ORBES

AN ECONOMIC ANALYSIS OF COAL SUPPLY IN THE

OHIO RIVER BASIN ENERGY STUDY REGION

PHASE II

OHIO RIVER BASIN ENERGY STUDY

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AN ECONOMIC ANALYSIS OF COAL SUPPLY IN THE OHIO RIVER BASIN ENERGY STUDY REGION

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PREFACE

This is a report of research completed on a grant between West Virginia University and the U.S. Environmental Protection Agency. Walter P. Page, West Virginia University, served as principal investigator.

The authors wish to thank John Gowdy and John Uribe for assistance with the calculations. Special thanks are extended to Mary Ann Albertazzie and Marilyn Rose for their competent typing services and cooperative attitude, and to the Bureau of Business Research, West Virginia University, for managing the grant.

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INTRODUCTION

The focus of this work is upon identifying the coal supply districts which have historically served the Ohio River Basin Energy Study (ORBES) region (see Figure 1) and to estimate the resource depletion costs associated with expanded levels of coal production, 1974-2000. Coal production levels for various ORBES scenarios are provided by the ORBES energy and fuel demand model (1). A separate research effort allocated the tonnage to producing districts by mine and coal type (2).

In Section II below we discuss the historic sources of coal supply to the ORBES region. Supplying districts which account for most coal consumed in the region consist of those in the Eastern Interior and Appalachian coal provinces. It was largely this information, together with other literature studies, which convinced us to focus on these two provinces as the sources of coal supply to the ORBES region for future time periods.

Estimating depletion costs rests upon properly specified supply curves. Supply curves are properly defined, however, only for competitive industries. Having identified the sources of supply in Section II, we examine the competitiveness of coal production in this supplying region in Section III.

Section IV presents the analytic model used for estimation of depletion costs over time. As with most other ORBES research, this work is based upon existing models. Among the alternative models found in the literature, the statistical model developed by M. Zimmerman at M.I.T. was selected for adaptation to this research (3). Appropriate modifications were made (data bases, parameters, etc.) in order that the Zimmerman model conform with the particular requirements of the present project.

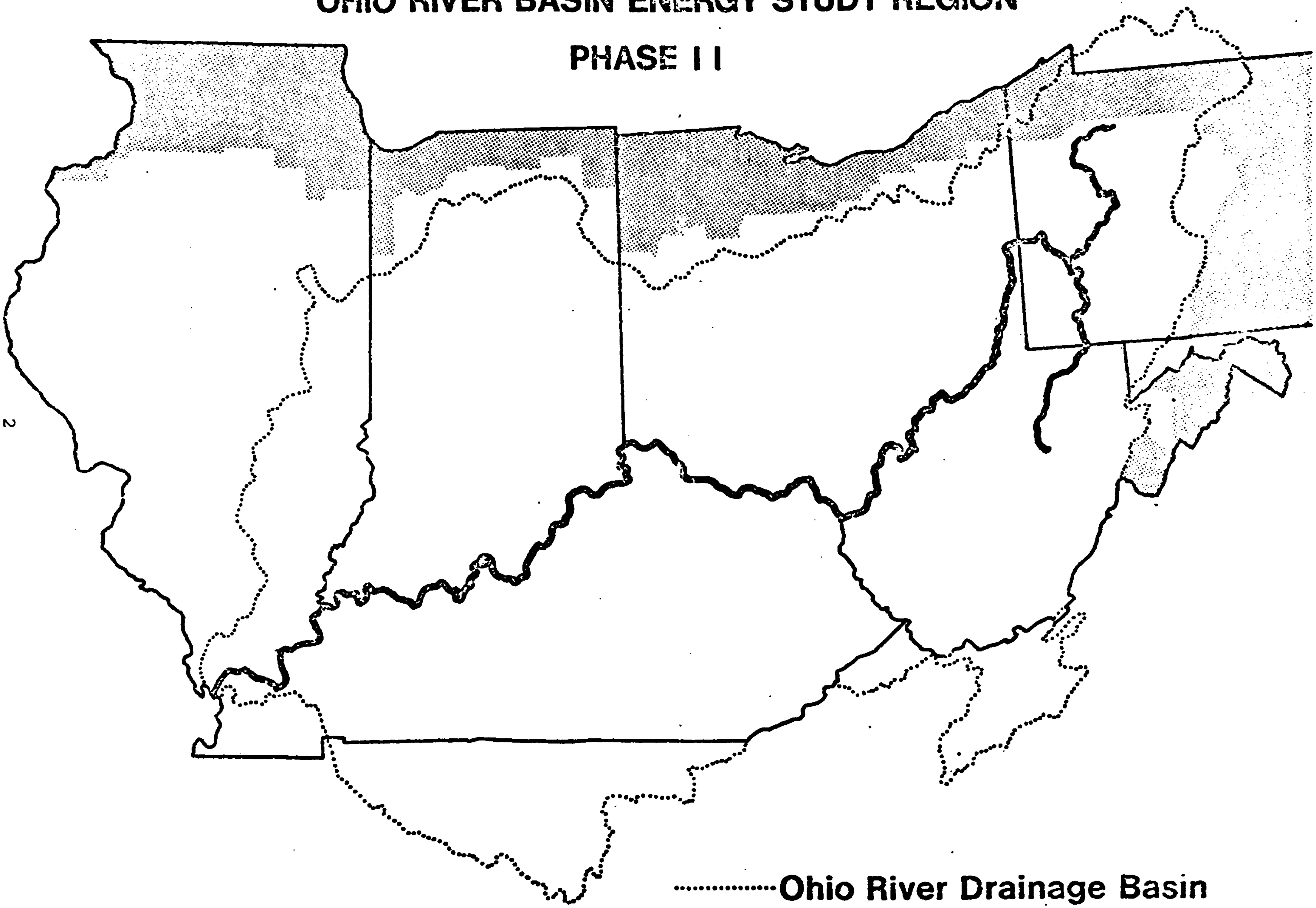
The last section of this report, Section V, presents the results of our analysis and discusses the significance of our findings for the coal industry in Appalachian and Interior Basins.

In this work, as in most ORBES research, certain parameters, policies, etc. were jointly decided upon by the ORBES Core Team. In some cases, these decisions influenced particular research results. In addition, the integrated nature of the ORBES project required that output of one research effort serve as input to another. Assumptions, decisions, etc. made in one research project, then, may have influenced the results obtained from another project. Because this was the case, we identify below those decisions made by the Core Team or other researchers which influenced the analysis:

Figure 1

OHIO RIVER BASIN ENERGY STUDY REGION

PHASE II



1. It was assumed that western coal makes no significant inroads into the regional market by the year 2000.

2. There were two sulfur categories considered in the analysis: less than or equal to 1.8 percent and greater than 1.8 percent. The first category was appropriate to State Implementation Plan (SIP) utilities; the second, to New Source Performance Standard (NSPS) and Revised New Source Performance Standard (RNSPS) utilities.

3. The ratios of utility and non-utility coal to total coal consumption in the region were assumed invariant over time. Similarly, the ratio of coal exports to total production in the region was invariant with respect to time. All ratios were in terms of baseline calculations of coal consumption and production.

4. The split between underground and surface coal in the future was to be the same as that existing in the base period.

SECTION II

SOURCES OF COAL SUPPLY AND END USES OF COAL: THE ORBES REGION

To estimate depletion costs for projected levels of coal production, it is necessary to identify producing areas which supply the ORBES region. Using standard data sources, we investigated the tonnage going into the six ORBES states by Bureau of Mines (BOM) producing districts. In terms of total coal consumed in the six ORBES states, Table 1 shows the pattern of supply, 1970-1976. Based on our investigations, BOM district 13 (Eastern Province) and Districts 12, 14, and 15 (Interior Province) are excluded from the table. In all four cases, the tonnage contribution to six-state consumption was less than 1 percent. In 1976, for instance, these four districts provided just over 0.2 percent of total coal consumed in the six states. From Table 1, approximately 99.5 percent of all coal consumed in the six-state area came from the Eastern and Interior Provinces in 1970. By 1976, the percentage had declined somewhat, to 93.4 percent. Over the 1970-1976 period, there has been some intrusion into the six-state market by Northern Great Plains and Rocky Mountain Province coals. It is unclear as to whether or not this coal has been coming into the ORBES region. Causal evidence from utility representatives suggests most of this coal is going into the non-ORBES portions of the six-state area, primarily along the northern tier of counties in Illinois, Indiana, and Ohio. In terms of total coal consumption in the six-state area (and certainly in the ORBES region), 1970-1976, almost all coal is supplied by BOM districts 1, 2, 3, 4, 6, 7, 8, 9, 10, and 11. For the most part, these districts are all contained within the ORBES boundaries and represent the Appalachian and Eastern Interior coal fields. Figure 2 provides a visual representation of Table 1 data.

The data, by district, state, and year, used for preparing Table 1 is found in Tables 2 through 8. Tables 2 through 8 reveal the 1970-1976 pattern of coal supply to the six states; e.g., the Eastern Province supplied almost all coal used in Pennsylvania, Ohio, and West Virginia, moderate amounts to Indiana and Kentucky (25.7 percent and 21.7 percent, respectively), and relatively little to Illinois.

Also of interest is the percent distribution of coal by end use in the six-state area, 1970-1976. Table 9 provides this information, by state, for the six-state area, and for four end uses of coal (electric utility, coke and gas, retail, and all others). These data reveal the shift in coal use over the 1970-1976 period. Beginning in 1970, electric utilities accounted for 57.5 percent of total coal use in the six-state area. This percentage increased throughout the period until utilities accounted for 71.4 percent of total coal use by 1976. Some of this increase in electric utility shares,

Table 1

QUANTITY AND PERCENTAGE OF COAL CONSUMED IN THE ORBES SIX STATES BY PRODUCING PROVINCE, 1970-76

Region / District		Eastern Province*		Interior Province#		Northern Great Plains Province		Rocky Mountain Province		Western Region+	
Year	Six-State Total	Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
1970	263,147	171,912	65.3	90,035	34.2	-	-	-	-	1,081	.4
1971	251,183	168,107	66.9	78,750	31.4	-	-	-	-	4,326	1.7
1972	280,807	186,020	66.2	88,611	31.6	-	-	-	-	6,176	2.2
1973	273,098	180,266	66.0	84,972	31.1	-	-	-	-	7,909	2.9
1974	275,168	183,470	66.7	79,715	29.0	6,857	2.5	5,126	1.9	-	-
1975	283,125	184,584	65.2	81,317	28.7	10,476	3.7	6,748	2.4	-	-
1976	286,648	187,859	65.5	79,906	27.9	10,051	3.5	8,831	3.1	-	-

SOURCE: Mineral Industry Surveys, Bituminous Coal and Lignite Distribution, appropriate years.

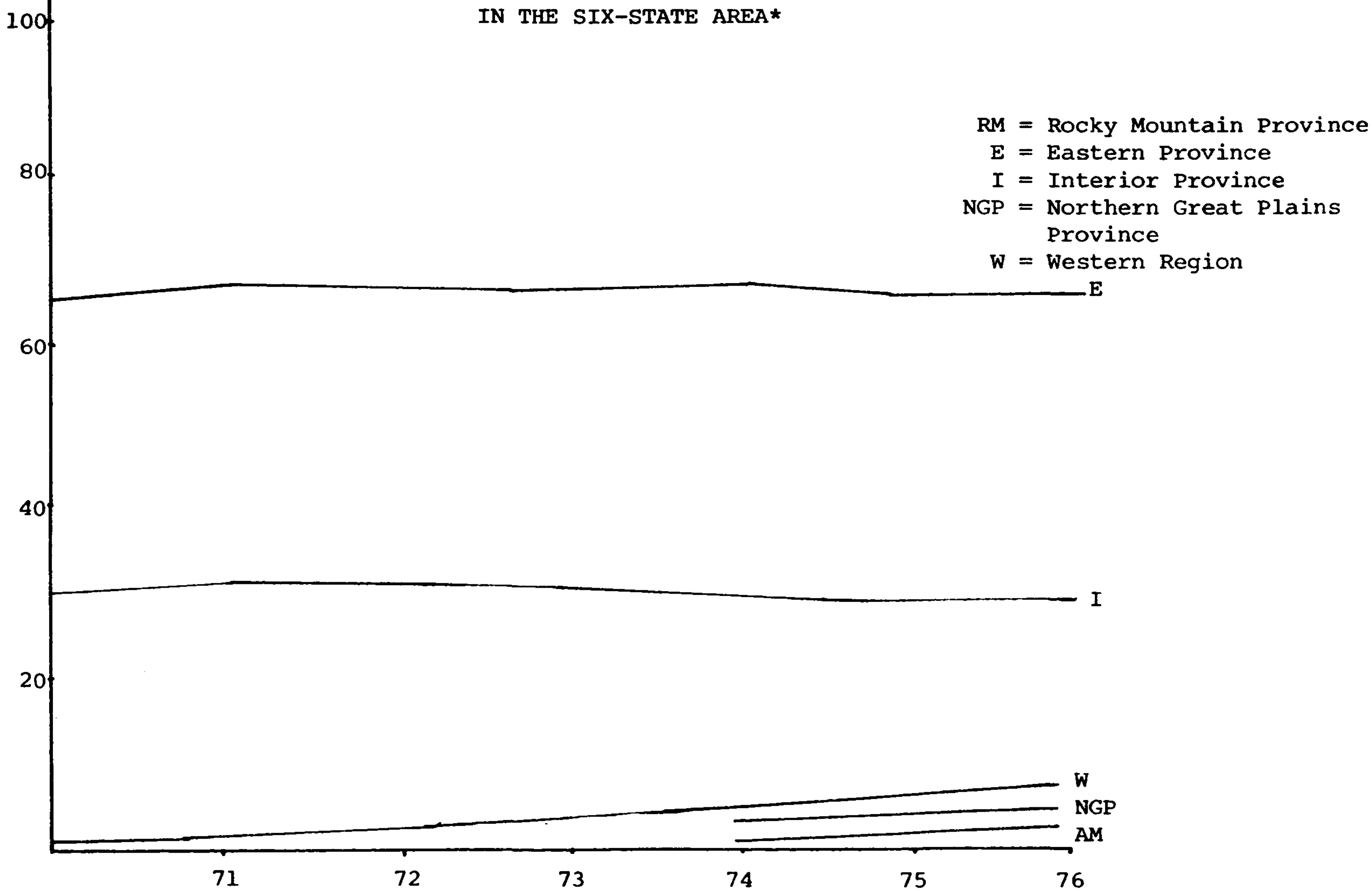
* Excludes district 13.

Excludes districts 12, 14, 15.

+ Northern Great Plains and Rocky Mountain Provinces are not distinguished in standard sources prior to 1974.

Figure 2

PERCENTAGE OF TOTAL COAL CONSUMED
BY SUPPLYING PROVINCE, 1970-76
IN THE SIX-STATE AREA*



*Plotted from data in Table 1.

Table 2

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1970

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	63,009	20,999	22,613	12,760	191	3,533	2,913	3	63,009	100	0	0	0	0	0	0	0	0	0	63,009	100
OH	67,375	239	6,463	4,642	35,553	2,564	15,232	0	64,693	96.0	0	2,682	0	0	0	0	0	2,682	4.1	67,375	100
IN	42,385	0	0	110	119	4,425	6,253	3	10,910	25.7	0	6,853	6,404	18,218	0	0	0	31,475	74.3	42,385	100
IL	42,311	13	0	30	5	849	2,997	0	3,894	9.2	0	2,600	33,978	761	0	0	0	37,339	88.2	41,233	97.4
KY	23,672	0	0	0	0	322	4,811	0	5,133	21.7	0	15,475	2,804	260	0	0	0	18,539	78.3	23,672	100
WV	24,395	1,667	3,174	8,302	1,809	830	8,613	0	24,395	100	0	0	0	0	0	0	0	0	0	24,395	100
Six State Total	263,147	22,918	32,250	25,844	37,677	12,523	40,819	3	172,034	65.4	0	27,610	43,186	19,239	0	0	0	90,035	34.2	262,069	99.6

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1970.

Table 3

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1971

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	58,982	21,874	18,314	11,182	263	3,198	4,151	0	58,982	100	0	0	0	0	0	0	0	0	0	58,982	100
OH	63,116	199	5,151	4,503	33,603	2,344	15,615	0	61,415	97.3	0	1,701	0	0	0	0	0	1,701	2.7	63,116	100
IN	38,599	185	544	215	247	2,880	4,805	0	9,876	25.6	0	6,514	5,543	15,990	0	0	0	28,047	72.7	37,923	98.2
IL	38,289	27	0	2	4	702	2,957	0	3,692	9.6	0	1,582	28,540	825	0	0	0	30,947	80.8	34,639	90.5
KY	25,590	0	0	11	0	367	7,157	0	7,535	29.4	0	13,740	3,803	512	0	0	0	18,055	70.6	25,590	100
WV	26,606	1,992	2,965	7,939	2,920	696	10,094	0	26,606	100	0	0	0	0	0	0	0	0	0	26,606	100
Six State Total	251,182	24,277	26,974	23,852	37,037	11,187	44,779	0	168,106	66.9	0	23,537	37,886	17,327	0	0	0	78,750	31.4	246,856	98.3

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1971.

Table 4

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1972

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	64,518	25,988	19,254	10,410	114	3,111	5,641	0	64,518	100	0	0	0	0	0	0	0	0	0	64,518	100
OH	67,795	675	5,669	4,871	35,130	2,273	17,385	0	66,003	97.4	0	1,417	0	375	0	0	0	1,792	2.6	67,795	100
IN	46,618	284	990	2	0	4,432	6,425	0	12,133	26	0	6,418	6,253	20,426	0	0	0	33,097	71	45,230	97
IL	42,028	0	0	14	2	612	3,111	0	3,739	8.9	0	1,717	31,331	453	0	0	0	33,501	79.7	37,240	88.6
KY	27,389	0	0	11	0	302	6,855	0	7,168	26.2	0	15,857	3,595	769	0	0	0	20,221	73.8	27,389	100
WV	32,459	2,085	3,221	10,794	2,675	778	12,906	0	32,459	100	0	0	0	0	0	0	0	0	0	32,459	100
Six State Total	280,807	29,032	29,134	26,102	37,921	11,508	52,323	0	186,020	66.2	0	25,409	41,179	22,023	0	0	0	88,611	31.6	274,631	97.8

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1972.

Table 5

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1973

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	64,469	26,179	19,690	8,642	174	3,143	6,641	0	64,469	100	0	0	0	0	0	0	0	0	0	64,469	100
OH	65,557	984	4,854	5,114	33,209	2,398	17,052	0	63,611	97.0	0	1,508	0	438	0	0	0	1,946	3.0	65,557	100
IN	45,061	457	1,008	0	5	3,697	6,521	0	11,688	25.9	0	5,844	6,013	19,834	0	0	0	31,691	70.0	43,379	96.3
IL	40,628	0	0	17	0	496	2,607	0	3,120	7.7	0	1,779	29,075	425	0	67	0	31,346	77.2	34,466	84.8
KY	25,098	0	0	31	0	172	4,880	0	5,083	20.3	0	16,605	2,923	467	0	0	0	19,995	79.7	25,078	100
WV	32,305	2,050	3,022	11,395	1,497	689	13,652	0	32,305	100	0	0	0	0	0	0	0	0	0	32,305	100
Six State Total	273,098	26,670	28,574	25,199	34,885	10,595	51,353	0	180,276	66.0	0	25,376	38,011	21,164	0	67	0	84,978	31.1	265,254	97.1

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1973.

Table 6

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1974

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	63,322	26,295	20,195	6,586	339	2,483	2,483	0	58,381	92.2	0	0	0	0	0	0	0	0	0	58,531	92.2
OH	69,642	1,239	5,545	4,740	33,044	2,530	19,275	17	66,390	95.3	0	1,760	23	347	0	0	0	2,080	3.0	68,470	98.3
IN	43,921	840	881	160	31	3,272	6,226	43	11,453	26.1	0	3,506	6,922	19,140	0	43	0	29,611	67.4	41,064	93.5
IL	39,054	24	0	37	0	596	2,501	0	3,158	8.1	0	1,269	26,366	493	0	0	0	28,128	72.0	31,286	80.1
KY	25,445	7	0	60	0	245	5,215	0	5,527	21.7	0	16,166	2,006	1,656	0	0	0	19,828	77.9	25,355	99.6
WV	33,784	1,852	3,185	11,187	1,642	542	15,246	0	33,654	99.6	0	0	0	0	0	0	0	0	0	33,654	99.6
Six State Total	275,168	30,257	29,806	22,770	35,056	9,668	50,946	60	178,563	64.9	0	22,651	35,317	21,636	0	43	0	79,647	28.9	258,210	93.8

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1974.

Table 7

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1975

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	63,390	27,529	19,289	6,312	345	2,229	7,681	0	63,385	99.9	0	0	0	0	0	0	0	0	0	63,385	99.9
OH	68,019	841	6,266	5,005	33,468	2,367	16,658	8	64,615	95.0	0	1,899	0	72	0	31	0	2,002	2.9	66,617	97.9
IN	46,928	1,142	898	15	0	3,614	6,190	164	12,023	25.0	0	4,267	6,273	20,373	0	0	0	30,913	65.9	42,936	91.5
IL	41,948	38	0	5	0	478	2,206	0	2,727	6.5	0	901	26,044	386	0	0	0	27,331	65.2	30,058	71.7
KY	28,480	0	0	49	0	184	7,317	0	7,550	26.5	0	17,089	1,982	1,689	0	0	0	20,760	72.9	28,310	99.4
WV	34,360	2,803	3,040	12,550	742	506	14,643	0	34,284	99.8	0	76	0	0	0	0	0	76	100	34,360	100
Six State Total	640,826	52,675	29,493	42,421	34,555	9,380	54,695	172	184,584	28.8	0	24,232	34,299	22,520	0	31	0	81,082	12.7	265,666	41.5

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1975.

Table 8

SOURCES OF COAL SUPPLY, BY BOM DISTRICT, TO THE SIX ORBES STATES, 1976

Province	EASTERN PROVINCE										INTERIOR PROVINCE										
District / State	State Total	1	2	3 & 6	4	7	8	13	Province Total	%	5	9	10	11	12	14	15	Province Total	%	Two Province Total	%
PA	64,592	24,457	19,399	6,338	781	2,224	7,393	0	64,592	100	0	0	0	0	0	0	0	0	0	64,592	100
OH	70,964	581	5,627	4,292	35,401	2,382	17,418	34	65,735	92.6	0	1,841	0	16	0	7	0	1,864	2.6	67,599	95.3
IN	45,837	984	779	138	0	3,109	5,787	145	10,942	23.9	0	4,356	6,080	20,633	0	13	2	31,084	67.8	42,026	91.7
IL	41,455	36	0	5	0	333	2,335	31	2,740	6.6	0	1,381	24,972	477	0	187	34	27,051	65.3	29,791	71.9
KY	27,320	0	0	63	54	100	7,153	0	7,370	27.0	0	16,908	1,487	1,512	0	1	0	19,908	72.9	27,278	99.9
WV	36,480	3,134	2,924	12,669	196	981	16,525	0	36,429	99.9	0	0	0	0	0	0	51	51	0.1	36,480	100
Six State Total	286,648	33,192	28,729	23,505	36,432	9,129	56,611	210	187,808	66.5	0	24,486	32,539	22,638	0	208	87	79,958	27.9	267,766	93.4

SOURCE: Mineral Industry Survey, Bituminous Coal and Lignite Distribution, 1976.

Table 9

PERCENTAGE DISTRIBUTION BY END USES OF COAL IN ORBES STATES, 1970-76*

STATE	END USE \ YEAR	1970	1971	1972	1973	1974	1975	1976	PERCENT CHANGE IN COAL USE, 1970-76
ILLINOIS	TOTAL	100	100	100	100	100	100	100	- 2.0
(1)	ELECT. UTIL.	69.6	72.9	76.8	79.9	79.0	83.1	84.5	18.9
(2)	COKE AND GAS	8.7	8.7	7.7	7.3	7.9	7.4	6.6	-25.8
(3)	RETAIL	6.1	4.9	3.4	2.3	1.9	1.2	1.3	-79.3
(4)	ALL OTHERS	15.5	13.4	12.1	10.5	11.1	8.3	7.7	-51.8
INDIANA	TOTAL	100	100	100	100	100	100	100	8.1
(1)	ELECT. UTIL.	53.7	56.5	56.0	57.2	57.6	61.2	63.8	28.4
(2)	COKE AND GAS	29.9	28.9	29.6	30.2	31.0	30.0	27.2	- 1.8
(3)	RETAIL	1.9	1.7	1.8	1.0	.9	1.3	.8	-56.1
(4)	ALL OTHERS	14.4	13.0	12.6	11.7	10.5	7.6	8.3	-38.0
OHIO	TOTAL	100	100	100	100	100	100	100	5.3
(1)	ELECT. UTIL.	55.1	61.1	62.3	63.7	63.4	68.2	70.6	35.0
(2)	COKE AND GAS	18.8	16.8	18.9	20.5	18.8	18.4	17.6	- 1.5
(3)	RETAIL	2.8	2.1	1.9	1.6	1.6	1.1	1.0	-63.3
(4)	ALL OTHERS	23.2	20.0	17.0	14.3	16.2	12.3	10.8	-51.2
KENTUCKY	TOTAL	100	100	100	100	100	100	100	15.4
(1)	ELECT. UTIL.	80.7	84.5	85.7	86.7	85.3	90.3	91.4	30.7
(2)	COKE AND GAS	6.7	6.5	6.0	4.6	5.5	4.4	3.0	-49.0
(3)	RETAIL	2.5	1.3	1.2	1.3	1.0	.7	.6	-71.9
(4)	ALL OTHERS	10.0	7.7	7.2	7.4	8.1	4.7	5.0	-42.1
PENNSYL.	TOTAL	100	100	100	100	100	100	100	2.5
(1)	ELECT. UTIL.	45.0	51.3	55.0	54.2	54.3	56.4	57.7	31.2
(2)	COKE AND GAS	42.1	36.9	35.9	36.0	36.3	36.0	36.0	-12.2
(3)	RETAIL	1.3	1.1	.7	1.0	.5	.3	.3	-76.6
(4)	ALL OTHERS	11.6	10.7	8.4	8.8	8.9	7.3	6.0	-46.8

(continued)

Table 9 (continued)

STATE	END USE \ YEAR	1970	1971	1972	1973	1974	1975	1976	PERCENT CHANGE IN COAL USE, 1970-76
W.VA.	TOTAL	100	100	100	100	100	100	100	49.5
(1)	ELECT. UTIL.	58.7	65.6	70.1	69.7	71.1	76.6	77.1	96.2
(2)	COKE AND GAS	20.8	16.2	15.5	16.1	15.1	13.0	14.5	4.2
(3)	RETAIL	.9	.9	.8	.8	1.0	.5	.3	-51.3
(4)	ALL OTHERS	19.5	17.2	13.5	13.5	12.8	9.9	8.1	37.8
SUM OF SIX ORBES STATES	TOTAL	100	100	100	100	100	100	100	8.9
(1)	ELECT. UTIL.	57.5	62.8	64.9	65.6	65.6	69.9	71.4	35.4
(2)	COKE AND GAS	23.7	21.1	21.3	21.8	21.5	20.6	19.9	- 8.3
(3)	RETAIL	2.6	2.0	1.6	1.3	1.2	.9	.7	-70.3
(4)	ALL OTHERS	16.2	14.2	12.2	11.3	11.7	8.7	8.0	-46.7

SOURCES: Mineral Industry Surveys, "Bituminous Coal and Lignite Distribution," Calendar Years 1970-76.

*All percentages rounded to nearest tenth of one percent.

1970-1976, reflects the decline in absolute amounts used in the other three end use categories; some reflects rising absolute consumption of coal by utilities over the period. Total coal use in the six-state area rose by approximately 9 percent over the period (see Table 1). All other end uses of coal (coke and gas, retail, and all others) experienced declines in percent shares over the 1970-1976 period in total six-state area use.

The percentage shares in the six-state total do not adequately reflect conditions at the individual state level. In 1976, for instance, the utility share in state total coal use for Illinois, Indiana, Ohio, Kentucky, Pennsylvania, and West Virginia, respectively, was 84.5 percent, 63.8 percent, 70.6 percent, 91.4 percent, 57.7 percent, and 77.1 percent. Percentages for other end uses also vary widely. The interested reader is referred to Table 9 for these details.

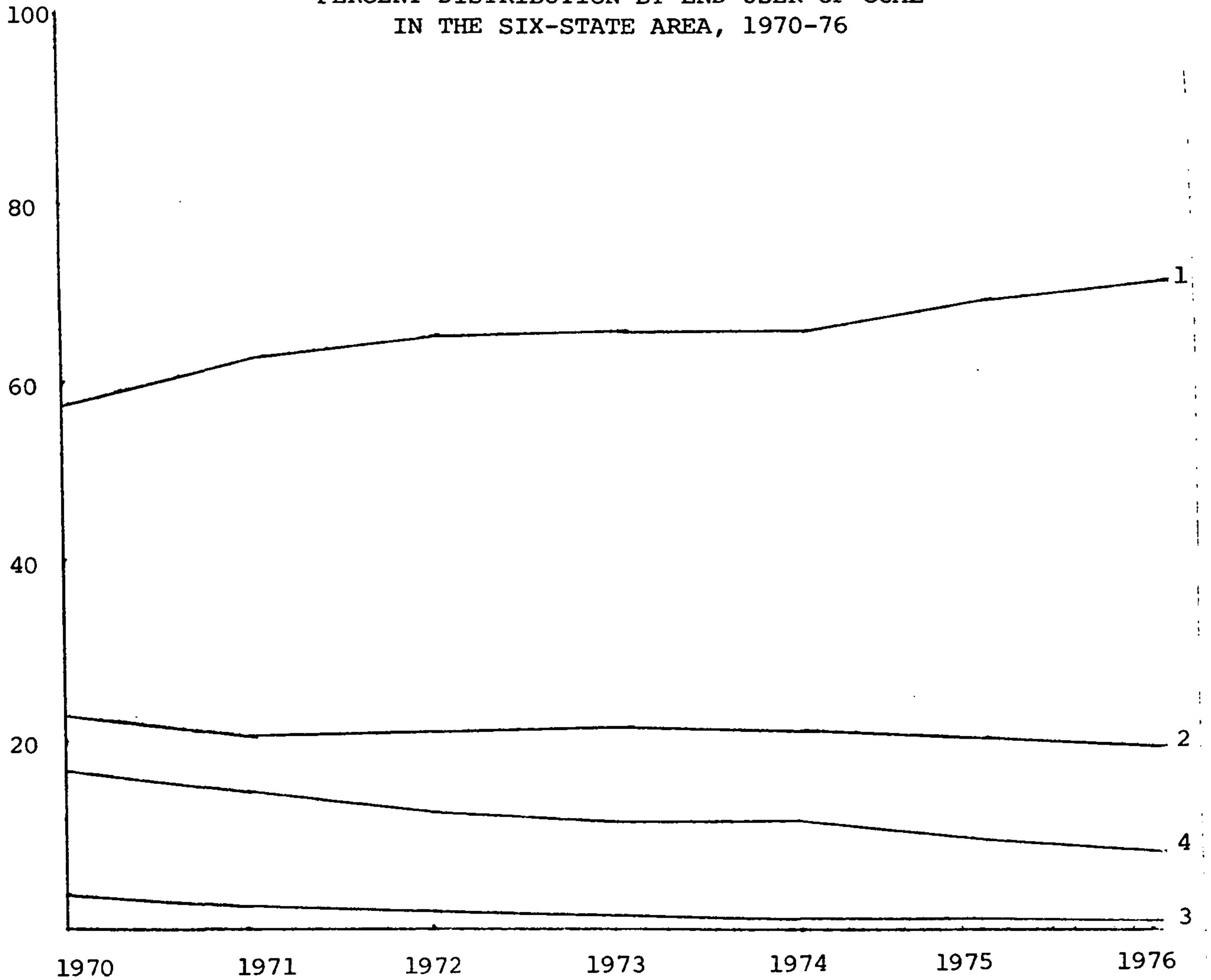
A somewhat different perspective on six-state and individual state changes in coal use may be found from examination of the last column of Table 9, "Percent Change in Coal Use, 1970-1976." With respect to the six-state data, consumption of coal declined in all end uses except electric utilities: coke and gas by 8.3 percent, retail by 70.3 percent, and all others by 46.7 percent. Electric utility consumption of coal increased by 35.4 percent. As a result of the positive increase in electric utility use, total coal consumption in the six-state area increased by 8.9 percent. Again, there is a great deal of variation among individual states. In consumption of coal by electric utilities, for instance, the percent change, 1970-1976, for Illinois, Indiana, Ohio, Kentucky, Pennsylvania, and West Virginia, respectively, was 18.9 percent, 28.4 percent, 35 percent, 30.7 percent, 31.2 percent, and 96.2 percent. Other end use sectors also show diverse patterns when individual states are compared.

Figures 3 through 9 provide visual representation of the data found in Table 9. Figure 3 contains line plots of the percent distribution of coal, by end user, in the six-state area, 1970-1976. Figures 4 through 9 provide similar plots for the individual states. These figures portray percentage value for each end user as well as the time trend in percent shares.

In the six-state area, then, most coal consumed is supplied by Eastern Interior and Appalachian BOM districts (excluding district 13 from Eastern coal), and the dominant use of coal is for electric generation (71.4 percent); coke and gas ranked second (19.9 percent). The large amount of coal consumed in the electric utility sector suggests that estimates of depletion costs will be most influenced by changes in generating capacity in the region. This is particularly true in light of the fact that only electric utility use of coal, 1970-1976, shows an increase (35.4 percent). Coke and gas use of coal, the second ranked sector in 1976, experienced a decline in use (-8.3 percent) over the 1970-1976 period.

Figure 3

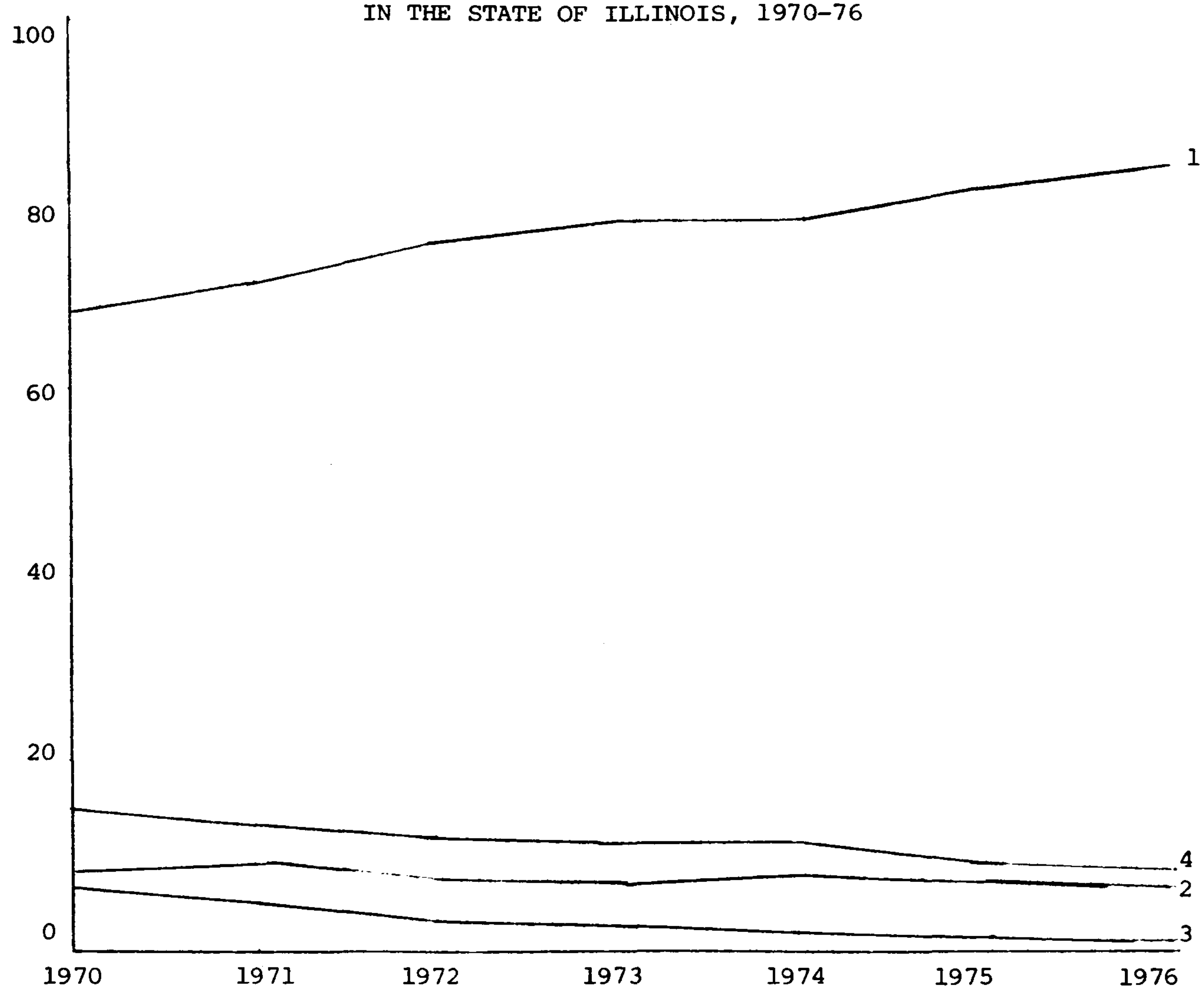
PERCENT DISTRIBUTION BY END USER OF COAL
IN THE SIX-STATE AREA, 1970-76



Legend: 1 - Electric Utilities
2 - Coke and Gas
3 - Retail
4 - All Others

Figure 4

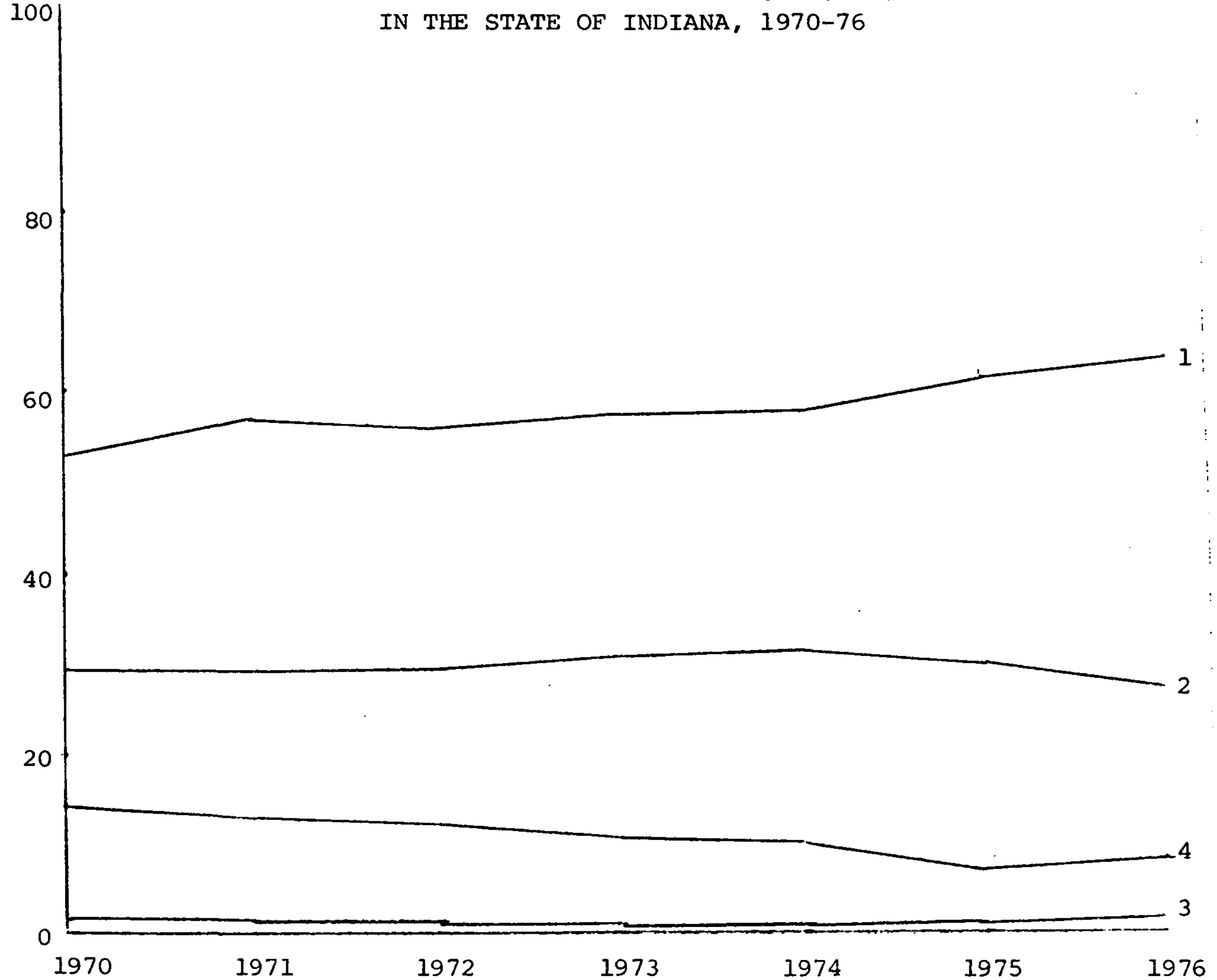
PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF ILLINOIS, 1970-76



Legend: 1 - Electric Utilities 3 - Retail
2 - Coke and Gas 4 - All Others

Figure 5

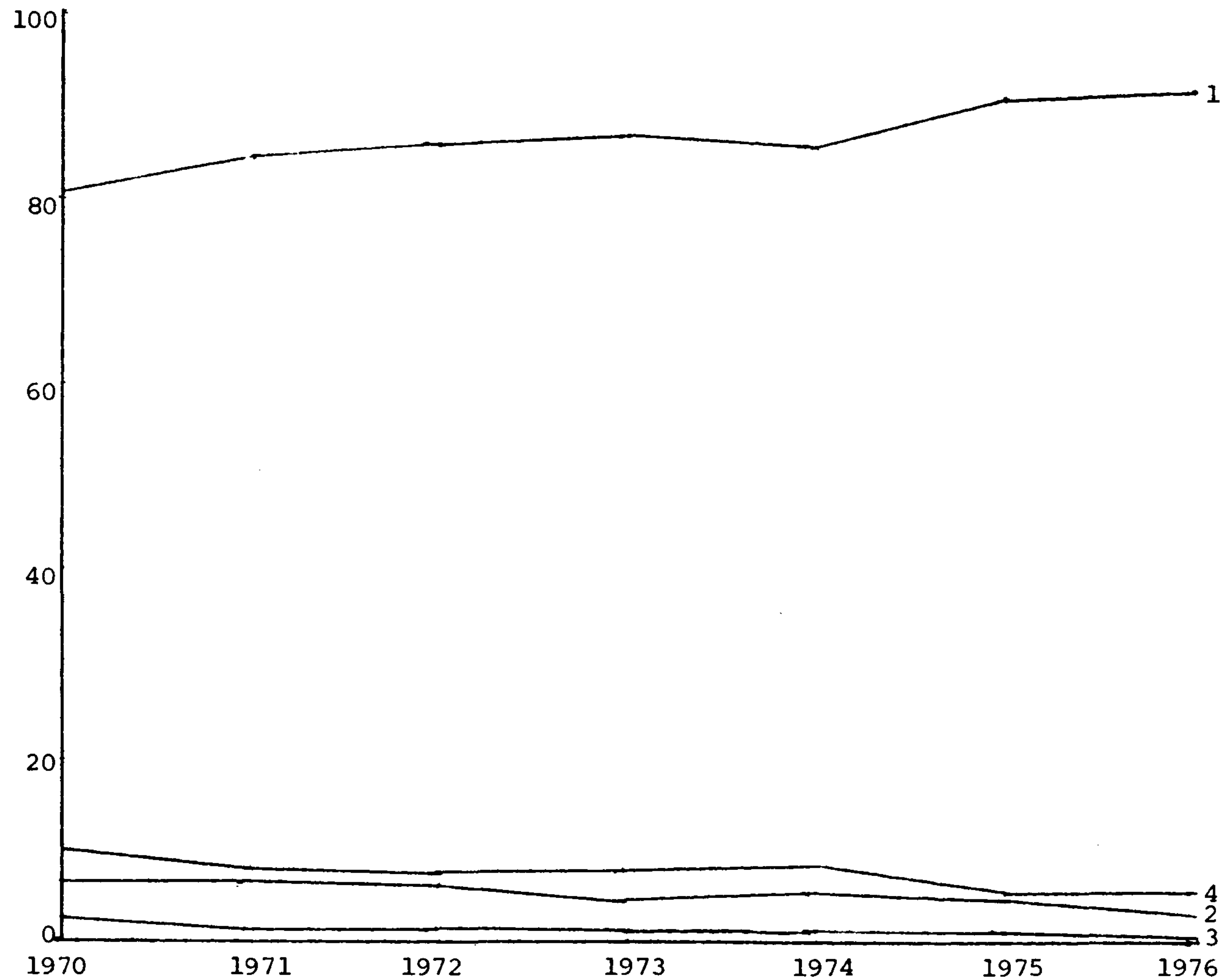
PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF INDIANA, 1970-76



Legend: 1 - Electric Utilities 3 - Retail
2 - Coke and Gas 4 - All Others

Figure 6

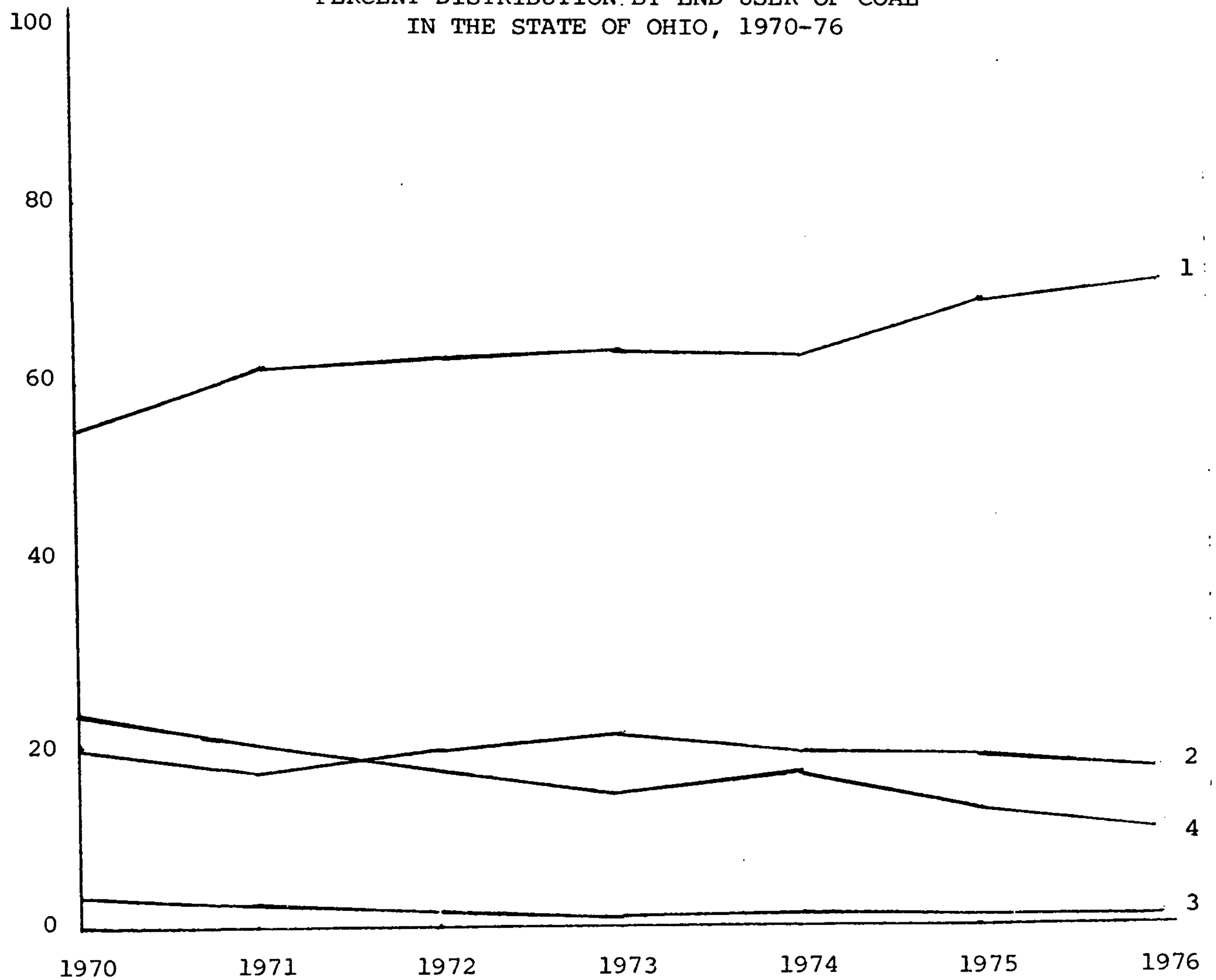
PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF KENTUCKY, 1970-76



Legend: 1 - Electric Utilities 3 - Retail
2 - Coke and Gas 4 - All Others

Figure 7

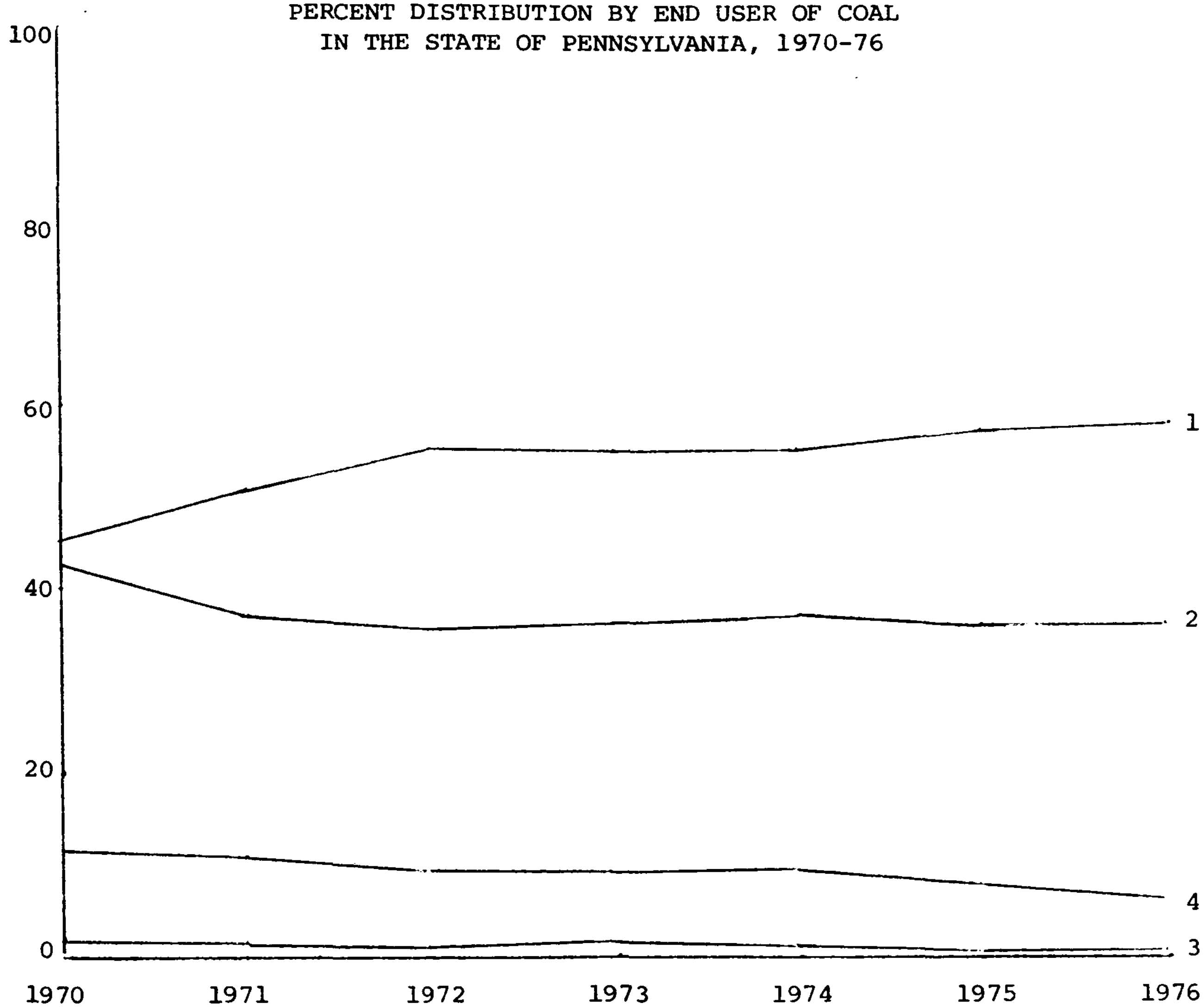
PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF OHIO, 1970-76



Legend: 1 - Electric Utilities 3 - Retail
2 - Coke and Gas 4 - All Others

Figure 8

PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF PENNSYLVANIA, 1970-76



Legend: 1 - Electric Utilities
2 - Coke and Gas
3 - Retail
4 - All Others

Figure 9

PERCENT DISTRIBUTION BY END USER OF COAL
IN THE STATE OF WEST VIRGINIA, 1970-76

Legend: 1 - Electric Utilities
2 - Coke and Gas
3 - Retail
4 - All Others

SECTION III

COMPETITIVENESS IN THE ORBES-REGION COAL MARKET

It is a well-known proposition in economics that supply curves are well-defined only for competitive industries. Estimating depletion costs in the ORBES region is accomplished by estimating long-run coal supply curves (or approximations to such curves) for the various supply districts. For our procedure to be valid, we need to know whether or not the supplying region is characterized by competitive conditions. Existing literature does not provide an answer to this question in terms of the regional market of interest: no previous work has focused on this particular supplying district, and most studies fail to evaluate the concentration in ownership of reserves. As this is the case, we examine the question of competitiveness in coal production for the producing districts which supply the ORBES region.

Competitiveness in coal markets should be evaluated in terms of both production and reserve concentration ratios. Such ratios would reflect both the current competitiveness among coal suppliers and any potential competitive threat from ownership of reserves. Analytic work assessing competitiveness has focused on the structure-performance relationship, where structural variables are linked with market performance. Most efforts have been directed toward establishing a relationship between sellers' concentration and allocative efficiency measured in terms of long-run profits (this, and other measures, are reviewed in Weiss (4)). Although such a relationship is not, by itself, sufficient information to establish the competitiveness of an industry, it is, nonetheless, a widely used and accepted measure of market power. Entry barriers and institutional variations between industries are the most often cited additional data necessary for a complete assessment of competitiveness (see (5) and (6) for further discussion). The relationship, then, is one which asserts that high concentration ratios are associated with a high probability of successful collusion and, hence, with high long-run profits, and vice versa for low concentration ratios. In studies of competitiveness of coal markets, primary concentration has been on the structure-performance relations (see (5) through (13).

The most widely used and cited "critical" ratios are those developed originally by Bain (14). For the four largest firms in an industry, his assessment of the probability of tacit cooperation and, hence, significant anticompetitive behavior, is as follows:

Largest 4 Firms' Market Shares	Likelihood of Tacit Cooperation
76-100 percent	High
51-75 percent	Moderate
26-50 percent	Low
0-25 percent	Very Low

Analyses are typically carried out for 4, 8, and 20 firm concentration ratios. Bain argues that, with roughly 35-50 percent for 4 firms and 45-70 percent for 8 firms, and with a large total number of producers, it is questionable if there exists an oligopoly or a significant potential for anticompetitive behavior. According to Bain, for 4 firm rates below the 25 percent level, essentially competitive conditions prevail. In any event, courts have had a tendency to utilize 50 percent ratios (4 firm) as evidence of significant potential for anticompetitive behavior. To be consistent with other analyses of energy market competitiveness, we report our results at the 4, 8, and 20 firm levels.

Interpretation of "relevant" markets under Section 7 of the Clayton Act has been a controversial matter (see (9) for a discussion of court attitudes on this matter). However one interprets the legal decisions concerning relevant markets and the appropriate criteria for defining a market, producing regions alone are not an appropriate definition. In this work we adopt the attitude that competitiveness is best measured by considering a demanding region in which the "Little In From Outside" criterion of Elzinga and Hogarty (9) applies. This definition seeks to identify whether or not a prescribed demand area secures most of its coal from identifiable districts within that demand area. If so, one is interested in calculating production and reserve ownership concentration ratios for those districts. The implicit assumption in this definition is that coal moves, on the average, similar distances within the market area as it does outside the area and, as a consequence, there is no sheltered (by transportation costs) market associated with coal supplying districts. That assumption is valid in the case of the ORBES region.

Applying the above criterion, the six-state area is a well-defined regional market for coal. The Eastern portion of the Interior Province and the Eastern Province are identified as the supplying districts in that regional market. It should be noted that the Eastern Interior and Eastern Provinces also sell substantial coal outside of the six-state area. As coal shipments move freely within the six-state area, however (Kentucky sells to Ohio, West Virginia sells to Illinois, etc.), there are clearly no well-defined "sheltered" markets within the area for producers (sheltered in terms of transportation costs). As a consequence of the above, competitiveness in this regional market is determined by examining concentration ratios in production and ownership of reserves for producers in the Eastern Interior and Eastern Provinces.

Table 10 contains production concentration ratios for the 4 firm, 8 firm, and 20 firm levels for the six states comprising the Eastern Interior and Eastern Provinces (district 13 is excluded for reasons noted earlier). The ratios are, respectively, 28.2 percent, 39.5 percent, and 51.8 percent for the 4, 8, and 20 firm levels. Using Bain's or any other criterion, these ratios are very consistent with the hypothesis of competitiveness. To place these ratios in some perspective, Table 11 contains production concentration ratios at the national and regional levels from several studies. Table 11 reveals the extent of similarity in the production ratios calculated for both 1962 and 1970 for the "Midwest." These relatively high ratios, however, would be extremely misleading if one draws the conclusion that, in a market sense, producers were able to exercise noncompetitive behavior. Because their output is sold in a regional market in conjunction with producers from the Eastern Province, the proper perspective on viewing the competitiveness of the market is to examine the concentration ratios for <u>all</u> producers serving the market. That is what our Table 10 portrays. In production, then, it is clear that the six-state market is readily classified as very competitive in coal production.

Studies of competition in coal markets are frequently criticized, among other things, for not considering ownership of reserves. Concentration in reserve ownership could be considered a <u>potential</u> competitive threat. Until the FTC work of 1974, such a consideration was not possible, because no adequate data source on reserve ownership existed. The FTC conducted an extensive survey of 1974 reserve ownership patterns. This remains the only comprehensive data base on reserve ownership. The present writer gained access to this data base under a non-disclosure agreement. As a consequence, the tables and discussion concerning reserve ownership may not reveal company names. The characteristics of the sample size, etc., for this data base are discussed in the FTC documents (8, 13). The concentration ratios for reserve ownership reveal a qualitative pattern quite similar to that observed for production ratios, although the quantitative differences between producing areas are less dramatic: concentration in the Eastern Province is somewhat less than in the Interior, while for the six-state market area, the ratios are similar to that of the United States. Tables 12 through 15 contain, respectively, Eastern Province, Interior Province, ORBES region, and United States concentration ratios for ownership in reserves. In the FTC data base, uncommitted and committed reserves for all sulfur categories are included, as is metallurgical coal.

The ORBES region has 4, 8, and 20 firm ratios, respectively, of 15.8, 22.2, and 29.8. These ratios are somewhat higher than for the United States, where the respective values are 13.3, 18.2, and 26.0. The slightly higher ratio values for the regional market are attributable to the influence of both Interior and Eastern Provinces. Unlike the case with production ratios, both the Eastern and Interior Provinces tend to have somewhat higher reserve ratios than the United States. In the case of the Eastern Province, 4, 8, and 20 firm ratios are, respectively, 15.3, 22.8, and 30, while for the Interior Province, the respective values are 22, 28.6, and 34.3 Again, as in the case with production ratios, the reserve ratios for the six-state market (Table 14) reveal no potential for anticompetitive behavior.

Table 10

RANK ORDER AND CONCENTRATION RATIOS OF LEADING 20 SIX-STATE AREA PRODUCING FIRMS, 1975*

Rank		1975 Output# (Tons)	Percentage Share of ORBES Region	Cumulative Percentage
1	Occidental Petroleum Co.	72,898,432	11.3	
2	Peabody Coal Holding Co.	50,062,811	7.8	19.1
3	Continental Oil Co.	34,390,365	5.3	24.4
4	Bethlehem Steel Co.	24,430,582	3.8	28.2
5	U.S. Steel Corp.	21,585,276	3.4	31.6
6	North American Coal Co.	18,860,951	2.9	34.5
7	Amax, Inc.	17,273,547	2.7	37.2
8	Gulf Resource & Chemical Corp.	14,568,081	2.3	39.5
9	Pittston Co.	14,399,004	2.2	41.7
10	American Elect. Power Serv. Co.	9,213,982	1.4	43.1
11	Ohio Petroleum Co.	8,891,436	1.4	44.5
12	General Dynamic Corp.	6,510,458	1.0	45.5
13	Exxon Corp.	5,647,412	0.9	46.4
14	Republic Steel Corp.	5,493,523	0.9	47.3
15	Falcon Seabord, Inc.	5,441,401	0.8	48.1
16	Westmoreland Coal Co.	5,398,188	0.8	48.9
17	Mapco, Inc.	5,346,832	0.8	49.7
18	Pennsylvania Power & Light Co.	4,418,986	0.7	50.4
19	Houston-Natural Gas Corp.	4,258,376	0.7	51.1
20	Rochester & Pittsburgh Coal Co.	3,942,562	0.6	51.7

(continued)

Table 10 (continued)

CONCENTRATION RATIOS		
4 firm	=	28.2
8 firm	=	39.5
20 firm	=	51.8

SOURCE: Keystone Coal Industry Manual, 1977.

* Supplying region consists of states of Kentucky, Illinois, Indiana, Ohio, Pennsylvania and West Virginia.

Total 1975 regional production = 643,648,158.

Table 11

NATIONAL AND REGIONAL CONCENTRATION RATIOS FOR COAL PRODUCTION*

	4 firm	8 firm	20 firm
Duchesneau (1972 national level)	30.4	40.4	55.1
FTC (1970 national level)	30.7	41.2	56.5
Markham (1974 national level)	26.6	36.7	51.2
Moyer (1962 Midwest region)	54.6	74.2	Not Available
FTC (1970 Midwest region)	65.6	85.6	97.0
FTC (1970 Appalachia)	28.2	39.8	51.9
Page (1975 Appalachi)	23.1	33.2	46.2

* See references for full citation.

Table 12

CONCENTRATION IN OWNERSHIP OF RESERVES, EASTERN PROVINCE, 1974*

Rank	1974 Reserves (million short tons)	Percent of# Total Reserves	Cumulative Percentage
1	7001	6.6	
2	3879	3.7	10.3
3	2701	2.6	12.9
4	2559	2.4	15.3
5	2245	2.1	17.4
6	2235	2.1	19.5
7	2116	2.0	21.5
8	1412	1.3	22.8
9	900	0.9	23.7
10	890	0.8	24.5
11	776	0.7	25.2
12	769	0.7	25.9
13	660	0.6	26.5
14	644	0.6	27.1
15	618	0.6	27.7
16	507	0.5	28.2
17	497	0.5	28.7
18	481	0.5	29.2
19	437	0.4	29.6
20	406	0.4	30.0

(continued)

Table 12 (continued)

CONCENTRATION RATIOS

4 firm	=	15.3
8 firm	=	22.8
20 firm	=	30.0

SOURCE: FTC survey data on 1974 reserve ownership for all coals.

* Based on total uncommitted and committed reserves for all sulfur categories.

Total U.S. reserves, from United States Geological Survey is 429,341 million short tons.

Table 13

CONCENTRATION IN OWNERSHIP OF RESERVES, INTERIOR PROVINCE, 1974*

Rank	1974 Reserves (million short tons)	Percent of# Total Reserves	Cumulative Percentage
1	9267	8.6	
2	8200	7.6	16.2
3	3589	3.3	19.5
4	2702	2.5	22.0
5	2080	1.9	23.9
6	1846	1.7	25.6
7	1605	1.5	27.1
8	1590	1.5	28.6
9	1240	1.6	30.2
10	1070	1.0	31.2
11	824	0.8	32.0
12	553	0.5	32.5
13	502	0.5	33.0
14	431	0.4	33.4
15	247	0.2	33.6
16	239	0.2	33.8
17	120	0.1	33.9
18	101	0.1	34.0
19	85	0.2	34.2
20	75	0.1	34.3

(continued)

Table 13 (continued)

CONCENTRATION RATIOS		
4 firm	=	22.0
8 firm	=	28.6
20 firm	=	34.3

SOURCE: FTC survey data on 1974 reserve ownership for all coals.

* Based on total uncommitted and committed reserves for all sulfur categories.

Total U.S. reserves, from United States Geological Survey is 429,341 million short tons.

Table 14

CONCENTRATION IN OWNERSHIP OF RESERVES, ORBES REGION, 1974*

Rank	1974 Reserves (million short tons)	Percent of# Total Reserves	Cumulative Percentage
1	9764	4.6	
2	9703	4.5	9.1
3	8200	3.8	12.9
4	6148	2.9	15.8
5	4548	2.1	17.9
6	4432	2.1	20.0
7	2286	1.1	21.1
8	2235	1.1	22.2
9	2116	1.0	23.2
10	2080	1.0	24.2
11	1605	0.8	25.0
12	1590	0.7	25.7
13	1420	0.7	26.4
14	1412	0.7	27.1
15	1240	0.6	27.7
16	985	0.5	28.2
17	890	0.4	28.6
18	824	0.4	29.0
19	776	0.4	29.4
20	769	0.4	29.8

(continued)

Table 14 (continued)

CONCENTRATION RATIOS		
4 firm	=	15.8
8 firm	=	22.2
20 firm	=	29.8

SOURCE: FTC survey data on 1974 reserve ownership for all coals.

* Based on total uncommittee and committed reserves for all sulfur categories.

Total U.S. reserves, from United States Geological Survey is 429,341 million short tons.

Table 15

CONCENTRATION IN OWNERSHIP OF RESERVES, EASTERN PROVINCE, 1974*

Rank	1974 Reserves (million short tons)	Percent of# Total Reserves	Cumulative Percentage
1	21841	5.1	
2	16487	3.8	8.9
3	11780	2.7	11.6
4	7091	1.7	13.3
5	6468	1.5	14.8
6	5206	1.2	16.0
7	4583	1.1	17.1
8	4549	1.1	18.2
9	4401	1.0	19.2
10	4389	1.0	20.2
11	4115	1.0	21.2
12	2858	0.7	21.9
13	2510	0.6	22.5
14	2505	0.6	23.1
15	2286	0.5	23.6
16	2116	0.5	24.1
17	2095	0.5	24.6
18	2080	0.5	25.1
19	1913	0.5	25.6
20	1730	0.4	26.0

(continued)

Table 15 (continued)

CONCENTRATION RATIOS		
4 firm	=	13.3
8 firm	=	18.2
20 firm	=	26.0

SOURCE: FTC survey data on 1974 reserve ownership for all coals.

* Based on total uncommitted and committed reserves for all sulfur categories.

Total U.S. reserves, from United States Geological Survey is 429,341 million short tons.

For the ORBES coal market, production and reserve concentration ratios reveal a pattern which would certainly be viewed as highly competitive. As a consequence, coal supply curves for the producing districts serving the region are well-defined.

SECTION IV

THE ANALYTICAL MODEL OF DEPLETION COSTS

M.B. Zimmerman has developed a model which can estimate the long-run marginal cost of mining as a function of cumulative output over time. The model links geological information on remaining deposits with cost (as a function of rate of output and present mining conditions) to derive a cumulative cost function. The model is particularly well-suited to estimation of depletion costs from cumulative production over time. Because this is the case, we make use of Zimmerman's model for this analysis. The discussion of the model structure below is based on the October 7, 1977, paper by Zimmerman (3). The model application is to underground coal production from the BOM districts described in the previous two sections. Only underground mining is considered, as in the long run, the price will be determined by extraction, etc. costs from underground mines.

Zimmerman's work is basically composed of two parts. The first part is to estimate the long-run average cost of coal mining on the basis of integrating a productivity equation of coal mining and an expenditure equation. The second part estimates the long-run incremental cost, using the cumulative cost function, which is derived by taking a log form of the average cost equation estimated in the first part and truncating it under the assumption that underground coal according to the cost of mining is log-normally distributed.

Zimmerman's productivity equation assumes that the productivity of coal production is a function of seam thickness, the number of producing units (or sections), the number of openings, and other coal characteristics. His productivity equation is defined as follows:

$$\frac{Q}{S} = q = A\ Th^{\gamma}\ S^{\beta}\ OP^{\alpha}\ \varepsilon \tag{1}$$

where Q = total mine output
S = the number of producing units
A = constant term
Th = seam thickness
OP = the number of mine openings
ε = disturbance term
γ, β, and α = coefficients of respective variables.

His total expenditure equation is based on the assumption that total expenditure is a function of the number of producing units and the number of mine openings, which is estimated for each class of expenditures--capital, labor, and supplies. Total expenditure is obtained by summing expenditures of three classes.

$$E = a + bs + C\ op + \varepsilon \tag{2}$$

where E = total expenditure for a mine.

For deriving a long-run total cost equation, the productivity equation can be rewritten in terms of producing units:

$$S = \left(\frac{\bar{Q}}{(\frac{q}{s})\ W}\right) \tag{3}$$

where $\bar{Q}$ = annual output and W = annual working hours.

Substituting equation (2) in equation (3):

$$S = \left(\frac{\bar{Q}}{W\ A\ Th^{\gamma} \cdot OP^{\alpha}}\right)^{1 + \beta} \tag{4}$$

where $\varepsilon = 0$.

Substituting equation (4) in equation (2):

$$E = a + b \left(\frac{\bar{Q}}{WA(Th)^{\gamma} \cdot OP^{\alpha}}\right)^{1 + \beta} + C\ (OP) \tag{5}$$

Long-run average cost can be obtained by solving equation (5) in terms of $E/\bar{Q}$. Marginal cost also can be obtained by taking the derivative of equation (5) with respect to $\bar{Q}$. Minimum efficient scale can be solved in terms of $\bar{Q}$ by setting $dE/d\bar{Q}$ equal to zero. As a consequence, when two mine openings is minimum, the long-run average cost equation in a simplified form is:

$$AC^{*} = \frac{K}{Th^{\gamma}} \tag{6}$$

where K = long-run total cost.

Zimmerman's estimation of equation (6) is:

$$AC = \frac{2,567}{Th^{1.1071}} \tag{6'}$$

Equation (6) can be rewritten in a log form as:

$$\log AC^* = \phi(\log c) = \log K - \gamma \log Th - \log \varepsilon \tag{7}$$

where ε = disturbance term.

Equation (7) implies that the distribution of underground coal according to the cost of mining depends upon γ, K, seam thickness (Th), and the disturbance term (ε). The parameters, γ and K, were estimated in equation (6').

Since tons of coal by the log of seam thickness is distributed lognormally, the distribution of tons of coal in underground according to the log of the cost of mining is the sum of two normal distributions and, therefore, itself lognormal. Consequently, the mean of equation (7) is equal to $\log K - \gamma \overline{\log Th}$, and its variance is equal to $\gamma^2 (\sigma_{\log Th})^2 + (\sigma_{\log \varepsilon})^2$, where $\overline{\log Th}$ is the mean of the distribution of log Th.

The source of the difficulty is the fact that the least cost deposits are mined first. That implies that the coal remaining in the ground must be at least as costly to exploit as today's long-run incremental cost. If the distribution of coal according to cost is C, then the distribution of coal according to the log of the cost of mining can be rewritten in a truncated form of the normal distribution as follows:

$$\frac{\phi\ (\log c)}{1 - \int_{-\infty}^{\log \bar{c}} \phi(\log c)\ dc} \tag{8}$$

where $\phi(\log c)$ is normally distributed.

With the truncated equation (8), we are able to calculate the distribution of coal in the ground according to the cost of production, which can be written as:

$$T_j \int_{\log \bar{C}_{ij}}^{\log C_{ij}} [\phi\ (\log C_{ij}) / 1 - \int_{\infty}^{\log \bar{C}_{ij}} \phi\ (\log C_{ij} dC_{ij}]\ dC_{ij} \tag{9}$$

Where T_j = coal reserve tonnage for j region (j = 1,...,4)
C_{ij} = incremental cost for j region and i period (i = 0,...,7)
$\bar{C}_{ij}$ = incremental cost for 0 period (base year) and j region, $C_{ij} \geq \bar{C}_{ij}$ for all i and j.

Equation 9 represents the amount of coal available in future time periods at an incremental cost more than the base year (1974), as the given amount of coal in the ground is mined over time. It expresses the multiplication of total reserve tonnage for a given region and the probability of the distribution of coal in the ground according to the cost of mining between incremental costs for base year and the future. As a consequence, equation (9) can be defined implicitly as a cumulative cost function of coal production remaining in the ground.

If a cumulative output total is specified, then equation (9) can be solved for the upper limit of integration. The C_{ij} of the upper limit is the incremental cost of mining resulting from prodúcing the specified cumulative output total. Therefore, equation (9) can be set equal to cumulative production:

$$T_j \int_{\log \bar{C}_{ij}}^{\log C_{ij}} [\phi(\log C_{ij}) / 1 - \int_{\infty}^{\log \bar{C}_{ij}} \phi(\log C)\, dC_{ij}]\, dC_{ij} = CP_{ij} \tag{10}$$

where CP_{ij} = cumulative production for i period and j region.

Simplifying equation (10),

$$\int_{\log \bar{C}_{ij}}^{\log C_{ij}} \phi(\log C_{ij})\, dC_{ij} = \frac{CP_{ij}}{T_j \ ISP_{ij}} \tag{11}$$

where ISP_{ij} = the inverse of supplimentary probability for preceding period:

$$= \frac{1}{1 - \int_{\infty}^{\log \bar{C}_{ij}} \phi(\log C_{ij})\, dC_{ij}}$$

as $\bar{C}_{ij}$ is known, ISP_{ij} is, therefore, considered as a predetermined parameter.

In equation (11), both right-side and left-side terms represent equally the probability of coal distribution at the range of base year's incremental cost to the future incremental cost in question. CP_{ij}, T_j, ISP_{ij}, and $\bar{C}_{ij}$ are predetermined parameters. C_{ij} is unknown. The right-side term of equation (11) must be converted to a normal distribution. The reason is that the distribution of coal according to the cost of mining is assumed to be log-normally distributed.

Converting equation (11) to a normal form of distribution:

$$\int_{\frac{1}{\sigma}(\log \bar{C}_{ij} - U_j)}^{\frac{1}{\sigma}(\log c_{ij} - U_j)} \frac{e^{-\frac{U_j^2}{2}}}{\sqrt{2\pi}} \, du_j = \frac{CP_{ij}}{T_j \cdot ISP_{ij}} \qquad (12)$$

$$\text{where } \phi(\log C_{ij}) = \frac{1}{C_{ij}\,\sigma\sqrt{2\pi}}\, e^{-\{\frac{1}{2\sigma^2}(\log C_{ij} - U_j)\}}$$

where U_j = the mean of $\phi(\log c_{ij})$ which is equivalent to equation (7).

$$U_j = \log K - \gamma\, \overline{\log Th}$$

σ = the standard deviation of $\phi(\log c_{ij})$,

$$= \gamma^2 \quad (\sigma_{\log Th})^2 + (\sigma_{\log \varepsilon})^2$$

As a result of converting equation (12), both the upper limit and the lower limit of integration in equation (12) are standardized values (Z - values) on the normal distribution curve. Therefore, equation (12) can be explained with the normal distribution curve below.

Normal Distribution Curve

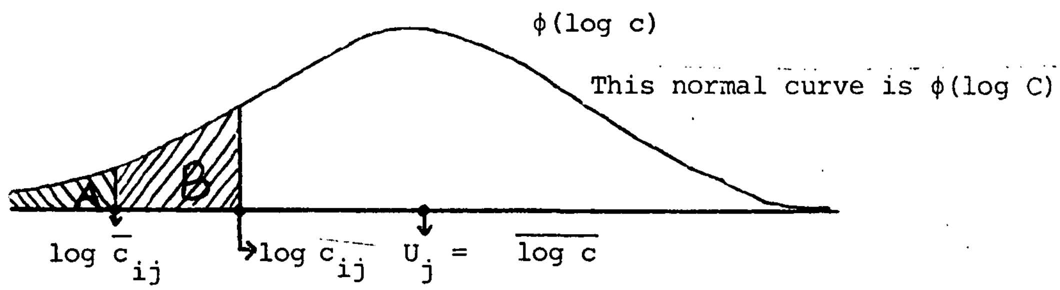


Figure 1

Equation (12) represents probability area B between two Z-values, $[(1/\sigma)(\log \bar{C}_{ij} - u_j)]$ and $[(1/\sigma)(\log C_{ij} - u_j)]$, or equivalently $\log \bar{c}_{ij}$ to $\log c_{ij}$ in Figure 1. Probability area A can be solved by substituting known parameters σ, u_j, and $\bar{c}_{ij}$ in the lower limit of equation (12) and then converting its Z-value to a probability in the normal distribution table.

Our objective is to calculate c_{ij} in question along the horizontal axis in Figure 1 with given predetermined parameters of equation (12), such as

$$\overline{(\phi(\log c)}, \sigma_{\phi(\log c)}, \overline{C}_{ij}, CP_{ij}, T_j, \text{ and } ISP_{ij}.$$

For calculating incremental cost sequentially over time, three steps must be repeated, as follows:

(1) The sum of the probabilities areas A and B is calculated and it must be converted to normal standardized values (Z-values).

(2) The Z-value is set to be equal to the upper limit of integration of equation (12), and solved in terms of log c_{ij}.

(3) The value of log c_{ij} must be taken anti-log to find the c_{ij} in question.

For solving equation (12) in terms of log c_{ij}, a remaining task is to estimate predetermined parameters of the equation.

<u>Estimation of the Mean and Standard Deviation</u>

As previously noted, the mean of $\phi(\log c_{ij})$ and its standard deviation are defined as:

$$\phi\overline{(\log c)} = \log K - \gamma \overline{\log Th} \tag{13}$$

where K = total cost of mining at a minimum average cost with a given seam thickness in equation (6) and (6'),

$$AC^* + K/TH^{\gamma} \text{ or}$$

$$AC^* = 2567/Th^{1.1071}$$

γ = the coefficient of seam thickness in equations (1), (6), and (6').

$\overline{\log Th}$ = the mean of the log of seam thickness.

and

$$(\sigma_{\phi(\log c)})^2 = \gamma^2 (\sigma_{\log Th})^2 + (\sigma_{\log \varepsilon})^2 \tag{14}$$

where γ = the same as in equations (6) and (6').

$(\sigma_{\log Th})^2$ = 0.0428, which is estimated for Pike County, Kentucky. This is uniformly applied to the whole reserve base.

In equations (13) and (14), K, γ, and $(\sigma_{\log Th})^2$ are known, but $\overline{\log Th}$ has to be estimated as follows:

In a formula of calculating the Z-value,

$$\frac{\log Th_i - \overline{\log Th}}{\sigma \log Th} = U \log Th \; .... \qquad (15)$$

where $\log Th_i$ = the log of a particular magnitude of seam thickness
$\sigma \log Th$ = standard deviation of the log of seam thickness
$U_{\log Th}$ = Z-value on the normal distribution curve corresponding to a particular $\log Th_i$

Simplifying equation (15) in terms of $\overline{\log Th}$,

$$\overline{\log Th} = \log Th_i - \sigma_{\log Th} \, U \log Th_i \qquad (15')$$

Application of the Zimmerman model to the ORBES work requires several estimated parameters for the defined supplying regions and sulfur categories. Examination of underground coal reserves and production convinced us that four supply regions from the Eastern Interior and Appalachian coal fields could be defined (the supply region to ORBES users): BOM districts 2, 4, 6, 10, and 11 constitute a high sulfur (greater than or equal to 1.9 percent sulfur content) producing region, districts 7 and 8 constitute a low sulfur (less than or equal to 1.8 percent) producing region, and districts 1 and 3 constitute both a low and high sulfur region. The reserve data base, by district and region, may be found in Table 16. The reader is reminded that "high" and "low" sulfur categories were defined by the ORBES Core Team. Data in Table 16 is used for estimating $U \log Th_i$ ($i = 1,...,4$) for seam thickness greater than 42 inches. The probability is converted to equivalent Z-values and $\log Th_i$ is 42 inches and $\sigma \log Th$ is 0.207. $\overline{\log Th}$, then, is calculated using equation (15'). The mean of $\phi(\log c)$ and its standard deviation are calculated using equations (13) and (14). The resulting estimates are shown in Table 17 for each of the four producing areas.

Before applying the model to the ORBES scenarios, it remains to estimate incremental cost, by region, for the base year (1974). Following Zimmerman's definition:

$$\overline{C}_{ij} = \frac{K}{(\overline{\pi \; Th^{\gamma}})^{1/n}} \qquad (16)$$

where K = the same as in equations (6) and (6')
γ = the same as in equation (1)

$(\overline{\pi \; Th^{\gamma}})^{1/n}$ = r-powered geometrical mean of seam thickness.

The solution to baseline incremental costs requires sample data on existing mines. The sample size and characteristics, of course, will be different from that found in Zimmerman's work, as we are dealing with different regions. For that purpose, samples by sulfur content were taken from old and new mines listed in the Keystone Coal Industry Manual (1976). The sample size, range of

Table 16

UNDERGROUND COAL RESERVE IN ORBES SUPPLYING DISTRICTS

District \ Sulfur Contents	≤ 1.8%	Ratio of Total	≥ 1.9%	Ratio of Total	Total*
2	2,575.36		7,551.31		12,226.24
4	871.75		8,641.15		15,669.17
6	28.86		3,155.03		3,527.72
9	0.24		5,668.83		5,769.32
. 10	3,234.27		33,914.32		40,533.42
11	877.09		5,042.31		7,546.04
Total 2-11	7,587.57	0.0883	63,972.95	0.7441	85,971.91
1	1,578.78		2,092.79		9,165.08
3	2,933.75		6,272.08		19,866.08
Total 1 & 3	4,512.53	0.1554	8,364.87	0.2881	29,031.16
7	2,977.19		30.51		5,823.44
8	8,083.79		1,095.80		18,388.97
Total 7 & 8	11,060.98	0.4568	1,126.31	0.0465	24,212.41

SOURCE: Bureau of Mines, The Reserve Base of Bituminous Coal and Anthracite for Underground Mining in the Eastern United States, Information Circular, 1974, IC 8655.

*Reason for discrepancy between the sum of sulfur contents and total reserves is that reserves for unknown sulfur contents are not counted.

Table 17

MEAN AND VARIANCE ESTIMATES FOR ϕ (LOG c)

Region	$(\overline{\log Th})$	Mean $(\overline{\phi \log c})$	Variance $(\sigma^2_{\phi(\log c)})$
2, 4, 6, 10 and 11 high sulfur	3.5017	3.9738	0.0525
1 & 3 low sulfur	3.6984	3.7560	0.0525
1 & 3 high sulfur	3.6112	3.7973	0.0525
7 & 8 low sulfur	3.6114	3.8523	0.0525

seam thickness, geometric means of seam thickness, and incremental cost estimates for 1974 are found in Table 18. The relationship between baseline incremental costs and the geometric mean of seam thickness found in Table 18 is as one would expect; $\bar{c}$ is greatest for the smallest geometric mean of seam thickness and least for the greatest value of seam thickness. The relatively large value of $\bar{c}$ for districts 7 and 8 is consistent with both the thin seam conditions in that region and the generally adverse mining conditions associated with met coal mining. The reader is cautioned about these values of $\bar{c}$. Sample sizes are small (only 9 in the case of low sulfur mines for districts 1 and 3) and there is no way to determine the direction or extent of bias in the samples. The values, nonetheless, do appear reasonable and are very similar to results reported by Zimmerman (Table 5 of reference (3)). In any event, we are not so much concerned with the absolute numbers as we are with the percentage change, 1974-2000, which can be attributed to depletion effects.

Table 18

INCREMENTAL COST ESTIMATES, 1974, FOR ORBES COAL SUPPLY REGIONS

District and Sulfur Contents	Number of Observations	Range of Seam Thickness	Geometric Mean of Seam Thickness	$\overline{C}$
2,4,6,9,10, and 11 high sulfur (≥1.9%)	18	48-90	61.22	26.99
1 & 3 low sulfur (≤1.8%)	9	42-84	58.80	28.22
1 & 3 high sulfur (≥1.9%)	17	40-96	87.10	18.27
7 & 8 low sulfur (≤1.8%)	32	31-72	47.27	35.96

SECTION V

ORBES SCENARIO RESULTS

Five scenarios were examined in this work for 1985 and 2000. For purposes of this discussion, the scenarios are distinguished with respect to total anticipated underground coal production, 1985 and 2000. Production levels, by scenario and producing region, were provided to us and are reported in the work of D. Blome for the ORBES project (2). Blome, in turn, was provided with total production levels for each scenario from the output of the ORBES energy and fuel demand model (1) and allocated anticipated total production to supplying regions according to procedures described in this report. Table 19 contains the production levels, by scenario and region, provided to us by D. Blome. For all practical purposes, scenarios 1 and 2 are indistinguishable (scenario 2 is a "business as usual" case); scenario 7 has the largest production levels in 1985 and 2000. Scenarios 3 and 4 are almost identical to scenario 2, 1974-1985, but reflect lower growth rates in production, 1986-2000, with scenario 4 reflecting the lowest growth rate in coal production. For scenario 2 (business as usual), the average annual compounded growth rate, 1974-1985, is approximately 3.6 percent for districts 1 and 3 (both high and low sulfur categories), with districts 2, 4, 6, 10, and 11 having a growth rate of 2.75 percent and districts 7 and 8, 2.7 percent. The average annual compounded growth rate, 1986-2000, for scenario 2 is less than the 1974-1985 rate for two regions (districts 2, 4, 6, 10, and 11 and districts 7 and 8), but greater for the remaining two producing regions. It is of some interest to note that the higher growth rates, 1986-2000, for districts 1 and 3 are associated with relatively low levels of production in terms of total production from all districts; low sulfur output from districts 1 and 3 is only 6.46 percent of total production in 2000, while high sulfur output from the same two districts is 10.41 percent. This statement is true with respect to all scenario production levels. Another way to view the matter is to observe that under all scenario conditions the bulk of total production from the region (83.1 percent) is associated with two of the regions delineated in this work (districts 2, 4, 6, 10, and 11 and districts 7 and 8).

As our procedure for estimating long-run incremental cost requires cumulative production data, it was necessary to devise a method for estimating annual production, by region, over the two subperiods 1974-1985 and 1986-2000. This was done by applying the subperiod growth rates in coal production to estimate annual production. The results of these calculations are reported in Tables 20-24 for, respectively, scenarios 1, 2, 3, 4, and 7. The cumulative production for each five-year subperiod is also reported in these tables. Our estimation procedure involved solving for the upper limit of integration in each 5-year subperiod out to 2000.

Table 19

UNDERGROUND COAL PRODUCTION AND GROWTH RATES FOR ORBES SCENARIOS

Selected Year		1974	1985		2000	
Production & Growth Rate						
Scenario	Region	Production	Production	Growth Rate (1974-1985)	Production	Growth Rate (1986-2000)
1	2, 4, 6, 10 & 11 high sulfur	103.796	142.368	0.0291	193.029	0.0205
	1 & 3 low sulfur	15.434	23.242	0.0379	31.512	0.0205
	1 & 3 high sulfur	24.895	37.442	0.0378	50.766	0.0205
	7 & 8 low sulfur	114.761	156.539	0.0286	212.242	0.0205
2	2, 4, 6, 10 & 11 high sulfur	103.796	139.860	0.0275	189.52	0.0205
	1 & 3 low sulfur	15.434	22.832	0.0362	30.94	0.0505
	1 & 3 high sulfur	24.895	36.782	0.0361	49.843	0.0505
	7 & 8 low sulfur	114.761	153.782	0.0270	208.384	0.0205

(continued)

Table 19 (continued)

Selected Year		1974	1985		2000	
Production & Growth Rate						
Scenario	Region	Production	Production	Growth Rate (1974-1985)	Production	Growth Rate (1986-2000)
3	2, 4, 6, 10 & 11 high sulfur	103.796	139.860	0.0275	162.789	0.0101
	1 & 3 low sulfur	15.434	22.832	0.0362	26.558	0.0101
	1 & 3 high sulfur	24.895	36.782	0.0361	42.784	0.0101
	7 & 8 low sulfur	114.761	153.782	0.0270	178.780	0.0101
4	2, 4, 6, 10 & 11 high sulfur	103.796	139.860	0.0275	123.984	-0.0080
	1 & 3 low sulfur	15.434	22.832	0.0362	20.241	-0.0080
	1 & 3 high sulfur	24.895	36.782	0.0361	32.607	-0.0080
	7 & 8 low sulfur	114.761	153.782	0.0275	136.325	-0.0080

(continued)

Table 19 (continued)

Selected Year / Production & Growth Rate: Scenario	Region	1974 Production	1985 Production	1985 Growth Rate (1974-1985)	2000 Production	2000 Growth Rate (1986-2000)
7	2, 4, 6, 10 & 11 high sulfur	103.796	139.860	0.0275	212.677	0.0283
	1 & 3 low sulfur	15.434	22.832	0.0362	34.720	0.0283
	1 & 3 high sulfur	24.895	36.782	0.0361	55.933	0.0283
	7 & 8 low sulfur	114.761	153.782	0.0275	233.846	0.0283

Table 20

ANNUAL PRODUCTION, BY REGION, OF COAL IN ORBES SUPPLYING DISTRICTS, SCENARIO #1

Region	2, 4, 6, 9, & 11		1 & 3 low sulfur		1 & 3 high sulfur		7 & 8	
Year	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production
1974	103.796		15.434		24.895		114.761	
1975	106.817		16.0189		25.836		118.043	
1976	109.925		16.626		26.813		121.419	
1977	113.124		17.256		27.826		124.892	
1978	116.416		17.910		28.878		128.464	
1979	119.803		18.589		29.970		132.138	
1980	123.290	793.167	19.294	121.128	31.102	195.320	135.917	875.634
1981	126.877		20.025		32.278		139.804	
1982	130.569		20.784		33.498		143.803	
1983	134.369		21.571		34.764		147.915	
1984	138.279		22.389		36.079		152.146	
1985	142.368	1,465.629	23.242	229.139	37.442	369.380	156.539	1,615.84
1986	145.287		23.719		38.210		159.748	
1987	148.265		24.205		38.993		163.023	
1988	151.304		24.701		39.792		166.365	
1989	154.406		25.207		40.608		169.775	
1990	157.571	2,222.462	25.724	352.695	41.440	568.423	173.256	2,448.008
1991	160.802		26.251		42.290		176.808	
1992	164.098		26.790		43.157		180.432	
1993	167.462		27.339		44.042		184.131	
1994	170.895		27.899		44.945		187.906	
1995	174.398	3,060.117	28.471	489.445	45.866	788.723	191.758	3,369.043
1996	177.974		29.055		46.806		195.689	
1997	181.622		29.650		47.766		199.700	
1998	185.345		30.258		48.745		203.794	
1999	189.145		30.879		49.741		207.972	
2000	193.029	3,987.232	31.512	641.820	50.766	1,032.54	212.242	4,388.440

Table 21

ANNUAL PRODUCTION, BY REGION, OF COAL IN ORBES SUPPLYING DISTRICTS, SCENARIO #2

Region	2, 4, 6, 9, & 11		1 & 3 low sulfur		1 & 3 high sulfur		7 & 8	
Year	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production
1974	103.796		15.434		24.895		114.761	
1975	106.650		15.993		25.794		117.860	
1976	109.583		16.572		26.725		121.042	
1977	112.597		17.172		27.690		124.310	
1978	115.693		17.793		28.689		127.667	
1979	118.875		18.437		29.725		131.113	
1980	122.144	789.337	19.105	120.506	30.798	194.316	134.653	871.406
1981	125.503		19.796		31.910		138.289	
1982	128.954		20.513		33.062		142.023	
1983	132.500		21.256		34.255		145.857	
1984	136.144		22.025		35.492		149.796	
1985	139.860	1,452.298	22.832	204.096	36.782	365.817	153.782	1,601.153
1986	142.727		23.300		37.536		156.935	
1987	145.653		23.778		38.306		160.152	
1988	148.639		24.265		39.091		163.435	
1989	151.686		24.763		39.892		166.785	
1990	154.796	2,195.799	25.270	301.207	40.710	561.352	170.204	2,418.664
1991	157.969		25.788		41.545		173.694	
1992	161.203		26.317		42.396		177.254	
1993	164.512		26.856		43.265		180.888	
1994	167.885		27.407		44.152		184.596	
1995	171.326	3,018.694	27.969	435.544	45.057	777.767	188.830	3,323.476
1996	174.838		28.542		45.981		192.242	
1997	178.423		29.127		46.924		196.183	
1998	182.080		29.724		47.886		200.205	
1999	185.813		30.334		48.867		204.309	
2000	189.520	3,929.368	30.940	584.211	49.843	1,017.267	208.384	4,324.799

Table 22

ANNUAL PRODUCTION, BY REGION, OF COAL IN ORBES SUPPLYING DISTRICTS, SCENARIO #3

Region	2, 4, 6, 9, & 11		1 & 3 low sulfur		1 & 3 high sulfur		7 & 8	
Year	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production
1974	103.796		15.434		24.895		114.761	
1975	106.650		15.993		25.794		117.860	
1976	109.583		16.572		26.725		121.042	
1977	112.597		17.172		27.690		124.310	
1978	115.693		17.793		28.689		127.667	
1979	118.875		18.437		29.725		131.113	
1980	122.144	789.337	19.105	120.506	30.798	194.316	134.653	871.406
1981	125.503		19.796		31.910		138.289	
1982	128.954		20.513		33.062		142.023	
1983	132.500		21.256		34.255		145.857	
1984	136.144		22.025		35.492		149.796	
1985	139.860	1,452.298	22.832	204.096	36.782	365.817	153.782	1,601.153
1986	141.273		23.063		37.154		155.335	
1987	142.699		23.296		37.529		156.904	
1988	144.141		23.530		37.908		158.489	
1989	145.597		23.796		38.291		160.089	
1990	147.067	2,173.075	24.009	321.763	38.677	555.376	161.707	2,393.677
1991	148.552		24.251		39.068		163.340	
1992	150.053		24.496		39.463		164.989	
1993	151.568		24.743		39.861		166.656	
1994	153.099		24.993		40.264		168.339	
1995	154.646	2,930.993	25.246	445.492	40.671	754.703	170.039	3,227.040
1996	156.207		25.501		41.081		171.757	
1997	157.785		25.758		41.496		173.491	
1998	159.989		26.918		41.915		175.244	
1998	160.989		26.2812		42.339		177.014	
2000	162.678	3,728.031	26.558	575.608	42.784	964.318	178.870	4,103.416

Table 23

ANNUAL PRODUCTION, BY REGION, OF COAL IN ORBES SUPPLYING DISTRICTS, SCENARIO #4

Region	2, 4, 6, 9, & 11		1 & 3 low sulfur		1 & 3 high sulfur		7 & 8	
Year	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production
1974	103.796		15.434		24.895		114.761	
1975	106.650		15.993		25.794		117.860	
1976	109.583		16.572		26.725		121.042	
1977	112.597		17.172		27.690		124.310	
1978	115.693		17.793		28.689		127.667	
1979	118.875		18.437		29.725		131.113	
1980	122.144	789.337	19.105	120.506	30.798	194.316	134.653	871.406
1981	125.503		19.796		31.910		138.289	
1982	128.954		20.513		33.062		142.023	
1983	132.500		21.256		34.255		145.857	
1984	136.144		22.025		35.492		149.796	
1985	139.860	1,452.298	22.832	204.096	36.782	365.817	153.782	1,601.153
1986	138.741		22.649		36.488		152.552	
1987	137.631		24.468		36.196		151.331	
1988	136.530		22.288		35.906		150.121	
1989	135.438		22.110		35.619		148.920	
1990	134.354	2,134.992	21.933	315.544	35.334	545.360	147.728	2,351.805
1991	133.280		21.758		35.051		146.547	
1992	132.213		21.584		34.771		145.374	
1993	131.156		21.411		34.493		144.211	
1994	130.106		21.240		34.217		143.058	
1995	129.066	2,790.813	21.070	422.607	33.943	717.835	141.913	3,072.908
1996	128.033		20.901		33.672		140.778	
1997	127.009		20.734		33.402		139.652	
1998	125.993		20.568		33.135		138.534	
1999	124.985		20.404		32.870		137.426	
2000	123.984	3,420.817	20.240	525.454	32.607	883.521	136.327	3,765.625

Table 24

ANNUAL PRODUCTION, BY REGION, OF COAL IN ORBES SUPPLYING DISTRICTS, SCENARIO #7

Region	2, 4, 6, 9, & 11		1 & 3 low sulfur		1 & 3 high sulfur		7 & 8	
Year	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production	Production for Individual Years	Cumulative Production
1974	103.796		15.434		24.895		114.761	
1975	106.650		15.993		25.794		117.860	
1976	109.583		16.572		16.725		121.042	
1977	112.597		17.172		27.690		124.310	
1978	115.693		17.793		28.689		127.667	
1979	118.875		18.437		29.725		131.113	
1980	122.144	789.337	19.105	120.506	30.798	194.316	135.653	871.406
1981	125.503		19.796		31.910		138.289	
1982	128.954		20.513		33.062		142.023	
1983	132.500		21.256		34.255		145.857	
1984	136.144		22.025		35.492		149.796	
1985	139.860	1,452.298	22.832	204.096	36.782	365.817	153.782	1,601.153
1986	143.818		23.478		37.823		158.134	
1987	147.888		24.143		38.893		162.609	
1988	152.073		24.826		39.994		167.211	
1989	156.377		25.528		41.126		171.943	
1990	160.803	2,213.257	26.251	328.322	42.290	565.943	176.809	2,437.859
1991	165.353		26.994		43.487		181.813	
1992	170.033		27.758		44.717		186.958	
1993	174.845		28.543		45.983		192.249	
1994	179.797		29.351		47.284		197.690	
1995	184.881	3,088.166	30.182	471.150	48.622	796.036	203.284	3,399.853
1996	190.113		31.036		49.998		209.037	
1997	195.493		31.914		51.413		214.953	
1998	201.026		32.817		52.868		221.036	
1999	206.715		33.746		54.364		227.292	
2000	212.677	4,094.190	34.720	635.383	55.933	1,060.612	233.846	4,505.017

The results of our investigations are reported in Tables 25-30. Tables 25-29 provide, for each scenario and subperiod, production, cumulative production, and incremental cost data. Table 30 is derived from Tables 25-29 and summarizes the incremental cost information, together with the percent change in incremental cost, 1974-1985 and 1974-2000.

The main results of interest are those found in Table 30. The first observation to be made concerns the percent change, 1974-1985 and 1974-2000, in incremental costs. Despite the differences in cumulative production reported in Tables 25-29, the percent change in incremental (marginal) costs is invariant across scenarios. This result appears to be due to two factors: the reserve base is very substantial in all four producing areas; and the differences in cumulative production, 1974-2000, by scenario, are not particularly large (see Tables 25-29). The second observation concerns the relatively large difference in percent change, 1974-2000, in incremental cost by producing region. High sulfur output from districts 1 and 3 has an increase of approximately 78 percent in incremental costs, 1974-2000, compared with roughly a 15 percent increase in low sulfur output from the same districts. Districts 7 and 8 have approximately a 33 percent increase, 1974-2000, while districts 2, 4, 6, 10, and 11 have 40 percent. The reader is reminded that output of both low and high sulfur coal from districts 1 and 3 constitutes a relatively small percentage of total output from the four supply regions (16.87 percent in 2000). These results (percent change in incremental cost by region) are due, of course, to (1) the geological information on remaining reserve base and (2) the particular allocation of total production of supplying regions. If one believes the allocations made by other ORBES researchers, then the percent changes in incremental cost reported in Table 30 are the clear implications of those assignments.

Focusing on the percent change, 1974-2000, in incremental cost, however, is somewhat misleading. If one examines the incremental cost for year 2000 in each supply region, the differences between regions are less dramatic. As one would expect, the highest incremental cost, year 2000, is in districts 7 and 8 (approximately $48). Districts 1 and 3 have, for both sulfur content coals, approximately the same incremental cost ($32), while high sulfur output from districts 2, 4, 6, 10, and 11 has an incremental cost of approximately $37. In large measure, then, the observed difference in percent change, 1974-2000, for the two sulfur content coals out of districts 1 and 3 is misleading. The large percent increase in districts 1 and 3 high sulfur output appears to be related to the relatively low base period incremental cost and the small change in low sulfur output to the high base period incremental cost estimates. As was observed earlier, there exist unknown biases in the samples used for deriving the base period incremental costs.

Table 25

INCREMENTAL COST ESTIMATES, BY SUBPERIOD, FOR SCENARIO #1

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
2, 4, 6, 10 and 11		Production for Scenario 1	103.796		142.368			193.029
Sulfur contents ≥ 1.9%	77,357.3	Cumulative production	103.796	792.169	1,465.629	2,222.464	3,060.117	3,987.232
$\overline{\phi(\log c)}$ = 3.973.8¢		Incremental cost	26.99	30.12	32.48	34.71	36.51	38.13
1 and 3		Production for Scenario 1	15.434		23.242			31.512
Sulfur contents ≤ 1.8%	9,076,6	Cumulative production	15.434	121.128	229.139	352.695	489.445	641.820
$\overline{\phi(\log c)}$ = 3.756¢		Incremental cost	28.22	28.63	29.43	30.46	31.60	32.78
1 and 3		Production for Scenario 1	24.895		37.442			50.760
Sulfur contents ≥ 1.9%	14,643.6	Cumulative production	24.895	195.320	369.380	568.423	788.723	1,032.540
$\overline{\phi(\log c)}$ = 3.7973¢		Incremental cost	18.27	25.30	27.73	29.50	31.24	32.86

(continued)

Table 25 (continued)

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
7 and 8		Production for Scenario 1	114.761		156.539			212.242
Sulfur contents ≤ 1.9%	21,285.0	Cumulative production	114.761	875.634	1,615.841	2,448.008	3,369.043	4,388.440
$\overline{\phi(\log c)}$ = 3.8523/		Incremental cost	35.96	36.51	37.44	38.66	40.05	48.17

Table 26

INCREMENTAL COST ESTIMATES, BY SUBPERIOD, FOR SCENARIO #2

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
2, 4, 6, 10 and 11		Production for Scenario 2	103.796		139.86			189.52
Sulfur contents $\geq$ 1.9%	77,357.3	Cumulative production	103.796	789.337	1,452.298	2,195.799	3,018.694	3,929.368
$\overline{\phi(\log c)}$ = 3.9738¢		Incremental cost	26.99	30.12	32.48	34.48	36.18	37.87
1 and 3		Production for Scenario 2	15.434		22.832			30.94
Sulfur contents $\leq$ 1.8%	9,076.0	Cumulative production	15.434	120.506	204.096	301.207	435.544	584.211
$\overline{\phi(\log c)}$ = 3.756¢		Incremental cost	28.22	28.63	29.37	30.25	31.31	32.41
1 and 3		Production for Scenario 2	24.895		36.782			49.842
Sulfur contents $\geq$ 1.9%	14,643.6	Cumulative production	24.895	194.316	365.817	561.352	777.767	1,017.267
$\overline{\phi(\log c)}$ = 3.7973¢		Incremental cost	18.27	25.30	27.73	29.64	31.31	32.86

(continued)

Table 26 (continued)

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
7 and 8		Production for Scenario 2	114.761		153.782			208.497
Sulfur contents $\leq$ 1.9%	23,285.0	Cumulative production	114.761	871.406	1,601.153	2,418.664	3,323.476	4,324.799
$\overline{\phi\ (\log c)}$ = 3.8523/		Incremental cost	35.96	36.51	37.44	38.66	40.01	48.17

Table 27

INCREMENTAL COST ESTIMATES, BY SUBPERIOD, FOR SCENARIO #3

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
2, 4, 6, 10, and 11		Production for Scenario 3	103.796		139.86			162.678
Sulfur contents $\geq$ 1.9%	77,357.3	Cumulative production	103.796	789.337	1,452.298	2,173.075	2,930.993	3,728.031
$\overline{\phi(\log c)}$ = 3.9738¢		Incremental cost	26.99	30.12	32.48	34.48	36.26	37.87
1 and 3		Production for Scenario 3	15.434		22.832			26.558
Sulfur contents $\leq$ 1.8%	9,076.0	Cumulative production	15.434	120.506	204.096	321.763	445.492	575.608
$\overline{\phi(\log c)}$ = 3.756¢		Incremental cost	28.22	28.63	23.37	30.32	31.38	32.41
1 and 3		Production for Scenario 3	24.895		36.782			42.784
Sulfur contents $\geq$ 1.9%	14,643.6	Cumulative production	24.895	194.316	365.817	555.376	754.703	964.318
$\overline{\phi(\log c)}$ = 3.7973¢		Incremental cost	18.27	25.30	27.73	29.64	31.31	32.78

(continued)

Table 27 (continued)

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
7 and 8		Production for Scenario 3	114.761		153.782			178.870
Sulfur contents $\leq$ 1.9%	23,385.0	Cumulative production	114.761	871.406	1,601.153	2,393.677	3,227.040	4,103.416
$\overline{\phi(\log c)}$ = 3.8523/		Incremental cost	35.96	36.51	37.44	38.66	39.92	47.95

Table 28

INCREMENTAL COST ESTIMATES, BY SUBPERIOD, FOR SCENARIO #4

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
2, 4, 6, 10 and 11		Production for Scenario 4	103.796		139.86			123.984
Sulfur contents $\geq$ 1.9%	77,357.3	Cumulative production	103.796	789.337	1,452.298	2,134.992	2,790.813	3,420.817
$\overline{\phi(\log c)}$ = 3.9738¢		Incremental cost	26.99	30.12	32.48	34.48	36.18	37.70
1 and 3		Production for Scenario 4	15.434		22.832			20.240
Sulfur contents $\leq$ 1.8%	9,076.0	Cumulative production	15.434	120.506	204.096	315.544	422.607	525.454
$\overline{\phi(\log c)}$ = 3.756¢		Incremental cost	28.22	28.63	29.37	30.60	31.53	32.26
1 and 3		Production for Scenario 4	24.895		36.782			32.607
Sulfur contents $\geq$ 1.9%	14,643.6	Cumulative production	24.895	194.316	365.817	545.360	717.835	883.521
$\overline{\phi(\log c)}$ = 3.7973¢		Incremental cost	18.27	25.30	27.73	29.57	31.17	32.57

(continued)

Table 28 (continued)

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
7 and 8		Production for Scenario 4	114.761		153.782			136.327
Sulfur contents ≤ 1.9%	23,285.0	Cumulative production	114.761	871.406	1,601.153	2,351.805	3,072.908	3,765.625
$\overline{\phi\,(\log c)}$ = 3.8523/		Incremental cost	35.96	36.51	37.44	38.57	39.83	47.84

Table 29

INCREMENTAL COST ESTIMATES, BY SUBPERIOD, FOR SCENARIO #7

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
2, 4, 6, 10 and 11		Production for Scenario 7	103.796		139.86			212.677
Sulfur contents $\geq$ 1.9%	77,357.3	Cumulative production	103.796	789.337	1,452.298	2,213.257	3,088.166	4,094.190
$\overline{\phi(\log c)}$ = 3.9738¢		Incremental cost	26.99	30.12	32.48	34.48	36.34	38.05
1 and 3		Production for Scenario 7	15.434		22.382			34.720
Sulfur contents $\leq$ 1.8%	9,706.0	Cumulative production	15.434	120.506	204.096	328.322	471.150	635.383
$\overline{\phi(\log c)}$ = 3.756¢		Incremental cost	28.22	28.63	29.37	30.02	31.38	32.55
1 and 3		Production for Scenario 7	103.796		139.86			212.677
Sulfur contents $\geq$ 1.9%	14,643.6	Cumulative production	103.796	789.337	1,452.298	2,213.257	3,088.166	4,094.190
$\overline{\phi(\log c)}$ = 3.7973¢		Incremental cost	26.99	30.12	32.48	34.48	36.34	38.05

(continued)

Table 29 (continued)

District and Sulfur contents	Coal Reserves		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000
7 and 8		Production for Scenario 7	114.761		153.782			233.846
Sulfur contents $\leq$ 1.9%	23,285.0	Cumulative production	114.761	871.406	1,601.153	2,437.859	3,399.853	4,505.017
$\overline{\phi(\log c)} = 3.8523$/		Incremental cost	35.96	36.51	37.44	38.66	40.01	48.17

Table 30

INCREMENTAL COSTS, BY SUBPERIOD AND SCENARIO, FOR THE ORBES COAL ANALYSIS

District and Scenario	Period	1974-1979	1980-1984	1985-1989	1990-1994	1995-19991	2000	Percent change (1974-1985)	Percent change (1974-2000)
2, 4, 6, 10, and 11	S1	26.99	30.12	32.48	34.71	36.51	38.13	20.34	41.27
	S2	26.99	30.12	32.48	34.48	36.18	37.87	20.34	40.31
sulfur contents	S3	26.99	30.12	32.48	34.48	36.26	37.87	20.34	40.31
	S4	26.99	30.12	32.48	34.48	36.18	37.70	20.34	39.68
≥ 1.9%	S7	26.99	30.12	32.48	34.48	36.34	38.05	20.34	40.98
1 & 3	S1	28.22	28.63	29.43	30.46	31.60	32.78	4.29	16.16
	S2	28.22	28.63	29.37	30.25	31.31	32.41	4.08	14.85
sulfur contents	S3	28.22	28.63	29.37	30.32	31.38	32.41	4.08	14.85
≤ 1.8%	S4	28.22	28.63	29.37	30.60	31.53	32.26	4.08	14.32
	S7	28.22	28.63	29.37	30.02	31.38	32.55	4.08	15.34
1 & 3	S1	18.27	25.30	27.73	29.50	31.24	32.86	51.78	79.86
	S2	18.27	25.30	27.73	29.64	31.31	32.86	51.78	79.86
sulfur contents	S3	18.27	25.30	27.73	29.64	31.31	32.78	51.78	79.42
≥ 1.9%	S4	18.27	25.30	27.73	29.57	31.17	32.57	51.78	78.27
	S7	18.27	25.30	27.73	29.64	31.29	32.86	51.78	79.86

(continued)

Table 30 (continued)

District and Scenario \ Period		1974-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000	Percent change (1974-1985)	Percent change (1974-2000)
7 & 8	S1	35.96	36.51	37.44	38.66	40.05	48.17	4.12	33.95
	S2	35.96	36.51	37.44	38.66	40.01	48.17	4.12	33.95
sulfur contents ≤ 1.9%	S3	35.96	36.51	37.44	38.66	39.92	47.95	4.12	33.34
	S4	35.96	36.51	37.44	38.57	39.83	47.84	4.12	33.04
	S7	35.96	36.51	37.44	38.66	40.01	48.17	4.12	33.95

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