 = [ICBS75 + 1.20*10^3(OB-10)]\ SZ\ [1-(SZ-1)/20] \quad (1)$$

$$DC75 = [DCBS75 + 0.25*10^3(OB-10)]\ SZ\ [1-(SZ-1)/20] \quad (2)$$

(b) For $SZ < 1$:

$$IC75 = [ICBS75 + 1.20*10^3(OB-10)]\ [1-0.05(1-SZ)/0.1] \quad (3)$$

$$DC75 = [DCBS75 + 0.25*10^3(OB-10)]\ [1-0.05(1-SZ)/0.1] \quad (4)$$

(c) For any SZ:

$$TPMD = [TPMDBS + 3(SZ-1)/0.1][1 - 0.1(OB-10)/5] \quad (5)$$

$$LAB75 = (SZ*10^3/TPMD)\ SLAB75 \quad (6)$$

$$PAS75 = [PSBS75 + 30(OB-10)]\ SZ \quad (7)$$

2. Deep Mines

Note that if $DP = 0$, $DR = 1$, and if $DP \neq 0$, $DR = 0$.

(a) For $SZ \geq 1$:

$$IC75 = [ICBD75 + 500(DP-700)/100 - 6000(DR)][1 + 0.06(72-ST)/12] * [1 + 0.30(SZ-1)] \quad (8)$$

$$DC75 = [DCBD75 - 3000(DR)][1 + 0.06(72-ST)/12][1 + 0.15(SZ-1)] \quad (9)$$

(b) For $SZ < 1$:

$$IC75^* = [ICBD75 + 500(DP-700)/100 - 6000(DR)][1 + 0.06(72-ST)/12]$$

$$IC75 = [IC75^* - 500(DP/100)]\ SZ + 500(DP/100) \quad (10)$$

$$DC75 = [DCBD75 - 3000(DR)][1 + 0.06(72-ST)/12]\ SZ \quad (11)$$

(c) For any SZ:

$$TPMD = TPMDBD - 1.0(72-ST)/12 + 0.5(SZ-1)/0.1 \quad (12)$$

$$LAB75 = (SZ*10^3/TPMD)\ DLAB75 \quad (13)$$

$$PAS75 = [PSBD75 + 0.15 * 10^3(72-ST)/12]\ SZ. \quad (14)$$

C. Cash Flow

$$CF_{JJ} = CRF_{ROR,MYR} * PV_{CAP} \tag{15}$$

where:

$$CRF_{ROR,MYR} = ROR/[1 - (1 + ROR)^{-MYR}]$$

$$PV_{CAP} = PV_{IC} + PV_{DC}$$

$$PV_{IC} = IC75(1 + ECAP)^{10-2/3}\ (1 + EPAS)^{2/3}$$

$$PV_{DC} = DC75^{*}(1 + ECAP)^{10} \sum_{JJ=1}^{MYR} DCF_{JJ} \left(\frac{1 + ECAP}{1 + ROR}\right)^{JJ}$$

$$DC75^{*} = DC75(MYR - 10)/10.$$

Let: $M25 = MYR/4$, $M50 = MYR/2$, $M75 = M25 + M50$, $M99 = MYR - 1$.

When MYR is perfectly divisible by four:

$$\begin{aligned} DCF_{JJ} &= .05/M25\ , \quad JJ = 1, \ldots., M25 \\ &= .90/M50\ , \quad JJ = M25 + 1, \ldots., M75 \\ &= .05/M99\ , \quad JJ = M75 + 1, \ldots., M99 \end{aligned}$$

When MYR is not perfectly divisible by four, an amended version of the allocation of deferred capital is needed. (This is discussed further in Goldman [1980]).

D. Operating Costs

$$\begin{aligned} OC_{JJ} = {} & LAB_{JJ} + PAS_{JJ} + PO_{JJ} + WC_{JJ} + RF_{JJ} + LF_{JJ} + IDC_{JJ} + TAI_{JJ} + DEP_{JJ} \\ & + [(FREC75 + FCL75)(1 + ECAP)^{11} + VREC75(1 + EMP)^{10+JJ} \\ & + VCL75(1 + EPAS)^{10+JJ} + AMR + BLUNG]\ SZ*10^{3}*YIELD \end{aligned} \tag{16}$$

where:

$$LAB_{JJ} = LAB75(1 + EMP)^{10+JJ}$$

$$PAS_{JJ} = PAS75(1 + EPAS)^{10+JJ}$$

$$PO_{JJ} = [0.20 + 0.01(EINS)]\ LAB_{JJ}$$

$$WC_{JJ} = [SZ*10^3(WEL*YIELD + WPD/TPMD)]\ (1 + EMP)^{10+JJ}$$

$$RF_{JJ} = [ROY*(SZ*10^3*YIELD)]\ (1 + ECAP)^{10+JJ}$$

$$LF_{JJ} = [LIC*(SZ*10^3*YIELD)]\ (1 + ECAP)^{10+JJ}$$

$$IDC_{JJ} = 0.15[LAB_{JJ} + (PAS_{JJ} - POW*SZ*(1+EPAS)^{10+JJ})]$$

$$TAI_{JJ} = 0.02[PV_{IC}/(1+EPAS)^{2/3}]\ (1 + ECAP)^{2/3+JJ}$$

$$DEP_{JJ} = \left[PV_{IC}/(1+EPAS)^{2/3} + DC75((MYR-10)/10)(1+ECAP)^{10} * \sum_{JJ=1}^{MYR} DCF_{JJ}\ (1 + ECAP)^{JJ}\right] \Big/ MYR \qquad (17)$$

Note that for deep mines FREC75 = VREC75 = 0.0, and that ROY = 0.0 in every coal supply region.

E. Required Revenue and Depletion Allowance

It is assumed that the Federal Income Tax equals half of taxable income and that the depletion allowance equals 10% of required revenue up to 50% of gross profit.

From Appendix A.2 it can easily be shown that if $DEPL_{JJ} = 0.1 * RR_{JJ}$ then:

$$RR_{JJ} = \frac{0.5\ OC_{JJ} + CF_{JJ} - DEP_{JJ}}{0.55[1 - (SEVTR + FED)]} + \frac{0.5\ SEVT\$}{0.55} \qquad (18)$$

If $DEPL_{JJ} = 0.5 * GP_{JJ}$ then:

$$RR_{JJ} = \frac{4/3\ (CF_{JJ} - DEP_{JJ}) + OC_{JJ}}{[1 - (SEVTR + FED)]} + SEVT\$ \qquad (19)$$

where:

$$GP_{JJ} = [1 - (SEVTR + FED)]\ RR_{JJ} - OC_{JJ} - SEVT\$, \text{ and} \tag{20}$$

$$SEVT\$ = SEVT * 10^3 * SZ * YIELD.$$

Note that in Equations (18) to (20), one or both of SEVTR and SEVT$ will be zero in each coal supply region. Also, FED = 0 in all but seven Western regions.

F. Real Annuity Coal Price (RACP)

Again referring to Appendix A.2, it can easily be shown that if

$DEPL_{JJ} = 0.1 * RR_{JJ}$, then:

$$RACP = (APFAC{*}10^3{*}YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} \frac{1}{SZ} * \left[\frac{0.5\ OC_{JJ} + CF_{JJ} - DEP_{JJ}}{0.55[1 - (SEVTR + FED)]} + \frac{0.5\ SEVT\$}{0.55}\right] \tag{21}$$

If $DEPL_{JJ} = 0.5 * GP_{JJ}$:

$$RACP = (APFAC{*}10^3{*}YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} \frac{1}{SZ} * \left[\frac{4/3\ (CF_{JJ} - DEP_{JJ}) + OC_{JJ}}{[1 - (SEVTR + FED)]} + SEVT\$\right] \tag{22}$$

Substituting Equations (15), (16), and (17) into Equations (21) and (22) yields the following set of equations.

If $DEPL_{JJ} = 0.1 * RR_{JJ}$:

$$\text{RACP} = (\text{APFAC}*10^3*\text{YIELD})^{-1} \sum_{\text{JJ}=1}^{\text{MYR}} (1 + \text{RUT})^{-\text{JJ}} \; \frac{1}{\text{SZ}}$$

$$* \; [\text{C1} + \text{C2}(\text{B1}_{\text{JJ}}*\text{IC75} + \text{B2}_{\text{JJ}}*\text{DC75} + \text{B3}_{\text{JJ}}*\text{LAB75} + \text{B4}_{\text{JJ}}*\text{PAS75}$$

$$+ \text{B5}_{\text{JJ}}*(\text{SZ/TPMD}) + \text{B6}_{\text{JJ}}*\text{SZ})\;] \qquad (23)$$

where:

$\text{C1} = (0.5/0.55)\ \text{SEVT\$}$

$\text{C2} = 1/(0.55[1 - (\text{SEVTR} + \text{FED})]\ )$

$\text{B1}_{\text{JJ}} = (\text{T} + \text{ECAP})^{10-2/3}\ [\text{CRF}_{\text{ROR,MYR}}(1 + \text{EPAS})^{2/3} + 0.01(1 + \text{ECAP})^{2/3+\text{JJ}} - 1/(2*\text{MYR}$

$$\text{B2}_{\text{JJ}} = (1+\text{ECAP})^{10}\left[\text{CRF}_{\text{ROR,MYR}} \sum_{\text{JJ}=1}^{\text{MYR}} \text{DCF}_{\text{JJ}}\left(\frac{1+\text{ECAP}}{1+\text{ROR}}\right)^{\text{JJ}} - \frac{1}{2*\text{MYR}} \sum_{\text{JJ}=1}^{\text{MYR}} \text{DCF}_{\text{JJ}}(1+\text{ECAP})^{\text{JJ}}\right]$$

$$* \;\; (\text{MYR} - 10)/10$$

$\text{B3}_{\text{JJ}} = \frac{1}{2}\,(1 + \text{EMP})^{10+\text{JJ}}\ [1.35 + 0.01*\text{EINS}]$

$\text{B4}_{\text{JJ}} = \frac{1}{2}\,(1 + \text{EPAS})^{10+\text{JJ}}\ (1.15)$

$\text{B5}_{\text{JJ}} = \frac{1}{2}\,(1 + \text{EMP})^{10+\text{JJ}}\ (10^3*\text{WPD})$

$$\text{B6}_{\text{JJ}} = \frac{1}{2} * 10^3 * \text{YIELD}\ [\ (1 + \text{EMP})^{10+\text{JJ}}\ (\text{WEL} + \text{VREC75}) + (1 + \text{ECAP})^{10+\text{JJ}}(\text{ROY}+\text{LIC})$$

$$+ (1 + \text{EPAS})^{10+\text{JJ}}\ \text{VCL75} + (1 + \text{ECAP})^{11}\ (\text{FREC75} + \text{FCL75}) + \text{AMR} + \text{BLUNG}\ ]$$

$$- \frac{1}{2}\,(1 + \text{EPAS})^{10+\text{JJ}}\ (0.15*\text{POW}).$$

Recall again that for deep mines FREC75 = VREC75 = 0.0.

If $\text{DEPL}_{\text{JJ}} = 0.5 * \text{GP}_{\text{JJ}}$:

$$\text{RACP} = (\text{APFAC}*10^3*\text{YIELD})^{-1} \sum_{\text{JJ}=1}^{\text{MYR}} (1+\text{RUT})^{-\text{JJ}}\ \frac{1}{\text{SZ}}\ [\ \text{C1}^* + \text{C2}^*(\text{B1}^*_{\text{JJ}} * \text{IC75}$$

$$+ \text{B2}^*_{\text{JJ}} * \text{DC75} + \text{B3}^*_{\text{JJ}} * \text{LAB75} + \text{B4}^*_{\text{JJ}} * \text{PAS75} + \text{B5}^*_{\text{JJ}} * (\text{SZ/TPMD})$$

$$+ \text{B6}^*_{\text{JJ}} * \text{SZ})] \qquad (24)$$

where:

$C1^* = SEVT\$$

$C2^* = 1/[1 - (SEVTR + FED)]$

$$B1^*_{JJ} = (1+ECAP)^{10-2/3}\left[\frac{4}{3}\,CRF_{ROR,MYR}(1+EPAS)^{2/3} + 0.02(1+ECAP)^{2/3+JJ} - 1/(3*MYR)\right]$$

$$B2^*_{JJ} = (1+ECAP)^{10}\left[\frac{4}{3}\,CRF_{ROR,MYR}\sum_{JJ=1}^{MYR} DCF_{JJ}\left(\frac{1+ECAP}{1+ROR}\right)^{JJ} - \frac{1}{3*MYR}\sum_{JJ=1}^{MYR} DCF_{JJ}\,(1+ECAP)^{JJ}\right] * (MYR - 10)/10$$

$B3^*_{JJ} = 2 * B3_{JJ}$

$B4^*_{JJ} = 2 * B4_{JJ}$

$B5^*_{JJ} = 2 * B5_{JJ}$

$B6^*_{JJ} = 2 * B6_{JJ}$

Substitution of Equations (1) to (7) into Equations (23) and (24) yields a closed-form expression for RACP as a function of the surface mine physical variables, SZ and OB.

Substitution of Equations (8) to (14) into Equations (23) and (24) yields a closed-form expression for RACP as a function of the deep mine physical variables, SZ, ST, and DP.

G. RACP Derivatives

Note that all derivatives below are calculated assuming that in each year of the mine's lifetime $DEPL_{JJ} = 0.1*RR_{JJ}$. If in any year $DEPL_{JJ} = 0.5*GP_{JJ}$ then $C1^*$, $C2^*$, $B1^*_{JJ}$, $B2^*_{JJ}$, $B3^*_{JJ}$, $B4^*_{JJ}$, $B5^*_{JJ}$, and $B6^*_{JJ}$ must be substituted appropriately.

1. Surface Mines

(a) For SZ ≥ 1.

Price derivative with respect to overburden ratio:

$$\begin{aligned}
\frac{\partial(RACP)}{\partial(OB)} = {} & (APFAC*10^3*YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} \\
& * \; C2 \Bigg[[B1_{JJ}(1.20*10^3) + B2_{JJ}(0.25*10^3)][1 - (SZ-1)/20] \\
& + \; (0.02) \; [B3_{JJ}(10^3*SLAB75) + B5_{JJ}][TPMDBS + 3(SZ-1)/0.1]^{-1} \\
& * \; [1 - 0.1(OB-10)/5]^{-2} \; + \; 30*B4_{JJ} \Bigg] \qquad (25)
\end{aligned}$$

Price derivative with respect to mine size:

$$\begin{aligned}
\frac{\partial(RACP)}{\partial(SZ)} = {} & (APFAC*10^3*YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} \; \Bigg\{ - C1/(SZ)^2 \\
& + C2 \Bigg[- \frac{1}{20} B1_{JJ} \; [ICBS75 + 1.20*10^3(OB - 10)] \\
& - \frac{1}{20} B2_{JJ} \; [DCBS75 + 0.25*10^3(OB - 10)] \\
& - 30 \; [B3_{JJ}(10^3*SLAB75) + B5_{JJ}] \; [TPMDBS + 3(SZ - 1)/0.1]^{-2} \\
& * [1 - 0.1(OB - 10)/5]^{-1} \Bigg] \Bigg\} \qquad (26)
\end{aligned}$$

(b) For $SZ < 1$.

Price derivative with respect to overburden ratio:

$$\begin{aligned}
\frac{\partial(\text{RACP})}{\partial(\text{OB})} = {} & (\text{APFAC}*10^3*\text{YIELD})^{-1} \sum_{\text{JJ}=1}^{\text{MYR}} (1 + \text{RUT})^{-\text{JJ}} \\
& * \text{C2} \Big[[\text{B1}_{\text{JJ}}(1.20*10^3) + \text{B2}_{\text{JJ}}(0.25*10^3)] [1 - 0.05(1-\text{SZ})/0.1] \frac{1}{\text{SZ}} \\
& + (0.02) [\text{B3}_{\text{JJ}}(10^3*\text{SLAB75}) + \text{B5}_{\text{JJ}}] [\text{TPMDBS} + 3(\text{SZ}-1)/0.1]^{-1} \\
& * [1 - 0.1(\text{OB}-10)/5]^{-2} + 30*\text{B4}_{\text{JJ}} \Big] \qquad (27)
\end{aligned}$$

Price derivative with respect to mine size:

$$\begin{aligned}
\frac{\partial(\text{RACP})}{\partial(\text{SZ})} = {} & (\text{APFAC}*10^3*\text{YIELD})^{-1} \sum_{\text{JJ}=1}^{\text{MYR}} (1+\text{RUT})^{-\text{JJ}} \Big\{ - \text{C1}/(\text{SZ})^2 \\
& + \text{C2} \Big[-\text{B1}_{\text{JJ}}[\text{ICBS75} + 1.20*10^3(\text{OB}-10)] \frac{1}{2*(\text{SZ})^2} \\
& - \text{B2}_{\text{JJ}}[\text{DCBS75} + 0.25*10^3(\text{OB}-10)] \frac{1}{2*(\text{SZ})^2} \\
& - 30[\text{B3}_{\text{JJ}}(10^3*\text{SLAB75}) + \text{B5}_{\text{JJ}}] [\text{TPMDBS} + 3(\text{SZ}-1)/0.1]^{-2} \\
& * [1 - 0.1(\text{OB}-10)/5]^{-1} \Big] \Big\} \qquad (28)
\end{aligned}$$

2. Deep Mines

(a) For SZ ≥ 1.

Price derivative with respect to seam thickness:

$$\begin{aligned}\frac{\partial(RACP)}{\partial(ST)} = {} & (APFAC*10^3*YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} * C2 \Big[-(0.005)\ B1_{JJ} \\ & * [ICBD75 + 5(DP - 700) - 6000*DR]\ [1 + 0.30(SZ-1)]\ \frac{1}{SZ} \\ & - (0.005)\ B2_{JJ}[DCBD75 - 3000*DR]\ [1 + 0.15(SZ-1)]\ \frac{1}{SZ} \\ & - \frac{1}{12}\ [B3_{JJ}(10^3*DLAB75) + B5_{JJ}]\ [TPMDBD - (72-ST)/12 + 0.5(SZ-1)/0.1]^{-2} \\ & - \frac{1}{12}\ (0.15*10^3)\ B4_{JJ} \Big]\end{aligned} \tag{29}$$

Price derivative with respect to seam depth:

$$\begin{aligned}\frac{\partial(RACP)}{\partial(DP)} = {} & (APFAC*10^3*YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} * C2 \Big[5*B1_{JJ} \\ & * [1 + 0.06(72-ST)/12]\ [1 + 0.30(SZ-1)]\ \frac{1}{SZ} \Big]\end{aligned} \tag{30}$$

Price derivative with respect to mine size:

$$\begin{aligned}\frac{\partial(RACP)}{\partial(SZ)} = {} & (APFAC*10^3*YIELD)^{-1} \sum_{JJ=1}^{MYR} (1 + RUT)^{-JJ} \Big\{ - C1/(SZ)^2 \\ & + C2 \Big[-(0.7)\ B1_{JJ}[ICBD75 + 5(DP-700) - 6000*DR] \\ & * [1 + 0.06(72-ST)/12] \frac{1}{(SZ)^2} - (0.85)\ B2_{JJ}[DCBD75 - 3000*DR] \\ & * [1 + 0.06(72-ST)/12]\ \frac{1}{(SZ)^2} - 5[B3_{JJ}(10^3*DLAB75) + B5_{JJ}] \\ & * [TPMDBD - (72-ST)/12 + 0.5(SZ-1)/0.1]^{-2} \Big] \Big\}\end{aligned} \tag{31}$$

(b) For SZ < 1.

Price derivative with respect to seam thickness:

$$\begin{aligned}\frac{\partial(\mathrm{RACP})}{\partial(\mathrm{ST})} = {} & (\mathrm{APFAC}*10^3*\mathrm{YIELD})^{-1} \sum_{\mathrm{JJ}=1}^{\mathrm{MYR}} (1 + \mathrm{RUT})^{-\mathrm{JJ}} * \mathrm{C2} \Big[-(0.005)\ \mathrm{B1}_{\mathrm{JJ}} \\ & * [\mathrm{ICBD75} + 5(\mathrm{DP}-700) - 6000*\mathrm{DR}] - (0.005)\ \mathrm{B2}_{\mathrm{JJ}} \\ & * [\mathrm{DCBD75} - 3000*\mathrm{DR}] - \frac{1}{12} [\mathrm{B3}_{\mathrm{JJ}}(10^3*\mathrm{DLAB75}) + \mathrm{B5}_{\mathrm{JJ}}] \\ & * [\mathrm{TPMDBD} - (72-\mathrm{ST})/12 + 0.5(\mathrm{SZ}-1)/0.1]^{-2} - \frac{1}{12} (0.15*10^3)\ \mathrm{B4}_{\mathrm{JJ}} \Big] \end{aligned} \qquad (32)$$

Price derivative with respect to seam depth:

$$\begin{aligned}\frac{\partial(\mathrm{RACP})}{\partial(\mathrm{DP})} = {} & (\mathrm{APFAC}*10^3*\mathrm{YIELD})^{-1} \sum_{\mathrm{JJ}=1}^{\mathrm{MYR}} (1 + \mathrm{RUT})^{-\mathrm{JJ}} * \mathrm{C2} \Big[5*\mathrm{B1}_{\mathrm{JJ}} \\ & * [\ (1 + 0.06(72-\mathrm{ST})/12) \ + (\ \frac{1}{\mathrm{SZ}} - 1\ )\ ] \Big] \end{aligned} \qquad (33)$$

Price derivative with respect to mine size:

$$\begin{aligned}\frac{\partial(\mathrm{RACP})}{\partial(\mathrm{SZ})} = {} & (\mathrm{APFAC}*10^3*\mathrm{YIELD})^{-1} \sum_{\mathrm{JJ}=1}^{\mathrm{MYR}} (1 + \mathrm{RUT})^{-\mathrm{JJ}} \Big\{ - \mathrm{C1}/(\mathrm{SZ})^2 \\ & + \mathrm{C2} \Big[-5*\mathrm{B1}_{\mathrm{JJ}}*\mathrm{DP} \frac{1}{(\mathrm{SZ})^2} - 5\ [\mathrm{B3}_{\mathrm{JJ}}(10^3*\mathrm{DLAB75}) + \mathrm{B5}_{\mathrm{JJ}}] \\ & * [\mathrm{TPMDBD} - (72-\mathrm{ST})/12 + 0.5(\mathrm{SZ}-1)/0.1]^{-2} \Big] \Big\} \end{aligned} \qquad (34)$$

H. RACP Elasticities

The elasticities of the real annuity coal price with respect to each physical variable, for both surface and deep mines, are calculated in the usual way. Let X denote any physical variable. Then the elasticity of RACP with respect to X is given by:

$$\frac{X}{RACP} \frac{\partial(RACP)}{\partial(X)} \quad . \tag{35}$$

I. Final Notes

(a) Note that for surface mines the derivatives of RACP with respect to OB and SZ are not continuous at SZ = 1.

(b) Note that for deep mines RACP is not continuous at DP = 0 (i.e., for deep drift mines) and that the derivatives of RACP with respect to ST, DP, and SZ are not continuous at both SZ = 1 and DP = 0.

(c) Each elasticity has its expected sign.

APPENDIX A.2 THE CONCEPT OF MINIMUM ACCEPTABLE REAL ANNUITY COAL PRICES--A FORMULATION*

The ultimate objective of the Coal Supply Module (CSM) of the National Coal Model is to produce supply schedules for coal as viewed by purchasers. Supply schedules reflecting the producer's point of view are derived, and these schedules are then adjusted to reflect the purchaser's point of view. A central concept of this procedure is the notion of minimum acceptable real annuity coal prices. Since the model documentation (ICF [1977]) does not adequately describe this concept, our own construction of it is presented below.

The modelers' objectives in employing the minimum acceptable real annuity coal pricing concept were twofold. First, the coal prices ought to reflect the stream of required prices for the entire life of the mine, and second, the prices must be internally consistent with other inflating price series such as oil/gas prices, coal transportation costs, and electric utility O&M costs. The objectives were achieved by the use of real annuity prices that implicitly inflate at the general rate of inflation, thereby remaining constant in real terms. All other inflating series employed in the CSM are expressed in similar terms.

In this appendix the coal pricing logic employed in the CSM is explained in a step-by-step manner starting with the calculation of the coal producer's minimum acceptable selling price.

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*This material draws heavily on Goldman [1980].

1. For each model mine type in each supply region the present value of capital investment (as of the case year, 1985) is calculated using a given initial capital cost and a given distribution of deferred capital costs over the mine lifetime.

The present value of the total capital investment of coal producers, PV_{CAP} (in case year dollars, as of the beginning of the case year, 1985) is given by:

$$PV_{CAP} = PV_{IC} + PV_{DC}$$

$$PV_{IC} = IC_{75}(1 + g_c)^{10-2/3}(1 + k_p)^{2/3}$$

$$PV_{DC} = DC_{75}(1 + g_c)^{10} \sum_{i=1}^{N} DCF_i \frac{(1 + g_c)^i}{(1 + k_p)^i} \qquad (1)$$

where:

PV_{IC} = present value of initial capital cost, in case year dollars, as of beginning of case year (1985)

PV_{DC} = present value of deferred capital cost, in case year dollars, as of beginning of case year (1985)

IC_{75} = initial capital cost in base year, beginning-1975, dollars

DC_{75} = deferred capital cost in base year, beginning-1975, dollars

DCF_i = fraction of deferred capital spent at end of year i

k_p = coal producer's nominal discount rate (after-tax nominal cost of capital)

g_c = total capital escalation rate (including general inflation and real escalation)

g = general rate of inflation

N = mine lifetime in years

Note that initial capital is inflated at the nominal escalation rate from the base year to eight months before the case year. Deferred capital is escalated to the end of the year in which is money is considered spent.

Let: K_p = coal producer's real discount rate (after-tax real cost of capital)

Recalling that $1 + K_p = \frac{1+k_p}{1+g}$, we point out that

$$PV_{CAP} \neq PV_{IC} + DC_{75}(1 + g_c)^{10} \sum_{i=1}^{N} \frac{DCF_i}{(1 + K_p)^i} \qquad (2)$$

Equation (2) only holds if $g=g_c$.

Using the distribution for deferred capital costs given on page III-49 of ICF[1977], we have for N=20:

$DCF_i = .01 \quad , \quad i = 1\text{-}5$

$= .09 \quad , \quad i = 6\text{-}15$

$= .0125 \quad , \quad i = 16\text{-}19$

Except for mine lifetime, the following parameter values represent recent figures used by ICF to calculate PV_{CAP}. Although NCM is currently using a mine lifetime of 30 years, we use a value of 20 years in Equations (3) and (4) since for this lifetime, the distribution used by ICF for deferred capital costs is documented.

$k_p = .15 \quad , \quad g_c = .06 \quad , \quad g = .055$

$$1 + K_p = 1.15/1.055 \quad \Rightarrow \quad K_p \cong .09 \qquad (3)$$

Utilizing Equations (1) and (3), we now have:

$$PV_{CAP} = PV_{IC} + DC_{75}(1 + g_c)^{10} \left[.01 \sum_{i=1}^{5} \left(\frac{1.06}{1.15}\right)^i \right. \qquad (4)$$

$$\left. + .09 \sum_{i=6}^{15} \left(\frac{1.06}{1.15}\right)^i + .0125 \sum_{i=16}^{19} \left(\frac{1.06}{1.15}\right)^i \right].$$

2. A minimum acceptable or required annual cash flow (equivalent to annualized capital cost) in nominal terms, CF, can be calculated by annualizing PV_{CAP} using the coal producer's nominal discount rate, k_p, and the mine lifetime, N. This cash flow is constant in <u>nominal</u> terms (i.e., constant in current year dollars). It is given by:

$$CF = \frac{PV_{CAP}}{\sum_{i=1}^{N} \frac{1}{(1+k_p)^i}} = PV_{CAP} \bullet CRF_{k_p, N} \qquad (5)$$

where:

$CRF_{k_p, N}$ = capital recovery factor = $k_p \left[1 - (1+k_p)^{-N}\right]^{-1}$.
(based on <u>nominal</u> discount rate)

A minimum acceptable annual cash flow with the same present value but constant in real terms is obtained simply by substituting K_p for k_p in Equation 4.

Note that for the NCM analysis, a cash flow constant in real terms was used.

3. Utilizing given total operating costs for the base year, depreciation, and the above calculated minimum acceptable annual cash flow, total required revenues (referred to as sales by ICF) for the case year can be estimated from the appropriate equation on page III-50 of the NCM documentation ICF [1977]. (Since ICF assumes that the depletion allowance equals 10 percent of required revenues up to 50 percent of gross profit, there are two possible required-revenue equations. Both are derived in the addendum to this appendix. Adjustments to these equations, including severance tax rates as a percentage of sales, severance tax charges in dollars per ton, and Federal royalties, are not included.) The coal producer's minimum acceptable selling price, MASP, for the case year is determined by dividing required revenue by the annual output of the mine.

4. Starting from the MASP in the case year, 1985, a minimum acceptable coal price series in nominal terms is generated over the assumed 20-year mine lifetime as follows: The minimum acceptable cash flow or annualized capital cost is constant in nominal terms over the mine

lifetime. Variable costs are escalated from year to year over the life of the mine using a 6.5% rate for labor costs, including approximately 1% real escalation, and the 5.5% general inflation rate for the cost of power and supplies and for other operating expenses. Required revenues are recalculated (as described in step 3 above) for each year, creating a stream of minimum acceptable prices in nominal terms (i.e., in current year dollars). By construction, via this required price stream, the coal company will recover all of its costs and earn the required return on its investment.

5. The coal producer's minimum acceptable coal price series in nominal terms, calculated in the previous step, is present-valued or discounted to the case year using the after-tax <u>nominal</u> cost of capital to electric utilities, k_u. The utility industry's discount rate is used at this stage because the utilities decide which stream of prices is preferable (i.e., which mines are opened) and make the trade-off decisions between various fuels and between capital-intensive and high-variable cost plants. Currently, NCM is using a 10% after-tax nominal cost of capital to utilities. The present-value (as of the case year) of the coal price series, PV_{ps}, is calculated as follows (note that the values p_i are neither constant in real terms nor in nominal terms):

$$PV_{ps} = \sum_{i=1}^{N} \frac{p_i}{(1+k_u)^i} = \sum_{i=1}^{20} \frac{p_i}{(1.10)^i} \qquad (6)$$

where:

p_i = coal producer's minimum acceptable coal price in ith year in nominal terms (for model mine type and supply region under consideration).

6. Finally, a minimum acceptable "real annuity coal price," RACP, is capculated from PV_{ps} using k_u and the general inflation rate, g. This calculation implicitly defines an after-tax real cost of capital to electric utilities, k_u.

$$\underset{\substack{\text{(constant}\\ \text{in real}\\ \text{terms)}}}{\text{RACP}} = \frac{PV_{ps}}{\sum_{i=1}^{N} \left(\frac{1+g}{1+k_u}\right)^i} = \frac{PV_{ps}}{\sum_{i=1}^{N} \frac{1}{(1+K_u)^i}} \qquad (7)$$

$$= PV_{ps}/APFAC$$

where:

APFAC = annuity price factor, and

$1 + K_u = 1.10/1.055 \Rightarrow K_u \cong .0427.$

The real annuity coal price is a case year value in case year dollars that inflates at the general rate of inflation (i.e., RACP is constant in real terms). Note that while the methodology described above is projecting coal prices p_i in actual nominal terms, it is only the present value of the coal price series that is important. The associated real annuity, given by Equation (7), has the same present value to the utility as does the nominal price series.

Other prices in the NCM are all assumed to inflate at the general rate of inflation (i.e., to remain constant in constant case year dollars). Therefore, the 1985 price for, say, oil/gas is both its actual price in 1985 and the value of the real annuity for oil/gas stated in 1985 dollars. So the real annuity coal price has the advantage of being consistent with other data inputs, such as oil prices. Its other advantage is that it makes the NCM static linear programming framework possible.

It is the minimum acceptable real annuity coal price (deflated to 1978 dollars), for each model mine type in each supply region, that appears in the linear programming matrix as the cost coefficients of the coal mining activity variables in the objective function.

Addendum: Derivation of Required-Revenue (Sales) Equations

(For further discussion see ICF[1977], p. III-50.)

Case 1: Depletion = .50 • Gross Profit (GP) (1)

By definition:

Annual Cash Flow (CF) = Net Profit (NP) + Depreciation (DEP) + Depletion. (2)

Assuming a 50% Federal income tax rate,

$$NP = .50\ (GP - \text{Depletion}) \qquad (3)$$

Substituting Equation (1) into Equation (3) yields:

$$NP = .50\ (GP - .5\ GP) = .25\ GP \qquad (4)$$

Substituting Equations (1) and (4) into Equation (2) we have:

$$GP = 4\ (CF\text{-}DEP)/3. \qquad (5)$$

By definition:

$$GP = \text{Required Revenue} - \text{Operating Costs}\ (OC) \qquad (6)$$

From Equations (5) and (6) we have:

$$\left[\text{Required Revenue} = OC + \frac{4}{3}\ (CF\text{-}DEP)\right]. \qquad (7)$$

Case 2: Depletion = .10 • Required Revenue (8)

From Equations (3) and (8):

$$NP = .50\ (GP - .10\ \text{Required Revenue}) \qquad (9)$$

Substituting Equations (6), (8), and (9) into Equation (2) yields:

$$CF - DEP = (.55)\ \text{Required Revenue} - (.50)OC \qquad (10)$$

Rearranging Equation (10) we have:

$$\left[\text{Required Revenue} = \frac{(.50)OC + CF - DEP}{.55}\right]. \qquad (11)$$

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