AN ECONOMIC ANALYSIS OF THE SOUTH AFRICAN COAL INDUSTRY WITH A FOCUS ON EXPORTS

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Submitted to the Alfred P. Sloan School of Management on May 18, 1979, in partial fulfillment of the requirements for the Degree of Master of Science.

South Africa, as the world's seventh largest producer and the fifth or sixth greatest exporter of coal, is a major focus of the growing attention directed towards an understanding of the potential for growth in world coal trade. Moreover, South Africa is widely regarded as a "pivotal" supplier in projections of coal trade; in other words, its importance in the future of coal trade outweighs its current ranking among major exporters. This is true in part because of the relatively very low cost of South African coal exports, and, of course, cost is a major factor in projecting world trade flows. Of equal signifance, however, is the highly uncertain outcome of the internal South African debate regarding the optimal use of its coal resources--a debate which is motivated by South Africa's intensifying isolation in a world which largely condemns its racial policies. The resolution of this debate may call for continuance of the current policy of expansion of steam coal exports. Alternatively, the outcome could swing national policy to an abandonment of exports altogether, and to the use of coal resources to support South Africa in its isolation. This isolation would be made possible, for example, through production of the lion's share of the country's liquid fuel requirements from its sophisticated "Sasol" coal conversion process.

This study addresses the South African coal industry from several perspectives. First, a discussion of the institutions which most profoundly affect the South African coal industry is presented. Emphasis is placed on understanding its historical ties with the gold mining industry. In addition, an examination is made of the impact on the coal industry of government-imposed price controls. Second, one must evaluate the concept of reserves as it relates to reserve estimates presented in a major study of South African coal resources, The Report of the Commission of Inquiry into the Coal Resources of the Republic of South Africa, otherwise known as the Petrick Commission Report. Recommendations are proposed for making reserves a more economically relevant figure. The "marginal mine" concept is presented as a tool for evaluating reserves over time, and this provides the foundation for the subsequent presentation of a systematic method for estimating the costs associated with the process of depletion. Resource curves are then constructed using this methodology. The following two sections analyze costs of labor, capital, and transportation in South African coal mining. In light of these first six sections, an essay on the potential for South African coal exports is presented. A rough forecast of costs is presented, and the results are compared with reasonable estimates of future U.S. coal prices. This comparison provides insight into the rapid change in the structure of world coal trade which may be expected as it is influenced by South Africa. The study concludes by suggesting that the present cost advantage of South African coal exports will deteriorate significantly before 1990 due to rapid labor and capital cost increases.

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"...South Africa might play the dominant role in the emerging steam coal market through the early 1990's..." (International Energy Agency)[1]

Section I: Introduction

The possibility of expanded world trade in coal is receiving increasing attention from several quarters. Existing and potential coal producing nations are re-evaluating, or creating for the first time, their energy plans to consider the location and the magnitude of markets for their coal resources. With each increase in oil prices, these resources become more reasonable as a source of energy supply to energy-importing nations.

South Africa, as the world's seventh largest producer and the fifth or sixth greatest exporter of coal, is a major focus of the growing attention directed towards an expansion of world coal trade. Moreover, South Africa is widely regarded as a "pivotal" supplier in projections of coal trade; in other words, its importance in the future of coal trade outweighs its current ranking among major exporters. This is true in part because of the relatively very low cost of South African coal exports, and, of course, cost is a major factor in projecting world trade flows. Of equal signifance, however, is the highly uncertain outcome of the internal debate regarding the optimal use of its coal resources--a debate which is motivated by South Africa's intensifying isolation in a world which largely condemns its racial policies. The resolution of this debate may call for continuance of the current policy of expansion of steam coal exports. Alternatively, the outcome could swing national policy to an abandonment of exports altogether, and to the use of coal resources to support South Africa in its isolation. This isolation would be made possible, for example, through production of the lion's share of the country's liquid fuel requirements from its sophisticated "Sasol" coal conversion process.

It is clear that an understanding of the South African coal industry and of its national debate is crucial if one is to construct an informed point of view regarding the future of world coal trade. This study, which comprises both a "practical" and theoretical examination of South African literature and personal communications with South African coal industry officials, attempts to deepen this understanding. This thesis thus repairs a major gap in our appreciation of the internal workings of this industry.

This study addresses the South African coal industry from several perspectives. First, a discussion of the institutions which most profoundly affect the South African coal industry is presented. Emphasis is placed on understanding its historical ties with the gold mining industry. In addition, an examination is made of the impact on the coal industry of government-imposed price controls. Second, one must evaluate the concept of reserves as it relates to reserve estimates presented in a major study of South Africa's coal resources, The Report of the Commission of Inquiry into the Coal Resources of the Republic of South Africa, otherwise known as the Petrick Commission Report. Recommendations are proposed for making reserves a more economically relevant figure. The "marginal mine" concept is presented as a tool for evaluating reserves over time, and this provides the foundation for the subsequent presentation of a systematic method for estimating the costs associated with the process of depletion. Resource curves are then constructed using this methodology. The following two sections analyze costs of labor, capital, and transportation in South African coal mining. In light of these first six sections, an essay on the potential for South African coal exports is presented. A rough forecast of costs is presented, and the results are compared with reasonalbe estimates of future U.S. coal prices. This comparison provides insight into the rapid change in the structure of world coal trade which may be expected as it is influenced by South Africa. The study concludes by suggesting that the present cost advantage of South African coal exports will deteriorate significantly before 1990 due to rapid labor and capital cost increases.

Note that while the recent cutoff of direct oil shipments from South Africa's major supplier, Iran, directly affects the long-term future of South Africa, that specific event is not addressed in this study. However, the growing isolation of South Africa is analyzed in terms of its effect of increasing labor and capital costs. Furthermore, since the effect of the Iranian embargo is similar to that of previous anti-South African developments in other parts of the world, little insight is lost by focusing on the difficulties resulting from growing isolation in general. The impact of this intensified isolation is addressed throughout this study.

FOOTNOTES

Chapter 1

1. International Energy Agency, Steam Coal Prospects to 2000, Organization for Economic Cooperation and Development, 1978, p. 134.

2. Republic of South Africa, Department of Mines, Report of the Commission of Inquiry into the Coal Resources of the Republic of South Africa (The Petrick Commission Report), 1975.

Section II: The Structure of the South African Coal Industry

The discussion which follows is a brief description of the institutional environment within which the South African coal industry operates. National policies which have guided the evolution of this environment are described as well. This section thus provides necessary background for a more complete understanding of the chapters which follow.

South Africa's profile of energy use is unique in the world: production of indigenous coal provides over 75% of the country's primary energy supply.[1] (The remaining 25% is in the form of oil, mostly for private transport.) Table 1 provides the recent history of coal output in South Africa, and displays some important trends which I mention at this stage only briefly. First, tons mined increased at the rapid pace of 8.0% per year from 1972 to 1977; this compares with the lower annual rate of 4.9% over the entire time span, 1965-1977. Second, and most striking and significant for our purposes, is the sensationally expanding role of exports. The "sensations" are of two natures: growth in tons and increase in price.[2] We will return to these phenomena in detail later. Finally, note the spread between domestic

Table 1

South African Coal Output and Value, 1965-1977 (metric tons, Rand[1])

	Tons Mined (10^3 tons)	Waste[2]	Tons Sold	Domestic Sales	Value[1] 10^3R	Value[4] Per Ton	Export Sales	Export Value	Export[4] Value Per Ton
1977	98103	12693	85411	72302	506855	7.01	12702	248551	19.57
1976	86664	10211	76453	69760	414349	5.94	5961	103427	17.35
1975	78217	8777	69440	66433	278785	4.20	2687	37305	13.88
1974	73969	——[3]	66056	62354	178337	2.86	2277	21643	9.51
1973	71043	——	62352	59604	138159	2.32	1945	13947	7.17
1972	66646	——	58440	55945	118761	2.12	1243	8020	6.45
1971	66860	——	56982	55538	109528	1.97	1444	9849	6.82
1970	62809	——	54612	51618	99674	1.93	1367	10239	7.49
1969	60329	——	52752	50051	98679	1.97	1230	7588	6.17
1968	59995	——	51655	45479	90262	1.82	1082	6681	6.17
1967	57326	——	49301	47269	81040	1.71	1058	5851	5.53
1966	55901	——	47942	45943	76575	1.67	979	4886	4.99
1965	55333	——	48460	46532	75172	1.62	1052	6195	6.33

1 - Rand conversion values: 1975-1977: $1,15/Rand; 1974: $1,45/R; 1973: $1,49/R; 1972; $1,28/R; 1971: $1,31/R; 1970: $1,39/R; 1969;$1,39/R; 1963-1968: $1,39/R

2 - Mostly washery discards.
3 - "——" means not available.
4 - Values per ton are useful as rough indexes of the value of an "average" ton of coal; of course, there does not exist an "average" coal.

Source: Department of Mines, Republic of South Africa, <u>Mining Statistics 1977</u>, p. 21.

average value and export average value. The magnitude of this difference is not due to quality difference alone, but is due in large part to controlled domestic prices. These controlled prices are a focal point in the current South African coal debate.

The mix of demand for South African coal is represented in Table 2 for 1970 and 1977. Notice the sustained dominance of the electricity generating sector of consumers, the slippage in domestic commercial demand, the growth in importance of oil from coal and exports, and the relative stagnation of domestic metallurgical consumption. These relative changes accompany a rapid growth in total coal consumption -- a growth of 7.2% per year compounded annually.

The path to this heavy dependence on coal was laid as early as 1922, with signing of the Electricity Act of 1922.[3] The state thus recognized the importance of hard rock, especially gold, mining in South Africa by promising to build and maintain a nationwide electricity grid fueled by cheap coal whose price was to be controlled by the state. Much of this very cheap electricity was destined for the electricity-hungry gold mining industry. The subserviant position of coal mining was thus institutionalized. This early relationship led to the complications which fuel the current South African coal debate. I quote the Petrick Commission:

Table 2

Allocation of South African Coals to End-Uses
1977 and 1970

(millions of metric tons)

	1977[1]	%	1970[2]	%
Electrical Generation	42.0	47.4	29.5	54.0
Commercial Market (local)	23.0	25.9	18.8[3]	34.0
Oil from Coal	5.0	5.6	—	0.0
Metallurgical Industries	6.0	6.8	5.0	9.2
Export	12.7	14.3	1.3	2.4
TOTAL	88.7	100.0	54.6	99.6[4]

1 - The first four figures in this column are approximations given by: Granville, A., and A.J. Venter, "South Africa's Coal Industry Expands," in World Coal, November 1978, p. 53.

Since these are rough approximations, the total does not exactly equal that of Table 1.

2 - From Petrick Commission Report, Table 6.1.2/3.

3 - Includes "SAR" category.

4 - Does not equal 100 due to rounding.

> The demand for the vast amounts of power required in convenient form to carry out extensive hard rock mining and milling, soon led to the acquisition and development of known coal fields...as sources of fuel for the steam plants of electrical power stations. In the event all major coal producing areas have come directly under the ownership and control of the larger gold mining houses.
>
> The emphasis of mining interests on low cost electric power, and the establishment of the Electric Supply Commission (Escom) to generate and distribute power on a 'no profit' basis as a matter of State policy, have led to the acceptance of cheap energy as a matter of ordinary providence by the many other sections of consumption that were generated either directly by gold mining or which came into being after gold mining had placed the economy on firm footing.[4]

Two gold mining concerns dominate coal mining in South Africa. The General Mining and Finance Corporation, Limited, is "responsible for approximately 40% of South Africa's total coal production."[5] Anglo American Corporation of South Africa, Limited, adds another 26-27%,[6] making these two concerns producers of two-thirds of South Africa's coal. It is clear, therefore, that the gold and coal mining industries are closely related. Further, it is clear that there is potential for coal price manipulation in the domestic market. However, as mentioned above, the potential is eliminated since these domestic prices are controlled by the state.

Price Controls:

The long-standing committment of the state to low electricity (and therefore coal) prices is manifested in domestic price controls on coal. The current price-setting structure was established under the Price Control Act of 1964, which is administered by the Department of Commerce. Table 3 shows a collection of domestic prices for various dates and coal types. This table provides greater detail of the trends hinted at in Table 1. The price spread between Grade A exports and Grade A coal consumed internally amounts to nearly $15. Naturally, coal producers are eager to sell exports. This eagerness is fortified by the knowledge that they (the producers), not the government, set export prices and allocate export rights via producers associations -- the Transvaal Coal Owners Association (1923) Limited, the Natal Associated Colliences (Pty) Limited, the Anthracite Producers Association (Pty) Limited, and the Coke Producers (Pty) Limited. The export rights themselves are controlled by government policy[7] and constrained in the short term by port capacity. However, export prices remain uncontrolled.

Let us examine the prices for domestically-consumed Grade A coal (with a heating value of around 12,000 BTU per pound) and Grade D coal (about 10,700 BTU per pound)---- prices which held in the July, 1976 to January, 1978 period.

Table 3

CONTROLLED PRICES FOR DOMESTICALLY-CONSUMED COAL:

SOUTH AFRICA

Type of Coal	Date Effective	Rand/ Metric Ton	$/ Metric Ton
Grade A[b]	Feb., 1978	7.76	8.92
	July, 1976-Jan.,1978	6.93	7.96
Grade D	July, 1976-Jan.,1978[d]	6.68	7.68
	June, 1976	3.46	3.98
Escom	1977	6.12	7.04
Exports(Grade A)	1978	20.72	23.83
Anthracite(Domestic)	1978	20.59	23.68
Anthracite(Export)	1978	22.72	26.13

a - \$1.15 = R1.00

b - Grade A coal has a heating value of about 12,000 BTU/pound.

c - Grade D coal has a heating value of about 10,700 BTU/pound.

d - Latest dates available.

e - Coal which is burned by the government-controlled generating plants of the Electricity Suppy Commission.

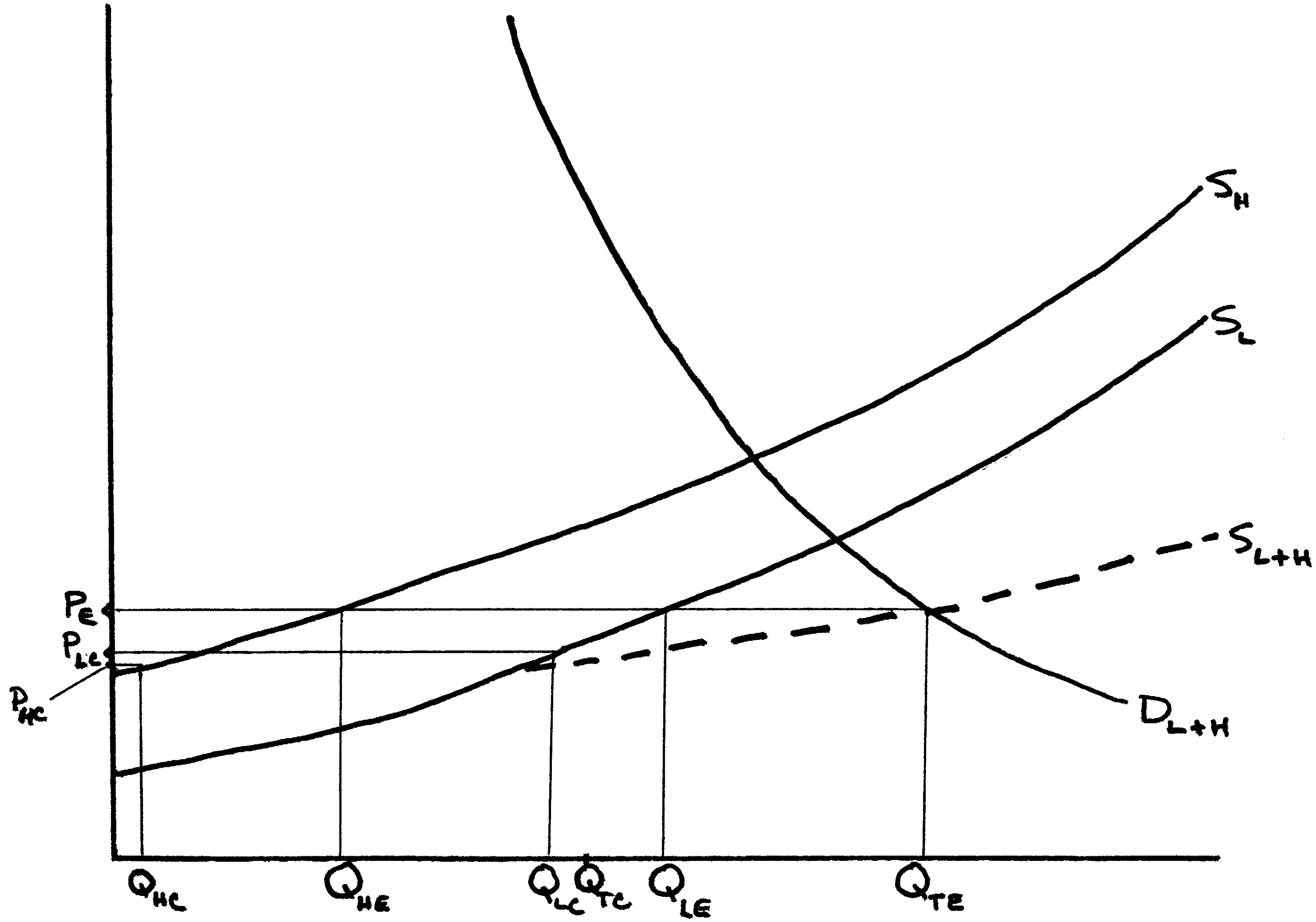
Sources: Granville, A., and A.J. Venter, "South Africa's Coal Industry Expands, World Coal, November 1978, p. 53. See also Sealey, A.A., "South Africa's Depleting Quality Coal: How to Save the Best Reserves," South African Mining and Engineering Journal, December, 1977, pp. 27-28.

Grade A coal at \$7.96 per metric ton averaged 30.1¢ per million BTU. It is surprising that Grade D coal cost more per million BTU at 32.6¢. If we consider BTU content alone, therefore, consumers would naturally prefer low-cost high-grade coal -- if they can get it.

It is natural that producers bring some reservations about meeting these demands for we know that, in general, price controls decrease the total amount of coal produced for domestic consumption, and alter the mix of coal grades produced. For price controls to be effective they must, of course, be less than the equilibrium price of coal (See Figure 2). Thus, in our situation, the equilibrium price of coal per million BTU, P_E, is greater than the controlled price of low-grade coal, P_{LC}, which is greater than the controlled price of high grade coal, P_{HC}. P_E is determined by adding (horizontally) the supply curves for low grade (S_L) and high-grade (S_H) coal to reach a total supply curve (S_{L+H}). This curve meets the total demand curve (D_{L+H}) at a price, P_E, and quantity, Q_{TE}. The reader can see from our example that at this equilibrium price, this quantity is comprised of Q_{LE} tons of low-grade coal at around 3/5 of the total, with Q_{HE} tons of high grade coal filling the other two-fifths. Contrast this with the current regime of controlled prices. At P_{LC} only Q_{LC} is produced, while at P_{HC} only Q_{HC} is produced. Total tons produced under controlled prices is Q_{TC}. Of this

FIGURE 1

LOW AND HIGH GRADE COAL UNDER PRICE CONTROLS



*Refer to text page 20.

amount (which, as is readily seen, is much less than quantity produced without price controls) a much smaller proportion is high grade coal than under market equilibrium. Thus, the supply and demand responses run counter to one another. Under price controls, consumers desire more coal, and in this case want more of that coal to be high-grade (since $P_{LC} > P_{HC}$). Producers are unwilling to produce the coal demanded, and they will produce a smaller proportion of high-grade coal than without price controls.

Note that this analysis has assumed that Grade A and Grade D coals possess different supply curves. Grade A usually requires washing, which adds to costs and differentiates the Grade A supply function from the "no-wash" case. However, in many cases, collieries are constructed to supply coal as fuel for one use only. Originally, a major singular use was generation of electricity for gold mining in the region of the coal mine. Coal was transferred <u>within</u> the gold mining company from its subservient coal mining subsidiary to the gold mining site <u>as the coal was needed</u>. Little or no market existed for the coal the gold mine didn't use. Usually only the highest quality (highest heat content) coal was mined since its production cost per BTU was lower than that of lower quality coal within the same seam (in layers over- or underlying the better coal) or in seams nearby. The result was an irrational and wasteful use of high quality coal on a process that could easily have used lower quality material.

Current "tied" operations are not limited to supplying the needs of gold mining. Iscor (the state-regulated steel-producing organization) and Escom (the state electricity-generating entity) operations are often fed by a single colliery. While the seams being mined usually contain a breadth of coal types, the singular purpose of the colliery prohibits the effective mining and marketing of these different materials. Such practices have led to a call for "rationalization" of coal mining in South Africa. That is, there is a growing movement to locate and develop markets for different coal types.

Thus, price controls of two types have resulted in inefficient allocation of coal resources for domestic use in South Africa: explicit price controls operating on multiple-purpose mining operations effect economic disequilibrium for the several types of coal mined; implicit controls -- that is, the internal "pricing" schemes of gold mining, Iscor, and Escom tied-colliery operations -- encouraged wasteful use of different coals for a single purpose.[8]

In general, the coal mining "(i)ndustry believes that the present controlled price is not sufficient to justify the opening of new mines to support the (domestic) commercial market."[9] Fortunately, price controls do not apply to the focus of this study -- export coals. These coals realize what the world market will bear which, as we have seen, is a great deal more than that allowed by domestic controls. Therefore, as long as the bounds of the constraint of national policy and railway/port capacity (See Section 6) are not reached, new mines will be opened for the export market.

FOOTNOTES

Section II:

1. Granville, A., and A.J. Venter, "South Africa's Coal Industry Expands," World Coal, Nov. 1978, p. 52.

2. Table 2 really says almost nothing about price. The "value" presented includes a range of transaction prices, some of which are determined by long-term contracts signed years ago. Marginal value is discussed later.

3. Smith, Jan H., "The South African Energy Situation," The South African Mechanical Engineer, Vol 25, Nov. 1975, P. 348.

4. Republic of South Africa, Department of Mines, Report of the Commission of Inquiry into the Coal Resources of the Republic of South Africa, (Henceforth referred to as the Petrick Commission Report), 1975, Paragraph 1.2.3.

5. Letter to the author from S.P. Ellis, General Manager, Coal Division, General Mining and Finance Corporation Limited, Johannesburgh, South Africa, dated September 26, 1978.

6. Granville and Venter, Ibid. Eight mining groups produced 94% of total output in 1977.

7. The Fuel Research and Coal Act, Act 35 of 1963, is the principal regulation governing export policy. It is administered by the Department of Industries.

8. Petrick Commission Report, Ibid.

9. Sealey, A.A., "South Africa's Depleting Quality Coal: How to Save the Best Reserves," S.A. Mining and Engineering Journal, December 1977, p. 27. (1977 controlled prices). Sealey describes a price per ton for high quality coal which he believes is the correct price. He assumes Grade D coal sells for R6.675, as in 1976-1977, and that washing costs are 50¢ per ton. At 70% yield, washed Grade A coal should equal (R6.675/0.7)+ 0.5 = R10.04 per ton for a parity with Grade D. Sealey uses a washery yield of 62%, which seems low.

Section III: Coal Reserves in South Africa: How Meaningful a Figure?

A contentious debate regarding the optimal way to extract and to utilize domestic coal resources is now raging in South Africa. The rhetoric deployed in this conflict is familiar to observers of American energy policy -- energy independence, price controls, balance of trade problems, environmental degradation, and labor "shortages" (rapidly increasing wages) play a part in the billowing verbiage. The sides break down roughly into two groups: one that believes that South Africa's coal resources are not extensive and that coal should be conserved "at almost any cost"' the other "maintains that there is sufficient coal till well into the next century and that (South Africa) should not take any precipitate action on coal at this stage."[1] The position one takes largely depends on one's perception of the extent of coal reserves.

This concept of "reserves" as it applies to South Africa will be examined in this section. It is necessary to determine whether recently published estimates of South African coal resources define reserves as that coal which is economically extractable given today's technology and market conditions. If this definition of reserves is that which informs published reserve estimates, then one is better able to judge opposing arguments on South African coal utilization -- including the debate over coal exports which provides the basis for this study.

American Coal Reserves: An Illustration

The problem of defining American coal reserves illustrates the issues and provides a basis for understanding the meaning of reserves in South Africa. Table 4 displays the categories of resources used by the U.S. Bureau of Mines and the definition of each category according to seam depth and thickness.[2] Total resources, identified resources, reserves, and subeconomic resources are each further defined by degree of geologic assurance as measured, indicated, or inferred. To classify as measured, "the points of observation and measurement are so closely spaced and the thickness and extent of coal beds so well defined that the calculated tonnage is judged to accurate within 20 percent of the true tonnage."[3] In general, the points of observation are no further apart than 1/2 mile.

Resources qualify as "indicated" based on boreholes, outcrops, mine workings, or other observation points that are no more than 1 1/2 miles apart from beds of "known continuity". The "inferred" category consists of coal whose existence is

Table 4

Coal Resource/Reserve Criteria[1]
United States

Category and coal rank	Depth, feet	Thickness, inches
Total resources and undiscovered resources:		
Anthracite and bituminous	6,000 or less	14 or more
Subbituminous and lignite	6,000 or less	30 or more
Identified resources:		
Anthracite and bituminous	3,000 or less	14 or more
Subbituminous and lignite	3,000 or less	30 or more
Reserves:		
Anthractie and bituminous	1,000 or less	28 or more
Subbituminous	1,000 or less	60 or more
Lignite	120 or less	60 or more
Subeconomic resources:		
Anthracite and bituminous	0-1,000	14-28
	1,000-3,000	14 or more
Subbituminous	0-1,000	30-60
	1,000-3,000	30 or more
Lignite	0- 120	30-60
	120-3,000	30 or more

Source: U.S. Bureau of Mines, Department of Interior, Information Circular 8678, "The Resource Base of Coal for Underground Mining in the Wester United States", 1975, p.5.

[1]Included in reserves, identified, and total resources are thinner and/or deeper beds that presently are being mined or for which there is evidence that they could be mined commercially at this time. Identified resources are classified as measure, indicated, and inferred according to the degree of geologic assurance as described in the text.

based on judgement using available geological evidence.

The reserve category in Table I is supposed to contain coal which "could be mined commercially" at the present, either by strip or underground methods. In examining the meaning of "commercial", one must first note that (a) the theory of resource economics predicts that the cheapest resources will be exploited first, and (b) in the long run in a competitive industry, the cost of the last unit of output produced will equal the minimum average cost of production. This latter premise must be modified for a mineral industry such as coal. Contrary to the usual interpretation, in the coal industry

> ...(all) firms are not identical. Mines in better deposits, in this case, thicker seams and generally more favorable mining conditions, will coexist with less productive mines. As mining proceeds from more to less favorable deposits, costs rise. Those mines opened under more favorable conditions will earn a high rate of return at prices that are just high enough to keep the less favored mines in business.[4]

The cost function for coal production, therefore, is determined by geologic conditions as well as rate of output. Large mines may be opened at the same time as small mines and operate with equal costs at the outset because of different geological conditions. As cumulative production from these mines increases, mining will progress to less favorable deposits. The "less favored" mine which just breaks even at current prices produces coal at a rate and under geologic conditions which minimize average cost. This mine will be referred as an "incremental mine". The incremental mine is the last mine opened to satisfy demand, and is the first to close if demand decreases. Its minimum average cost is the long-run marginal cost of the coal industry. The incremental mine can be studied over time to determine how economics and geology can be combined to produce a cost curve for coal. If new mines are extracting coal reserves which lie on the least attractive fringes of the definition of reserves offered by the Bureau of Mines, then reserves likely reflect today's economically-exploitable coal.

Work completed elsewhere concludes that, in fact, the U.S. reserves as defined in Table I include much coal that cannot be extracted economically using today's technologies at today's prices, especially coal mined by underground methods.[5] This work concludes that a major determinant of geologic conditions, and therefore costs, is seam thickness. However, the thickness categories used by the Bureau of Mines are too broad to be of much assistance in estimating costs. Further, while thickness is the single most important determinant of production costs, other less easily observed geologic characteristics are collectively of equal importance. Roof, floor, water, grade and gas conditions are included among these factors; yet none is considered in the BOM definition of reserves.

The _interactions_ among all cost-affecting conditions must be better understood in order to estimate the behavior of costs over time and cumulative production. That is, it is the combination of all cost-affecting factors which determines the cost of production in any mine. More specifically, marginal mine A may extract steam coal from a seam three metres thick, while marginal mine B produces the same quality of coal from a seam only one metre in thickness. The two mines produce at the same cost because, in this case, mine A is characterized by methane gas leakages which force the mine to close periodically for ventilation. Conversely, mine B's seam may exhibit no gradient, minimal water seepage, and no gas leakage problems. Seam thickness is an important cost determinant in both mines (if you have ever seen crouched miners work in a one-metre seam, you realize the constraints to human and machine mobility). But it is the tradeoffs among _all_ cost-effecting factors that determine production costs.

These are the insufficiencies of definition which confuse the concept of "reserves" in American coal estimates. These inconsistencies are no less confusing in the analysis of South African coal.

The South African Example

The need to define U.S. coal reserves in an economically meaningful way can be applied as well to South African reserves and resources. The principal source for South African estimates to which I refer is the influential Report of the Commission of Inquiry into the Coal Resources of the Republic of South Africa, better known as the Petrick Report, which was published in 1975.[6] It contains an important discussion of reserves and the parameters which define reserves as reproduced here in Table 5. I suggest that this South African interpretation of reserves is, on the surface, more thoughtful and more concisely defined than that employed by the U.S. Bureau of Mines.[7] However, I shall argue that the report, by failing to recognize the importance of the interaction of numerous geologic conditions which affect costs, paints an inaccurate picture of the potential for South African coal production.

Some Definitions

The Petrick Commission calls "coal in situ" (the U.S. Bureau of Mine's "total resources") "an academic figure which will not be published."[8] With this dismissal, one immediately recognizes a conservatism resulting perhaps from a fear of

TABLE 5

SOUTH AFRICAN RESERVE SPECIFICATIONS

RELIABILITY	NUMBER OF BOREHOLES OR ADITS PER 2000 ha: PROVEN: MORE THAN	INDICATED: FROM-TO	INFERRED: FEWER THAN
WATERBERG	8	7-3	2
SOUTH RAND	10	9-3	2
SPRINGFIELD : WESTERN AREA LIMPOPO : SPRINGBOK FLATS SOUTPANSBERG	10	9-5	4
MOLTENO-INDWE S.W.A. GIBEON : S.W.A. OVAMBO O.F.S.-VIERFONTEIN VEREENIGING-SASOLBURG WITBANK SEAMS 2, 4A & 4 UP HIGHVELD SEAMS 2, 4 & 5 PAFURI	10	9-3	2
EASTERN TRANSVAAL : UTRECHT KLIPRIVER : VRYHEID : ZULULAND	20	19-5	4
KOMATIPOORT	30	29-5	4
WITBANK SEAMS 1, 3 & 5 HIGHVELD SEAMS 1 & 3	30	29-10	9

SPECIFICATIONS FOR MINEABLE COAL IN SITU (b) (c)

TYPE OF (a) COAL			BITUMINOUS: RAW	BITUMINOUS: WASHED		ANTHRACITIC COAL (WASHED)
FACTOR	LOCAL NAME		LOW GRADE STEAMCOAL	HIGH GRADE STEAMCOAL	METAL-LURGICAL COAL	ANTHRACITIC COAL
	SYMBOL		LGSC	HGSC	METL	ANTH
DEPTH (METRES)		MAX	300	400	500	500
		MIN	15	15	15	15
WORKABLE THICKNESS (METRES)		MAX	6	6	6	6
		MIN	1,2	1,2	0,7	0,7
MINIMUM YIELD AT S.G.			RAW	70% 1,6	50% 1,4	60% 1.6
ASH		MAX	35%	17%	14%	15%
DRY ASH-FREE VOLATILES		MAX	-	-	-	14%
		MIN	16%	16%	16%	8%
SWELLING INDEX		MIN	-	-	2	-

SPECIFICATIONS FOR EXTRACTABLE COAL (d)

FACTOR \ TYPE OF COAL			LGSC	HGSC	METL	ANTH
CONTROL FILE NUMBER			010020	010007	010017	010016
UNDERGROUND	MINIMUM METRIC TONS MINEABLE IN SITU (e)	RAW	150	-	-	-
		(f)	—	30	3	2
	RANGE OF DEPTH	METRES	15-300	15-400	15-500	15-500
	RANGE OF THICKNESS	METRES	1,2-6,0	1,2-6,0	0,7-6,0	0,7-6,0
	EXTRACTION % (A MINING LOSS OF 10% HAS BEEN DEDUCTED)		BORD AND PILLAR SALAMON FORMULA	AS FOR LGSC TO 200 m THEN 85%	15-100m BORD AND PILLAR THEN 85%	85%
OPENCAST (INCLUDES COAL LEFT IN PILLARS)	MINIMIMTONNAGE (e)		AS FOR UNDERGROUND MINING			
	DEPTH (METRES)		0-15	15-50	50-500	
	EXTRACTION		90% THROUGHOUT			
	SEAMTHICKNESS		NOT CRITICAL			
	STRIPPINGRATIO M^3 OVERBURDEN TO M^3 MINEABLE COAL		UP TO 5:1	UP TO 10:1	UP TO 15:1	

PRIORITY FOR THE EXTRACTION OF COAL SEAMS WHICH ARE LIKELY TO BE CLOSE TOGETHER

COALFIELD \ PRIORITY	FIRST	SECOND	THIRD	FOURTH	FIFTH
LIMPOPO	BOTTOM	TOP	-	-	-
WATERBERG	7	6B	5B	3	2
PAFURI	2	1	-	-	-
WITBANK	2	1	4	-	-
HIGHVELD	4	4 UP	-	-	-
EASTERN TRANSVAAL (EXCEPT DAVEL)	C UP	C	-	-	-
EASTERN TRANSVAAL (DAVEL ONLY)	C LO	C UP			
KOMATIPOORT	K3A	K3B	-	-	-
SOUTH RAND	MAIN BOTTOM	MAIN MIDDLE	MAIN TOP	-	-
OLD SPRINGFIELD	2A	2B	1	-	-
VEREENIGING-SASOLBURG	2A	2B	1	-	-
O.F.S. VIERFONTEIN	BOTTOM	-	-	-	-
UTRECHT	MOSS	MAIN	YARD	-	-
KLIPRIVER	BOTTOM	TOP	-	-	-
VRYHEID	GUS	DUNDAS LOWER	DUNDAS UPPER	-	-
ZULULAND	MIDDLE	LOWER	-	-	-
S.W.A. GIBEON	LOWER B	-	-	-	-

Notes to Table 5

(a) Coal is a carbonaceous rock of sedeimentary origin containing not more than 50% of ash.

(b) Coal is situ is the total amount of coal in a given area occurring in its natural environment; since it includes all coal, however deep or thin it may be, this is an academic figure, which will not be published.

(c) mineable coal in situ is that portion of the coal in situ which can be mined by existing techniques.

(d) Extractable coal is that portion of the mineable coal in situ which is extractable in prevailing or slightly less rigorous economic conditions.

(e) Minimum tonnage means the smallest tonnage which will make an isolated property a viable proposition ; but two or more smaller properties within 5 km. of each other and making up the required tonnage are admissable.

(f) washery discards allowed for.

Source for Table 5: The table was taken in its entirety from the Petrick Commission Report, op. cit.

misrepresenting the huge, but economically meaningless, resource estimates. Instead, coal is broken down into the categories of (a) mineable in situ, and (b) extractable. Mineable in situ is "that portion of the coal in situ which can be mined by existing technologies...Extractable coal is that portion of the mineable coal in situ which is extractable in prevailing or slightly less rigorous economic conditions."[9] Let us explore these terms more fully.

Mineable coal is broken down into the following types: low grade steam coal, high grade steam coal, metallurgical coal, and anthracite. High grade steam coal, met coal, and anthracite all have to be washed due to the generally high ash content of South African coal. The distinction between low grade and high grade steam coal in the raw (pre-washed) state is based on BTU content. High grade steam coal contains more than 9000 BTU per pound. Low grade steam coal, because of its low heat content (below 9000 BTU per pound) is not economical to wash and must be used, if at all, for electric power generation, liquefaction, or gasification. Met coal is distinguished by its relatively low ash content and its swelling index.[10]

The mineability of each coal type depends, in part, on the depth of seam burial. Low grade coal is assumed to be mineable to 300 metres (984 feet), while high grade steam coal is mineable to 400 metres (1312 feet), and met coal to 500 metres (1641 feet). These changing depth constraints suggest that mineable coal in situ is contaminated by the economics of each coal type. However, the "mineability" -- that is, the physical ability to remove coal -- depends on roughly the same technology for each coal type. This category of "mineable in situ" should be immune, therefore, to economics and should not require different depth cutoff points. The economic considerations introduced by varying depth constraints among coal types make the usefulness of the "mineable coal" category unclear in this South American case. One must proceed, therefore, to an evaluation of "extractable coal" -- that is, coal which by the Petrick definition is economically mineable. This is the coal category which corresponds closely to what Americans call "reserves".

Extractable coal, a subset of proven plus indicated resources, is subdivided into underground and strippable coal. Underground coal reserves are constrained by four categories of requirements:

1. Minimum tons: this constraint establishes the "smallest tonnage which will make an isolated property a viable proposition..." The constraint recognizes the importance of economies of scale in the South African coal mining industry

2. Range of depth: defined above for mineable coal.

3. Range of thickness: the thinnest coal seams allowed vary by coal type. For low and high-grade steam coal, a minimum thickness of 1.2 metres (47 inches) is required; for met coal the minimum is 0.7 metres (28 inches).

4. Technology used: bord and pillar mining is assumed for low grade steam coal at all depths. Ellis and Kirstein present the following extraction rates for bord and pillar mining:[11]

Depth (metres)	% Extracted
30	82
100	60
200	40
300	28

High grade steam coal requires bord and pillar to 200 metres, then a technology which accomplishes 85% extraction -- either longwall, or an advanced pillar extraction method. Similarly, met coal requires bord and pillar to 100 metres, then the advanced technologies are used. The extraction technology changes by coal type because the more expensive the grade, the more incentive there is to employ technologies with high extraction rates (e.g., longwalling).

Petrick describes strip mineable reserves as being constrained by the same categories as underground mining, except that with strip mining overburden ratio replaces range of depth. This stripping ratio is defined as cubic meters of overburden per cubic meters of mineable coal. A maximum ratio of 5:1 is specified for low grade coal, and 10:1 for high grade and met coal. These ratios translate into roughly 3.4:1 and 6.9:1 in cubic metres of overburden per ton of coal.[12]

The reliability of reserve estimates is judged by the number of boreholes or adits per 2000 hectares (7.72 square miles). These drilling requirements change by minefield in accordance with the varying degrees of geological continuity associated with each area. Thus, while proven reserves in the Waterburg field, for example, are established by using only about one borehole per square mile, to prove Highveld coal requires nearly four drillings per square mile. This practice, by recognizing local geology, is superior to the more aggregated methods of the U.S. Bureau of Mines.

Petrick Commission Report Results:

Underground Reserves: Employing the constraints specified above, Petrick concludes that extractable coal (reserves) total 24,915,000,000 metric tons (out of 81,274,000,000 mineable metric tons) (See Table 6). Of these reserves, high grade (washed) steam coal amounts to 10.5 billion tons, with met coal comprising only 705 million tons. Subtracting the high grade and met coals from total underground reserves leaves about 13.4 billion tons of low grade reserves as extractable under ground.

TABLE 6

SOUTH AFRICAN RESOURCES AND RESERVES

REPUBLIC OF SOUTH AFRICA

SUMMARY OF THE RESOURCES 1974 : MILLIONS OF TONNES

SEAM DEPTH AND SEAM THICKNESS IN METRES

MINEABLE IN SITU.

RAW BITUMINOUS COAL (a)

ASH %	0-5	5-10	10-15	15-20	20-25	25-30	30-35	TOTAL
PROVEN	-	18	734	3 720	6 197	7 912	13 582	32 223
INDICATED	-	-	645	2 865	5 507	5 224	11 785	25 027
INFERRED	-	2	60	2 034	3 516	5 429	11 983	23 024
TOTAL	-	20	1 439	8 620	15 220	18 565	37 350	81 274

WASHED BITUMINOUS COAL

CALORIFIC VALUE	MEGAJOULES PER KILOGRAM				TOTAL
	<25.5	25.5-26.5	26.5-27.5	>27.5	
PROVEN	1 374	2 135	2 675	4 033	10 217
INDICATED	3 293	1 698	2 071	2 102	9 164
INFERRED	127	1 745	1 642	1 991	5 510
TOTAL	4 799	5 578	6 388	8 126	24 891

METALLURGICAL COAL (WASHED)	
PROVEN	443
INDICATED	644
INFERRED	2 364
TOTAL	3 451

ANTHRACITIC COAL (WASHED)	
PROVEN	118
INDICATED	381
INFERRED	245
TOTAL	744

EXTRACTABLE BY UNDERGROUND MINING

RAW BITUMINOUS COAL (a)

DEPTH BELOW SURFACE METRES \ SEAM THICKNESS METRES	1.2-2.0	2-4	4-6	TOTAL
15-50	1 207	1 866	2 566	5 639
50-200	3 770	5 832	8 677	18 279
200-300	370	501	126	997
TOTAL	5 347	8 199	11 369	24 915

WASHED BITUMINOUS COAL

DEPTH BELOW SURFACE METRES \ SEAM THICKNESS METRES	1.2-2.0	2-4	4-6	TOTAL
15-200	2 898	3 463	2 859	9 220
200-400	446	520	276	1 242
TOTAL	3 344	3 983	3 135	10 462

METALLURGICAL COAL — DEPTH (m) \ THICKNESS	0.7-2.0	2-4	4-6	TOTAL
15-100	130	43	39	212
100-500	321	165	7	493
TOTAL	451	209	46	705

ANTHRACITIC COAL — DEPTH (m) \ THICKNESS	0.7-2.0	2-4	4-6	TOTAL
15-200	116	48	-	164
200-500	211	-	-	211
TOTAL	327	48	-	375

(b) EXTRACTABLE BY OPENCAST MINING

STRIPPING RATIO	≤5:1				≤10:1				≤15:1			
TYPE OF COAL \ SEAM DEPTH (c) METRES	0-15	15-50	50-100	TOTAL	0-15	15-50	50-100	TOTAL	0-15	15-50	50-100	TOTAL
RAW BITUMINOUS COAL (a)	454	6 361	4 208	11 023	530	10 015	13 135	23 680	571	10 663	17 160	27 794
WASHED BITUMINOUS COAL	104	1 147	385	1 636	185	2 916	2 108	5 209	217	3 506	4 214	7 937
METALLURGICAL COAL	1	7	-	8	7	13	7	27	7	43	74	124
ANTHRACITIC COAL	-	-	-	-	0	21	5	26	0	27	5	32

NOTES TO TABLE 6

(a) Contains the washed bituminous coal and the metallurgical coal.

(b) Cannot be added to coal extractable by underground mining.

(c) Coal from 0-15 metres can only be extracted by open cast mining.

Source for Table 6: The table was taken in its entirety from the Petrick Commission Report, op. cit.

Strippable Reserves: Reserves extractable by strip mining methods are presented by coal type, overburden ratio, and depth. While "extractable" coals are listed for ratios up to 15:1 and for depths to 100 metres,

> ...the present maximum stripping ratio is about 5:1, and the maximum depth for opencasting is about 50 metres...(Therefore) the figures in the stripping ratio columns of less than 10:1 and less than 15:1 do not represent coal extractable under present economic conditions, but are inserted to indicate the potential.[13]

With this caveat in mind, strippable reserves total 6.8 million metric tons.

We could assume that all coal which can be strip mined will be strip mined. This is supported by current trends in South African mining. In fact, strip mining

> ...has been so successful that the...method is planned for wide use in South Africa, and it is likely that all future coal mines with a low enough stripping ratio will adopt the technique.[14]

Under this assumption, strip reserves are a subset of underground reserves and we may simply subtract the strip reserves from the total reserves "extractable by underground mining" to obtain a figure for reserves which will truly be mined underground. However, I hesitate to do this for two reasons. First, the Petrick Commission warns that "strip coal reserves cannot be added to coal extractable by underground mining" to yield total reserves.[15] No explanation is offered for this -- nor have I been able to find a satisfactory explanation in the literature or in conversations with mining officials. While this does not preclude the assumption that strip reserves are a subset of underground reserves, the statement and lack of explanation introduces a lack of clarity which muddies reserves definitions.

The second reason I hesitate to assume strip reserves are a subset of underground reserves is that some strip reserves will be unfit for underground mining. That is, in South Africa, as in the United States, some of the shallower strippable coal is really not underground mineable -- surface subsidence is a problem which prohibits underground activity at some shallower depths in some areas.

New Marginal Mines in South Africa:

Literature describing recent mine openings in South Africa mentions some of the parameters characteristic of the new mines which Petrick used to define reserves. I examined these data on seam thicknesses, overburden ratios, depth of burial, ash content, and technology to see if the limits of the reserve constraints prescribed in Petrick are being approached. My conclusion is that the Petrick report fails to adequately describe economically extractable coal in South Africa. The least economically attractive fringes of each of the parameters used to define "extractable" coal do not characterize coal to be extracted by mines which are scheduled to be opened between now and 1981. Characteristics other than seam thickness, depth, ash content, and minimum tonnage are, therefore, of great importance in determining costs.[16]

Table 7 lists each incremental mine along with some distinguishing features. Planned levels of output vary from 180,000 to 12 million tons per year. This obviously demonstrates the insufficiency of output in determining production costs. Thicknesses range from 0.8 metres to 9 metres -- evidence that thickness alone is an inadequate determinant of costs (See above, p. 30). Calorific, water, and ash values are also broadly spread. There clearly must be an interaction of these and other geologic factors in determining costs. Finally, the technological specifications of the Petrick Report do not appear to be verified by the limited data we have on new mines. The Coalbrook Colliery uses the longwall method to mine low grade coal. Petrick suggested that only bord and pillar mining would be practiced on low grade coal.

It is clear that in South Africa, as in the United States, seam thickness is the major determinant of mining costs. Evidence for this view exists in Table 5(d), "Priority for the Extraction of Coal Seams Which are Likely to be Close Together." Within each coal field, the seam extraction priority matches exactly the progression of seam thicknesses. For example, the Witbank seam hierarchy begins with number 2 seam as the

Table 7

NEW MINES IN SOUTH AFRICA

Location and Characteristics of Mines Recently Opened or Planned to Open Before 1981

Region	Field[1]	Mine Name	Market & Planned or Realized Output (10^6 tons)	Grade of Coal	Mining Technology	Seams Mined	Seam Thickness[2]	Ash Content[4]	Transport Type(s)
Transuaal									
	E. Transvaal	Ermelo	3-Export	High	Bord and Pillar, Mechanized	C-Lower	0.5	-	Rail and Ship
	Highveld	Bojesspruit	12-Sasol	-	Longwall, Continuous, with pillar extraction	#4	4.1	-	Tied[3]
		Kriel	8.5 Power	High	Strip	#4	4.1	22.9	Tied[3]
		Matla	9.6 Power		Longwall, Continuous, with pillar extraction	4, 2, 5	4.1, 2.6, 0.8		Tied[3]
	South Rand	Springfield (Grootvley Shaft)	2 Power	Low and High	Some continuous; Bord and pillar extraction	Bottom, Main	9,7	24.3	Tied[3]
	Waterberg	Grootegeluk	1.8 Steel 2.3 steam	Met, and High	Strip	-	1[5]	-	Rail, ship
	Witbank								
		Annyspruitt	6{Export Internal	High	Strip	Alfred, Gus, Dundas	1.8, 1.5, varies	-	Truck, rail, Ship
		Boschmans	2{Blend Coking	Met	Bord and Pillar, Pillar, ext.	2, 4, 5	6.2, 3.0, 1.5	-	Rail
		Duvha	9.4 Power	High		2, 1, 4	1.1-5	17.0	Tied[3]
		Kleinkopje	2 Export 1.6 Local 0.7 Low-Ash Blend Coking	High Met.	Strip	2, 1	6, 2.9	7.5-22.7	Rail

Region	Field	Mine Name	Market & Planned (P) or Realized Output (10^6 tons)	Grade of Coal	Mining Technology	Seams Mined	Seam Thickness[2]	Ash Content[4]	Transport Type(s)
		Optimum	6.4 Power	–	4.8 Strip 1.6 Under	2, 1, 4	6, 2.9, 2.3	21.2	Tied[3]
		Reitspruitt	5 Export	High	Strip	2,1,4, 5	6, 2.9, 2.3, 1.5	-	Rail
Natal									
	Klipriver								
		Navigation	3 Steel	Blend-coking	Strip	Main	1.5	10.4-24.9	Rail
	Vryheid								
		Aloe	0.18 Exports	Met	Strip	Alfred	1.8	14	Road & Rail
		Boschkrans	0.5 Export	Anthracite	Bord & Pillar	Dundas	<1[6]	-	Road & Rail
		Heritage	0.35 Export	High	Bord & Pillar	Alfred, GUS, Dundas	1.8, 1.5, <1[6]		Road & Rail
Orange Free State									
	Vareeniging								
		Coalbrook	3.3 Power	Low	Bord and Pillar, Continuous. Longwall	2	3.4-7.1[7]	31.9	Tied[3]

Sources:
(1) The Petrick Commission Report, South Africa, Department of Mines, Figures 4.2/1 - 4.2/20, 1975;
(2) South African Department of Mines, "Coal Mines in South Africa, Directory #2, 1978, pp.1-43.

Footnotes:
(1) These fields correspond to those in the Petrick Commission Report. However, the location of each mine was derived from the Dept. of Mines Report. See Sources.
(2) Seam thicknesses are largely thicknesses as presented in the Petrick Commission Report, which are representative for the field in question. That is, there is no guarantee that the thickness corresponds exactly to the portion of the seam extracted by the specific mine.

Footnotes:

(3) "Tied" collieries are usually connected to a nearby power plant by conveyor belt.

(4) In percent on an air-dry basis. Note that sulfur content is almost uniformly less than one-percent on an air-dry basis.

(5) "Upper sub-groups" are mined. The Waterberg field is characterized by numerous, very thin (often less than 1 metre) seams which lie very close to one another. These conditions make estimation of a representative seam thickness difficult. One metre is a not unlikely figure given limited information.

(6) The Dundas group is represented in the Petrick Report as a 3-seam split. The upper seam is 0.3 metres thick, and is separated from the middle seam by 3 metres. The middle seam of the split is 0.6 metres thick, and lies 3 metres above the lower seam, which is 0.3 metres thick. I chose less than 1 metre as the representative thickness because, even if the 3 sub-seams join, they would form a seam only 1.2 metres thick.

(7) The #2 seam in the Vareeniging field is comprised of two sub-seams. These sub-seams are 3.4 metres and 3.7 metres thick. I give a range from the lower bound, 3.4m, to the sum of the two.

most attractive, then number 1, then number 4. The number 2 seam is also the thickest at six metres, followed by number 1 at 2.9 and number 4 at 2.3 metres. The seam extraction hierarchy corresponds with the seam thicknesses hierarchy for each field.

It is impossible to infer, however, the hierarchy among fields from Table 5(d). This ranking may be clarified by referring once again to the marginal mine concept. Refer again to Table 7 , which displays the specifications of eighteen new mines. In a competitive market, and assuming that all coal mined is homogeneous in quality, we could use the facts that (a) all these marginal mines should have equal costs, (b) seam thickness is a major determinant of costs, and (c) the range of seam thicknesses mined is very wide, to draw conclusions regarding the size of epsilon (all unobserved cost-effecting factors) among fields. By associating an epsilon with each mine field, and knowing the thickness of all seams in each field, we could rank the economic attractiveness of all fields in South Africa.

Unfortunately, the domestic market is not competitive and coal is anything but homogeneous in physical composition (or end-use). Therefore we must control for the end-use variable before we can estimate economic preference among mine fields. This is done in Tables 8a to 8d.

The quality (market) categories for new mines are coal for export, domestic electric power, domestic steel, conversion to oil, and domestic commercial. A glance at the mean seam thickness for each category verifies our expectations concerning the effect of price on the choice of seam. The lucrative export mines exhibit the lowest group average seam thickness at 2.7 metres. Metallurgical coal is next at 2.9 metres followed by conversion to oil, electric power generation, and low-grade (commercial) coal.

Within each group we see wide variation in seam thicknesses for these marginal mines. As explained above, this demonstrates the importance of cost-effecting parameters other than seam thickness. The last column ranks the magnitude of these "other" factors by simply associating the highest (1 is highest) ranking with the thickest seam in the group.

This method has some shortcomings. First, only eight of sixteen fields are represented. The remaining fields are remote (high transport costs), contain poor quality seams, and/or are not fully prospected. Second, within each end-use market-defined group of new mines, there is a maximum of six entries. Little information can be gathered from these small samples. Finally, the seam thicknesses are the average thicknesses supplied by the Petrick Report. Applying them to specific mines as we do in Tables 8A to 8D is probably misleading for the purpose of estimating unobserved cost-

Table 8

New Mines by End-Use Market

A. New Mines Producing for Export

Mine	Field	Th	1/Th	Ranking of Magnitude of Unobserved Cost-Affecting Factors
Aloe	Vryheid	1.8	.555	3
Annyspruitt	Witbank	1.8	.555	3
Boschkrans	Vryheid	Less Than 1	1	5
Ermelo	E. Transvaal	0.5	2.0	6
Heritage	Vryheid	1.8	.555	3
Kleinkopje	Witbank	6.0	.167	1
Reitspruitt	Witbank	6.0	.167	1
Simple Mean		2.7		

B. New Mines Producing for Domestic Electric Power

Mine	Field	Th	1/Th	Ranking of Magnitude of Unobserved Cost-Affecting Factors
Coalbrook	Vareeniging	3.4	.294	5
Duvha	Witbank	1.1	.909	6
Kriel	Highveld	4.1	.244	3
Matla	Highveld	4.1	.244	3
Optimum	Witbank	6.0	.167	2
Springfield	South Rand	9.0	.111	1
Simple Mean		4.61		

C. New Mines Producing For Domestic Steel Production

Mine	Field	Th	$\frac{1}{Th}$	Ranking of Magnitude of Unobserved Cost-Affecting Factors
Boschmans	Witbank	6.2	.161	1
Grootegeluk	Waterburg	1.0	1.0	4
Navigation	Klipriver	1.5	.667	2
Simple Mean		2.9		

D. New Mines Producing for Conversion to Oil

Bojesspruitt	Highveld	4.1	.244	

E. New Low-Grade Coal Mines

Coalbrook	Vareeniging	3.4	.294	4
Matla	Highveld	4.1	.244	2
Springfield	South Rand	9.0	.111	1
Simple Mean		5.5		

affecting factors. Thus, while the method is correct in theory, it is rather crude in practice.[17]

We therefore rely on seam thickness as our sole guide to the economic priority of seam extraction. By doing so we recognize the principal determinant of extraction costs and de-emphasize some very important cost-effecting parameters. The resource curves derived in the next section should, therefore, be considered as useful first approximations of the effect of cumulative production on extraction costs in South Africa. Data are far too limited to provide better estimates of epsilon.

I conclude that there is little evidence that the Petrick Report recognizes current mining practice in its estimate of currently mineable coal. On the other hand, the geologic conditions other than those which Petrick uses are not sufficiently described in available literature to allow us to present a better estimate of today's economic resources. These definitional problems, however, do lead me to conclude that much time and effort are wastefully spent attempting to define an ephemeral, and therefore not very helpful, concept -- reserves. If every marginal cost-producing mix of geologic factors could be defined, that definition would be obsolete with any change in economic conditions. Since economic conditions are changing continuously, so is the theoretical reserve figure.

An alternative to relying on reserve figures for national coal utilization planning would be to (a) describe resources by as many cost-effecting physical parameters as possible, (b) identify those end-use markets for coal which are of interest to the national plan, and (c) identify the location and amount of the coal of interest by specifying the appropriate parameter ranges. This process recognizes that coal is a multitude of substances, and that the worth of coal in the ground is largely determined by the conditions of existing and projected markets which require specific types of coal.

The Petrick Commission does not go this far, nor does any other national coal utilization program of which I am aware. I therefore use the Petrick Commission numbers as a basis for this report. This basis provides an important input into the depletion study which comprises Section II. Before we abandon this reserves analysis to pursue this depletion study (the result of which will be the construction of resource curves) let us examine current opposition to the Petrick results within South Africa.

<u>Two Challenges to the Petrick Reserves Conclusions</u>:

R.E. Burnton, a senior engineer at the General Mining and Finance Corporation, believes that the Petrick estimates are far too low. He argues that approximately ten billion tons can now be added due to "new reserve discoveries, the shift of reserves from the inferred category into the proven category; and a legitimate reduction in the minimum mining height in terms of today's technology and economics."[18] He further suggests that using "today's technology and higher prices, one can confidently consider over 60% of the in situ reserves as being economically recoverable." He arrives at an estimate of 61 billion metric tons of recoverable reserves, a little less than triple the Petrick estimate.

Burnton's definitions and estimate betray his confusion regarding the concept of reserves. His suggestion that 60% of reserves can be economically recovered displays his rather cavalier definition of reserves. Reserves are, by definition, economically recoverable. Further, reserves should be recoverable at today's prices, not at some unidentified level of "higher" prices. A less bothersome point, but still an annoyance, is Burnton's failure to specify the reasons for the "legitimate reduction" of the minimum height. Most objectionable is Burnton's use of Petrick's mineable in situ and washable category as his recoverable high grade reserves. As noted in Section II, mineable coal is not an economically meaningful concept. It includes a lot of coal that is not economic at today's prices or technologies. Burnton would have been closer (but still off the mark) if he used the 10.5 billion tons of washable extractable coal (using underground methods) for his high grade steam coal estimates. However, this would have made his 61 billion ton reserve estimate even more questionable.

A recent article by R.K. Dutkiewicz present problems similar to those of Burnton, only in a more informed manner. He reminds us of the gradual increases characteristic of reserve estimates of most minerals, and he points out the 32% increase in reserves estimated in the Petrick Report over the 1969 van Rensburg Report[19] (see Table 9). Coal reserve estimates have been climbing in South Africa since the first national study was completed in 1947. After setting this moderate tone, Dutkiewicz ventures into guesses about future coal availability.

Assuming coal recovery increases to 60% by the end of the century (from about 40% on average today) and increasing allowable ash levels to 60% (assuming fluidized bed technologies are in wide use) by 2000, Dutkiewicz concludes that coal production may peak at over 900 million tons per year in 2075 -- fifty years after the Petrick peak of 300 million tons per year. This scenario is highly speculative with its very optimistic recovery factor and fluidized bed assumptions. Dutkiewicz is candid in presenting these events as being very "iffy". However, his projections of coal production in South Africa are less candidly speculative. He provides a bell

Table 9

Bituminous and Anthracite Reserve Estimates
for South Africa: A Recent History
(Millions of Tons)*

	Mineable in situ	Extractable	Author
1947	-	11,065	1947 Commission
1952	67,908	-	Venter
1959	72,455	-	Mineral Resources of S.A.
1969	-	18,877	Coal Advisory Board
1975	81,274	25,290	Petrick Commission

*Metric

curve of coal production which suggests that eventually over 100 billion tons of coal will be extracted from South Africa by some time after 2150. Assuming 60% recovery, this implies that coal in situ totals about 167 billion tons -- over twice Petrick's estimate of "mineable" coal in situ. I believe it to be unlikely that another 80 billion tons of coal will be found within the confines of South Africa. The Petrick Commission repeatedly warns that while discoveries of new coal continue to be made, the magnitude of these discoveries is bound to be small compared with currently estimated resources. Dutkiewicz's optimistic and speculative scenario is, therefore, of little practical use in expanding upon the Petrick estimates.

Finally, the International Energy Agancy states that "(w)ith present prices for coal in the international market, the (IEA) Secretariat estimates that economically recoverable coal reserves in South Africa could be as high as 55 billion tons."[20] However, the IEA is comfortable with the Petrick estimates, which they use in the only table on reserves included in their report. We must assume that their 55 billion tons reserve estimate is anticipating future developments.

FOOTNOTES

Section III:

1. Dutkiewicz, R.K., "Energy, The Road Ahead," in The South African Mechanical Engineer, Vol. 28, July 1978, p. 265.

2. US Bureau of Mines, Department of the Interior, Information Circular 8678, "The Resource Base of Coal for Underground Mining in the Western United States," 1975, p. 5.

3. Ibid, p. 6.

4. Zimmerman, Martin B., Draft report on US coal reserves to EPRI, 1/79, p. 8.

5. Ibid., p. 26.

6. Petrick Commission Report, op. cit.

7. Of course, it is much easier to be concise since the industry is about one-seventh the size of the US industry (production basis).

8. Petrick Commission Report, Section 5.1.6.5.

9. Ibid, Table 5.3/1.

10. We do not consider anthracite in this study due to its relative lack of importance in South African production.

11. Ellis, S.P., and F.E. Kirstein, "A Review of Mining Methods and Their Effects on the Reserves of Coal in Southern Africa," Paper 4-2, Energy Utilization Unit, University of Cape Town, 1977, p. 6.

12. Zimmerman, Draft Report, p. 11.

13. Petrick Commission Report, Section 5.5.8.2.

14. South African Mining and Engineering Journal, "Optimum Colliery Takes Lead with Open Cast Restoration," Sept. 1977, p. 26. 01. Petrick, Table 5.3/2. P. Burnton, R.E., "The Road Ahead: Coal as a Source of Energy," 1820 Settles National Foundation 1978 Conference, 1978, p. 14.

15. The strip and underground categories overlap. See International Energy Agency, Steam Coal Prospects to 2000, Paris 1978, p. 131.

16. The Petrick Commission presents a range of seam thicknesses for the reserve thickness constraint rather than a single lower bound. This appears at first to suggest that the Commission, in judging whether to include a specific body of coal into reserves (extractable coal), may have adjusted for allowable seam thickness based on other cost-effecting factors. That is, a thick seam with otherwise poor characteristics (gas and water leakage, steep gradient, etc.) might be excluded from reserves while a much thinner seam with no other negative conditions might be included. However, since the commission states that its reserve estimates "are based on physical parameters to determine extractability, but do not allow for the direct use of economic parameters...", it is clear that the range of thickness, and indeed all other specifications, for the most part ignore economics. I conclude, therefore, that no economic adjustment of seam thickness took place.

17. See p. 30 for a discussion of cost-affecting factors other than seam thickness.

18. Burnton, R.E., "The Road Ahead: Coal as a Source of Energy," 1820 Settlers National Monument Foundation 1978 Conference, p. 13.

19. Dutkiewicz, p. 265.

20. International Energy Agency, Steam Coal Prospects to 2000, Paris 1978, p. 131.

Section IV: The Cost of Coal Depletion in South Africa

One cause of increasing costs in mineral extraction is the process of moving to less geologically and economically attractive seams as cumulative production increases. This is especially true for coal in South Africa since, as argued above, further substantial additions to known resources are unlikely. Therefore, according to the theory of resource economics, the priority of seams to be extracted can be constructed based upon observable cost-affecting geologic conditions alone.

In this section we will address the process of depletion in South African coal. To this end, we first examine the method and results of a previous study of U.S. coal depletion to provide a vocabulary and frame of reference for our discussion of South Africa.[1] This method is a useful synthesis of geology, economics, and statistics. It relates the marginal cost of extracting a ton of coal to the thickness of the seam from which it is extracted, and to "non-observable" geologic conditions. This approach includes the following steps for underground mining:

1. Using data for Pike County, Kentucky, it is established that the distribution of tons of coal in the

ground by seam thickness closely approximates lognormal. It is assumed that the variance of this lognormal distribution is constant and that it holds throughout the United States.

2. Using Bureau of Mines reserve data, which breaks reserves into tons in seams 28 inches to 48 inches thick, and tons in seams greater than 48 inches thick, a representative (mean) thickness for each state is calculated. This is possible due to the assumption of lognormality.

3. For underground mining, Bureau of Mines and other data are used to statistically deprive:

a. Production per mining unit[2] as a function of seam thickness, number of producing units, and number of openings to the mine. Zimmerman's equation for the United States is:

$$\sqrt{s}\,\log\frac{q}{s} = \underset{\substack{(.4842)\\(1.5630)}}{.7568\,\sqrt{s}} + \underset{\substack{(.1205)\\(9.1906)}}{1.1071(\log TH)\sqrt{s}} - \underset{\substack{(.0594)\\(-3.6762)}}{.2185(\log s)\sqrt{s}} + \underset{\substack{(.0655)\\(.4314)}}{.0283\,(\log OP)\sqrt{s}}$$

(SE) and (t-STAT.) shown beneath each coefficient, respectively.

s = number of mining units.

q = total output of the mine.

Th = thickness of the coal seam in feet.

OP = number of openings to the mine.

b. This leads to a relationship describing the number of mining units required as a function of annual production, seam thickness, and mine openings:

$$s = \left[\frac{\tilde{Q}}{1566.579Th^{1.1071}\ OP^{.0283}}\right]^{1.2796}$$

$\tilde{Q}$ = annual production.

c. Total annual underground cost as a function of number of mining units and mine openings:

$$TC = \$1,743,222 + \$2,122,480(s) + 1,085,771(OP)$$

$$= \$1,743,222 + 2,122,480\left[\frac{Q}{1566.579^{1.1071}\ OP^{0.0283}}\right]^{1.2796} +$$

$$+ 1,805,771(OP)$$

d. Minimum efficient scale (annual production) of a mine as a function of thickness and number of mine openings (using "a" and "b" above):

$$Q^{*} = \left[\frac{1,743,222 + 1,085,771(OP)}{593,445}\right]^{.7815}\ 1567Th^{1.1071}\ OP^{.0283}$$

e. Minimum average cost as a function of thickness (assuming two openings):

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

Note that the constants, K and γ are unique to the method of mining used. For U.S. mines using continuous mining techniques, K = 2567. γ = 1.1071. E (this error term is a proxy for less observable mining conditions) is assumed to be lognormally distributed. This suggests that the representative new mine seam thickness is the geometric mean of marginal mine seam thicknesses. Ideally, a relationship for longwall and conventional mining methods should also be derived and used to compute costs for coals extracted by those methods. In this way, if reserves are defined by assuming a technology of extraction, the proper constant can be readily used to compute depletion costs.

For strip mining, the author (assuming a lognormal distribution of tons of coal in the ground by seam thickness from Powder River and Illinois data) derives the following:

a. Maximum Usefulness Factor[3] as a function of overburden removed (RQ) and number of machines in use (N):

(eq.a)

MUF =	-.446684 +	.612306(logRQ) +	.506967(logN)
(SE)	(2.31895)	(.145663)	(.229134)
(t-STAT)	(-.192623)	(4.20357)	(2.21254)

b. Total annual costs as a function of MUF and annual production. The value for MUF is substituted into the following equation for total annyal costs of a strip mine:

(eq.b) $TC = 3{,}170{,}223 + 467{,}262(MUF) + .96Q$

c. Average cost as a function of annual output and overburden ratio:

(eq.c) $AC = 3{,}170{,}223/Q + 467{,}262(MUF)/Q + .96$

d. Since ε is assumed to be lognormal, the "best guess" for an average MUF is derived by solving for MUF in equation (a) using the geometric mean of the observed value of overburden removed (RQ) and a value of one (the geometric mean) for ε. This value of MUF is substituted into equation (c), and the equation is solved for Q^*, the minimum efficient scale. At this level of output, minimum average cost, AC^*, is reached. The expression for the Powder River Basin is the following:

(eq.d) $AC^* = .52R^{1.63317} + .96$

e. Using the Bureau of Mines' data on reserves and using the above relationships describing cost as a function of thickness and tons of coal in the ground for each seam thickness, the distribution of coal in the ground according to cost of exploitation can be derived.

f. By specifying a cumulative output total, this exploitation cost distribution can be solved, the upper limit of which is the marginal cost for having mined that much coal. These are the marginal costs that construct Zimmerman's resource curves.

The South African Example

I have modified this method to accomodate the data available for South Africa. A vertical seam cross section is available for each mining district (an example is presented in Figure 2), as are reserves by district (see Table 5 for South African reserves). (Table 6 details reserve specifications.) Using this information, the ratio of a given (economically-exploitable) seam's thickness to the sum of all the seam thicknesses in a mining district is assumed to equal the share of that district's total reserves which are contained in that seam. Since we have this tons per seam information, we avoid having to assume that the distribution of tons of coal in the ground by seam thickness is lognormal (or perhaps some other distribution).

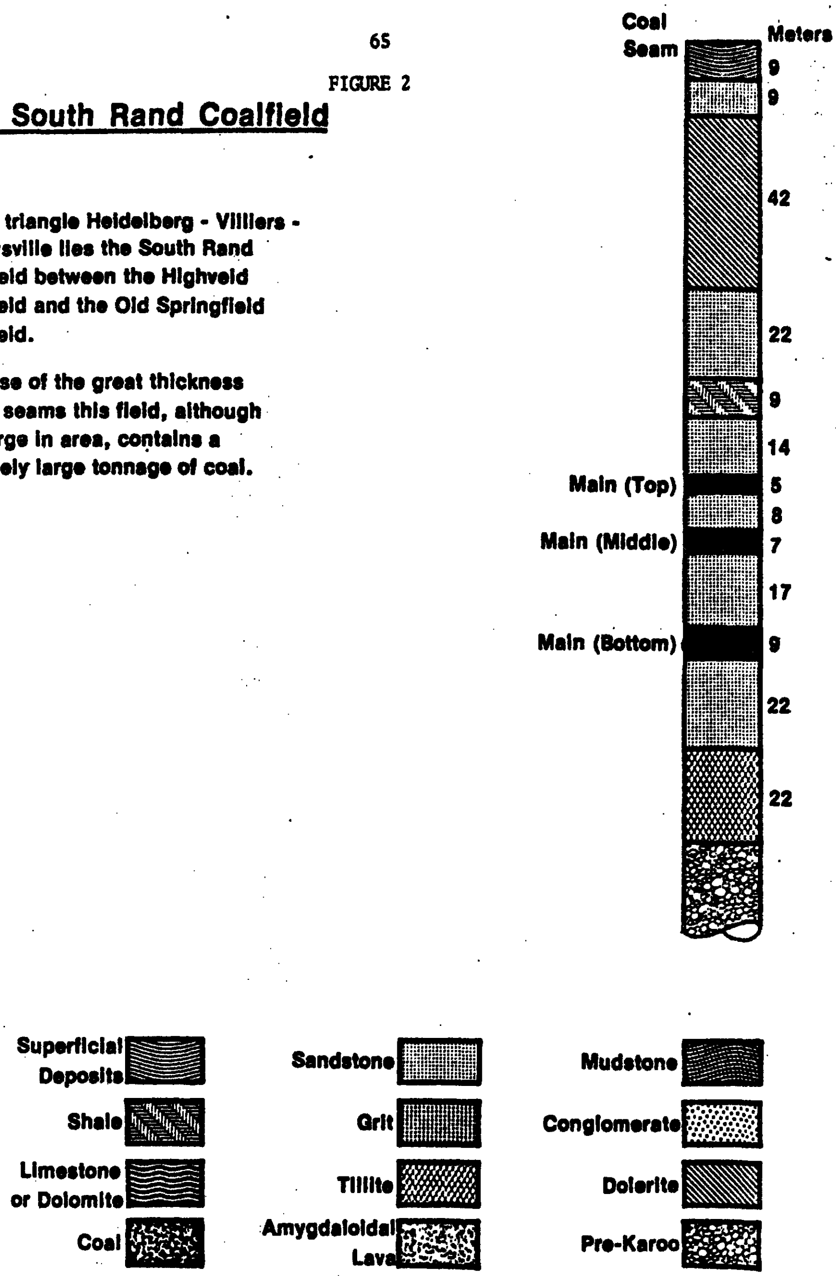
This analysis, as mentioned above, estimates depletion exclusively for coal mined underground.[4] The underground technology which is assumed is continuous mining with room and pillar extraction. Recall that Zimmerman assumes the same method. He arrives at an equation that relates productivity per mining unit (see p. 60 above) to seam thickness, number of mining units, and number of openings to the mine.[5]

FIGURE 2

The South Rand Coalfield

In the triangle Heidelberg - Villiers - Deneysville lies the South Rand Coalfield between the Highveld Coalfield and the Old Springfield Coalfield.

Because of the great thickness of the seams this field, although not large in area, contains a relatively large tonnage of coal.



The thickness coefficient in this log-form productivity equation becomes the exponent of thickness in the minimum average cost equation.

In South Africa, labor costs are much lower relative to capital costs than U.S. labor costs are to U.S. capital costs. This results in a widespread use of mining techniques in South Africa which are less efficient and more labor-intensive than continuous mining. However, assuming that continuous mining is the technology of the underground marginal mine, the change in productivity arising from changes in seam thickness will likely be very close in both the U.S. and South Africa. Therefore, the coefficient of seam thickness which Zimmerman derives for U.S. continuous mining is likely to be a close approximation of the South African thickness coefficient. Note from Table 7 that only four out of eight new underground mines in South Africa will use continuous mining. However, 78% of all new underground production will come from mines using continuous mining techniques. Further, as I noted in Section 2, a committment exists to waste less coal in mining. And in Section 5 on labor costs I point out that the transition to more capital-intensive mining methods is accelerating to counter rising labor costs. In addition, the equipment used in South Africa for these capital-intensive methods is, for the most part, identical to that used in the United States. Therefore, the coefficient of seam thickness in the minimum average cost equation for South Africa should be very close to the U.S. coefficient of 1.1. I use this value for the remainder of the analysis. Further, in this exercise we assume that the variance of the error term, which represents unobserved cost-effective conditions, is the same in South Africa as it is in the U.S. This allows us to examine, in an approximating way, the cost of depletion in South Africa.

To supply the appropriate constant, K, for the South African minimum available cost equation, we rely on cost estimates of a "typical" mine suggested by the Energy Utilization Unit of the University of Cape Town[6] (see Table 10). The room (bord) and pillar mine is 70 metres (233 feet) deep, and the seam is five metres (16 feet) thick.[7] The mine is large with an annual output of three million tons.[8]

The cost data for a "typical" mine which appears in Table 10 allow us to compute the constant K, for both washed and unwashed coal.[9]

Considering the "bord and pillar" example, we compute K using the following two steps:

1. Assume the industry is competitive. Therefore, the price is the marginal cost adjusted for an "adequate" return.[10]

Table 10

Specifications for "Typical" South African Mines

	Strip Mining	Longwall Mining	Bord & Pillar Mining
Nature of coal deposit:	30 metres cover 7 metres coal	300 metres cover 1 metres coal	70 metres cover 5 metres coal
Mining rate (t.p.a.):	4 million	2 million	3 million
Capital required without washing plant:	R18 million	R28 million	R24 million
Capital required with single stage washing plant:	R28 million	R34 million	R32 million
Operating costs per ton mined:	R1.50	R4.50	R2.50
Sales price required per ton of coal mined:	R2.55	R8.40	R4.60
Sales price required per ton if washed at say 70% yield:	R5.14	R13.70	R8.15

Source: Ellis, S.P., F.E. Kirstein, A Review of Mining Methods and Their Effects on the Reserves of Coal in South Africa, Paper 4-2, Energy Utilization Unit, University of Cape Town, 1975.

2. We use the relationship:

$$\text{marginal cost} = \frac{\text{Constant K}}{\text{Thickness}^{\text{constant}(\gamma)}\ \text{Error Term (E)}} \quad \text{or}$$

$$(*)\ MC = \frac{K}{Th^{\gamma}}$$, (assuming E equals its mean value of 1)

Therefore, $MC \cdot Th^{\gamma} = K$

But we have the marginal cost (R4.60 per ton), the thickness (5 metres or 16.4 ft),[11] and the coefficient of thickness (1.1).

Therefore:

$$(R4.60)\ (16.4)^{1.1} = K$$
$$99.82 = K$$

For washed coal:

$$(R8.15)\ (16.4)^{1.1} = K$$
$$176.86 = K$$

To estimate the cost for a given seam, we simply substitute the appropriate thickness into equation (*). I did this for each economically exploitable seam in South Africa. The results appear in Figures 3 and 4. Tables 11 and 12 list the name, tonnage, and cost of extraction for each seam and the step on the resource curve in which the seam in included.

While the South African resource curves consist of concrete steps, it is easy to imagine a "smoothed" version of

FIGURE 3

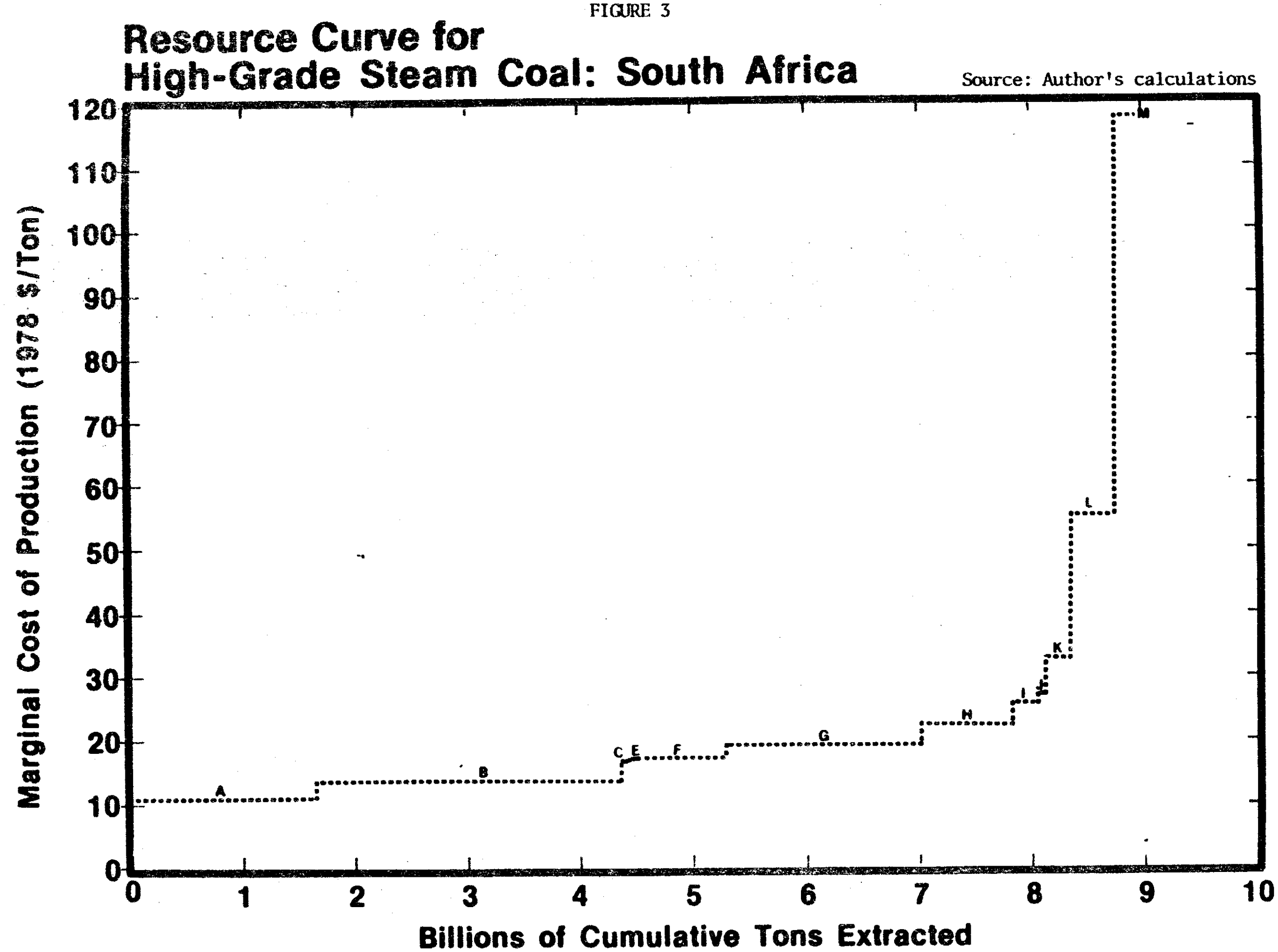

Resource Curve for
High-Grade Steam Coal: South Africa
Source: Author's calculations
Marginal Cost of Production (1978 $/Ton)
Billions of Cumulative Tons Extracted
0
10
20
30
40
50
60
70
80
90
100
110
120
1
2
3
4
5
6
7
8
9
10
A
B
C
E
F
G
H
I
K
L
M

FIGURE 4

Resource Curve for Low-Grade Steam Coal: South Africa

Source: Author's Calculations

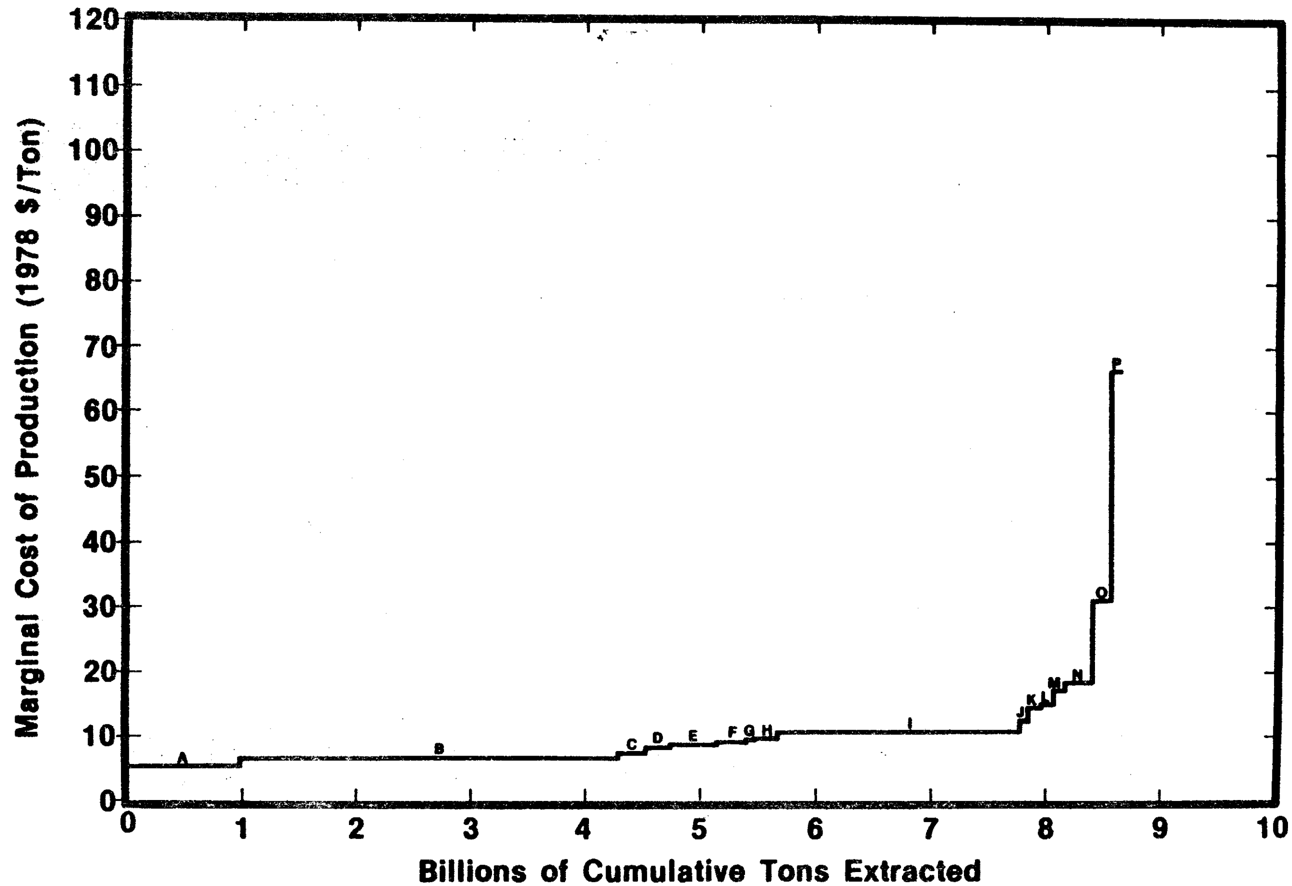


Table 11

High-Grade Coal Reserves by Seam

In South Africa

"Step" Label	Mining District(s) and Seam(s)	Metric Tons	Cost
A	Witbank 2	1,602	10.78
B	Highveld 4	2,757	13.45
C	South Rand H2*	45	16.44
E	East Transvaal H2*	32	16.52
	Klipriver Top	71	16.84
F	Witbank 1	774	17.06
G	Highveld 2	1,748	19.31
H	Witbank 4	774	22.02
I	East Transvaal C (UP)	261	25.68
J	Utrecht Moss	36	27.18
K	East Transvaal H3*	235	32.82
L	East Transvaal A	131	55.05
	" " B (UP)	131	55.05
	" " B	131	55.05
M	" " C	65	118.25
	" " D	65	118.25
	" " E	65	118.25
TOTAL		8,923	

Table 12

Low-Grade Coal Reserves by Seam
in South Africa

"Step" Label	Mining District(s) and Seam(s)	Metric Tons	Cost
A	South Rand H1*	352	5.29
	OFS-Vierfontein Bottom	236	5.29
	Limpopo Bottom	126	5.29
	Witbank 2	156	5.29
B	Highveld 4	3,316	6.60
C	Vareeniging 2A	236	7.37
D	Vareeniging 2B	216	8.08
E	Varreniging 3	197	8.95
	" 1	197	8.95
F	East Transvall H2*	20	9.32
	South Rand H2*	233	9.32
G	Witbank 1	75	9.63
H	Klipriver Top	201	10.86
I	Highveld 2	2,103	10.90
J	Witbank 4	75	12.42
K	East Transvaal C(UP)	117	14.49
L	Utrecht Moss	119	15.33
M	Vareeniging 5	108	17.33
N	East Transvaal H3*	91	18.53
	South Rand H3*	117	18.53
O	East Transvaal A	58	31.07
	" " B(UP)	58	31.07
	" " B	58	31.07
P	East Transvaal C	29	66.61
	" " D	29	66.61
	" " E	29	66.61
TOTAL		8,663	

each which would nicely approximate the shape of a classic long-run supply curve. This becomes intuitive when we consider that the depletion effect should hold for specific seams as it does for all of South Africa. As a seam is exploited, the cost of doing so will increase because of the progression to thinner and otherwise less desirable parts of the seam.[12] This seam depletion effect should in theory cause rising marginal costs from the start of extraction. Therefore, the "steps" should begin by sloping gently upward, then more rapidly, in a manner similar to the entire resource curve. Further smoothing would yield a continuous marginal cost (long-run supply) curve.

It would be helpful to get a feeling for the magnitude of increases in costs due to depletion that could occur to the year 2000. To this end, I made the following assumptions:

(a) Future levels of production: Granville and Venter argue that coal production in South Africa will increase 10% annually in the period 1977-1980, 5.7% in 1980-1987, and 3.5% in 1987-2000.[13] (See Table 13.)

I use the Granville and Venter numbers because of their proximity to the situation, and because the difference in the magnitude of depletion costs arising from other studies is insignificant.

(b) Smoothing of step functions: First, I calculate the rate of cost increase per ton of coal available for each

Table 13

Depletion Cost Estimates

Year	Total[a] Production (Million Metric Tons)	Low Grade (Million Metric Tons)	Depletion Cost (US$1975)	High Grade (Million Metric Tons)	Depletion Cost (US$1975)
1975	78	45.24		32.76	
1976	87	50.46	.05	36.54	.05
1977	93	53.94	.12	39.06	.10
1978	102	59.16	.18	42.84	.17
1979	113	65.54	.26	47.46	.23
1980	124	71.92	.34	52.08	.30
1981	131	85.15	.43	45.85	.38
1982	139	09.35	.54	48.65	.45
1983	146	94.90	.66	51.10	.53
1984	155	100.75	.78	54.25	.61
1985	164	106.60	.95	57.40	.69
1986	173	121.10	1.12	51.90	.78
1987	183	128.10	1.26	54.90	.87
1988	189	132.30	1.33	56.70	.96
1989	196	137.20	1.35	58.80	1.05
1990	203	14.210	1.39	60.90	1.15
1991	210	147.00	1.42	63.00	1.25
1992	217	151.90	1.45	65.10	1.35
1993	225	157.50	1.49	67.50	1.46
1994	233	163.10	1.52	69.90	1.57
1995	241	168.70	1.56	72.30	1.69
1996	249	174.30	1.60	74.70	1.81
1997	258	180.60	1.64	77.40	1.95
1998	267	186.90	1.68	80.10	2.08
1999	276	193.20	1.73	82.80	2.23
2000	286	200.20	1.77	85.80	2.38
TOTAL	4738	3208.21		1529.79	

step. I then apply an exponent, which represents the number of tons of coal (high or low-grade) mined during the year of interest, to the rate of increase per ton appropriate to the given step. This yields an increment to depletion cost for that year, which must be added to the sum of depletion charges for previous years to yield current depletion charges.

Let us calculate the depletion charge of 30¢ for high-grade coal in 1980. Notice that all depletion occurs on the first step of the resource curve. (This first step contains 1,602,000,000 metric tons, while only 1,539,790,000 tons of high grade coal is mined by 2000 under this production scenario.) Cost increases from \$10.78 to \$13.45 over this step due to depletion. The rate of cost increase for this step per 1000 tons mined is thus:

$$\left(\frac{\$13.45}{\$10.78}\right)^{\frac{1}{1,602,000}} = 1.000000138$$

Given the projected production of 52,080,000 metric tons of high-grade coal in 1980, the increment to depletion charge is thus computed:

a. $(1.000000138)^{52080} = 1.0072$

Apply this figure to the initial cost.

b. (1.0072)($10.78) - $10.78 = $.07

Add this to the cumulative depletion change for 1976-1979.

c. $0.23 + $.07 = $.30

= the depletion charge for 1980.

3. Proportion of coal that is washed:

About 48% of raw coal production is now washed. I assume this proportion slips to 35% in 1981-1985, and 30% in 1985-2000. Further, I assume all high-grade coal is washed. These assumptions are supported by recent trends in mining in South Africa.[14]

The projections of depletion costs made under the above assumptions appear in Table 13. These costs, (in $1975),reach $1.77 and $2.38 in the year 2000 for low and high-grade coal, respectively. Further, these costs (as is pointed out below) will likely not exceed 4% of total selling price.

A Discussion of Complications:

Note that mining may occur at the same time for more than one, or all, of the steps which make up Figures 3 and 4. This does not violate the assumption of "cheapest seams first", because factors other than seam thickness contribute to costs of extraction. Thus, while seam "B" is thinner than seam "A", gas or water or grade conditions may be unfavorable enough in seam "A" to increase the cost of extraction to parity with seam "B". An increase in demand could similarly bring into production seams of varying thicknesses. Some mines will earn large rents due to favorable conditions relative to the marginal mine.

As we discovered above, however, marginal (new) mines in South Africa produce from a wide range of seam thicknesses. This suggests that ranking costs by seam thickness, and therefore establishing the national priority of seams to be extracted, is simplistic. We only know that <u>within</u> each mine field the mining priority is established by seam thicknesses (see Table 3(d)). In other words, the variation in cost-effecting factors <u>other</u> than seam thickness is perceived by the Petrick Commission to be insignificant. In addition, we would like some measure of the variation in these factors (the "E" in equation 3(e), p. 62) <u>among</u> the fields.

Evidence of a qualitative nature regarding the characteristics of these factors among fields does exist. This (admittedly circumstantial) evidence supports the resource curves derived in this section as good first approximations of the effect of depletion on costs. The following points are relevant:

(1) Seam continuity among the major coal fields is similar. Table 3(a) shows that the Highveld, South Rand,

Vareeniging, and Witbank coal fields, which hold 80% of all raw extractable coal in South Africa, require more than 10 boreholes per 2000 hectores for inclusion of a seam in the "proven" category. The fact that horizontal discontinuity is of roughly the same magnitude for these fields suggests that this cost-effecting factor is similar on average for most of the coal in South Africa.[15] Further, there is "a correlation between seams of the Witbank-Middleburg field with those of the Highveld and Vareeninging-Sasolburg coal-fields. There is thus a remarkable continuity of coal seams over large areas."[16]

(2) The vertical cross-section of each field contained in the Petrick Commission Report illustrates the similar nature of strata overlying seams among coal fields.

These arguments are made to support the concept of seam thickness as the major determinant of extraction cost among coal fields. One can just as easily argue that, given the data presented in Section 3 on marginal mines, seam thickness alone gives an incomplete picture. This view was, in fact, a primary thesis of Section 3 (See especially Table 8). But it is clear that in light of widespread lateral continuity in the coal seams and vertical similarity in types of overlying strata, seam thickness takes on an even more important role than would be expected under more variable circumstances. I therefore rely on Figures 11 and 12, which were derived from research done for this study, as adequate first approximations of the cost of depletion in South African coal.

FOOTNOTES

Section IV:

1. Zimmerman, Martin B., "Estimating a Policy Model of US Coal Supply," unpublished paper. 10/7/77. Also see Modelling Depletion in a Mineral Industry: The Case of Coal," Bell Journal of Economics, Vol. 8, #1, Spring 1977.

2. A mining unit consists of a continuous mining machine, two shuttle cars, and a complement of miners.

3. Productivity for strip mines is defined as output per unit size of the dragline. The unit of "size" is defined by Zimmerman to be the maximum usefulness factor (MUF), which is equal to the product of the capacity of the dragline bucket and the dumping "reach." (Horizontal reach within which a dragline can dig coal.)

4. I believe that the inclusion of strip-mineable coal would not alter significantly the conclusions derived here regarding depletion.

5. The number of mining units can be shown to be a function of output of the mine, seam thickness, and number of openings to the mine. Openings are assumed to equal two -- a result validated by the data. Therefore, with a coefficient of .0283, the "opening" term equals 1.0198. This is an insensitive term. Eight openings would yield a term equal to 1.06. Output is determined by a minimum efficient scale equation which is the offspring of a total annual cost equation for U.S. underground mines using the continuous mining technique. Minimum efficient scale is, therefore, a function of seam thickness only. At that efficient level of output, cost is minimized.

6. Ellis, S.P., and F.E. Kirstein, "A Review of Mining Methods and Their Effects on the Reserves of Coal in Southern Africa," Energy Utilization Unit of the University of Cape Town, Paper 4.2, 1975.

7. Continuous miners cannot currently mine face heights much over 10 feet on one pass. Recovery of coal in seams which are thicker than 10 feet would likely result in decreased productivity per mining unit per shift due to the need for greater roof support. This suggests a break from $\gamma = 1.1$ to a figure somewhat smaller. However, we assume here that

the γ for this "typical" mine remains at 1.1, which allows us to compute a constant for the marginal cost function. Given the likelihood of continuing technology improvements in roof support systems, it is unlikely that this productivity break, if it does indeed exist, will exist for long, or that it is significant in magnitude.

8. Washed coal is coal processed to reduce the ash and sulfur content. There are several technologies available to do this. We refer to washed coal as "high-grade steam coal."

9. These costs are quite close to those suggested by Smith, ibid.

10. The return varies among the three technologies. This is likely due to varying risk. To compute the return on capital investment for room and pillar mining, we first estimate the capital charge per ton. To do this we subtract the operating cost per ton (R2.50) from the price (R4.60) to yield the capital charge (R2.10). This charge, divided by the capital required (R24 million for unwashed coal) yields the percent return on each dollar of capital invested (8.75% for bord and pillar unwashed; 13.93% for unwashed longwall 5.80% unwashed strip).

11. In the United States the usual maximum seam thickness actually mined is 10-12 feet. The South Africa figures of 16.4 feet for a typical mine appears, therefore, to be somewhat generous. That is, will productivity increase with thickness all the way to 16 feet? I am assuming that with the usual South African practice of leaving large pillars behind to support the roof, mining height can approach 16 feet with accompanying productivity increases. If we assume the U.S. maximum of 12 feet, South African costs constants would equal 70.77 for unwashed, and 125.39 for washed coal. Required price would be lowered by 299 in both cases for each step in the resource curve (See Figures 3 and 4, see also footnote 7 above.)

12. Capital aging should also cause the cost of extraction to increase from the start. But this is a time-related cost, and is not reflected in the resource curve.

13. Granville and Venter, op.cit., p. 53.

14. Note the proportion of unwashed coal to be produced from new mines in Table 7.

15. Note that some Witbank and Highveld seams require 30 boreholes instead of 10. The seams requiring such extensive verification hold, however, a small minority of the total reserves in these fields.

16. Petrick Report, op. cit., paragraph 4.3.3.

Section V: Labor and Capital Costs

It is clear from the previous discussion that costs associated with depletion of coal resources will not reach a magnitude in this century that would threaten the competitive advantage of South African coal exports. This conclusion does not hold for labor and capital costs. In this section I shall argue that both of these costs will probably escalate in real terms at rates which may eliminate South Africa as the world's lowest cost producer of coal. The Petrick Commission provides a suitable introduction to this discussion -- an introduction which once again underscores the interaction of the gold and coal mining industries:

> Recent developments in Southern Africa have led to a retardation in expansion in the unskilled labour available to the South African mining industry: this has had a particularly severe effect on the Republic's gold mining industry which obtained more than 70 per cent of its unskilled labour from outside the Republic.
>
> As a result of these developments the gold mining industry has dramatically increased its wages for unskilled labourers and has intensified its efforts to obtain a much greater proportion of its unskilled labour forces from within the Republic; this recruitment will take place in competition with other employers -- including the coal industry.
>
> The result could be soaring labor costs for the coal mining industry at a time when its capital costs are already increasing at an unprecedented rate. Unless these cost increases are matched by higher prices, they must lead to a reduction in the extractable reserves and to the shelving

> of plans to increase the percentage extraction of *in situ* coal by the use of more costly mining methods and, indeed, to the opening up of new pits.[1]

Labor Costs

South African labor statistics demonstrate eloquently the extent to which segregation of races is institutionalized in the South African socio-economic system. All statistics are broken down into the categories of "White", "Bantu", "Colored", and "Asiatics". Racial distinctions determine economic stratification, as one may conclude from studying Table 14 and Figure 5. But the magnitude of the differences among racial groups appears to be diminishing. In 1975, whites earned 9.4 times the real wage of blacks; the ratio was 20.6 to 1 in 1965. (The rates slipped further in 1977 to 8:1.) This closing gap is reflected in the annual real increase in wages from 1970 to 1975. White real wages increased during 1970-1975 at a compound annual rate of 2.9% -- down from 6.5% per year from 1965-1970. Black wages shot up at 22.2 per cent per year in the 1970-75 period, up from only 4.9% annually during 1965-1970. I should emphasize that the difference between black and white wages remains huge -- R572 (about $658) to R5375 ($6181). However, the gap is narrowing -- if not out of a budding desire for social equity, then out of a growing shortage of black labor. (See

TABLE 14

Trends in Real* Wages By Racial Group in South Africa: 1965-1975

Year	Number Employed: Total	White	Black[a]	Coloured	Asian	CPI	Total Real Wages Paid By Group: All Groups	Whites	Blacks	Coloureds	Asians	Real Wages Per Capita: Whites	Blacks	Coloureds	Asians	Percent Increase in Wages per Capita from Previous Year/ Percent Increase Annually Over Previous Five Years: Whites	Blacks	Coloureds	Asians
1975	78303	8046	69919	66	272	157.2	83795	43248	39971	115	460	5375	572	1742	1691	3.2/2.9	52.5/22.2	78.1/21/2	27.9/12.2
1974	75006	7450	67249	46	261	138.5	64448	38817	25247	45	345	5210	375	978	1322	4.3/3.8	40.4/13.3	49.3/18.4	12.1/12.2
1973	74793	7255	67231	55	252	124.1	54560	36278	17949	36	297	5000	267	655	1179	9.9/3.6	18.1/4.9	-5.2/7.7	11.0/716
1972	76593	7606	68684	45	258	113.1	50498	34638	15555	31	274	4554	226	689	1062	-1.3/2.2	14.7/1.8	31.2/9.7	24.8/5.2
1971	81839	7461	74021	61	296	106.4	49291	34429	14578	32	252	4615	197	525	851	-1.0/6.1	-6.6/0.9	-27.0/7.2	-11.9/2.1
1970	74877	7369	67178	60	270	100.3	48593	34215	14082	40	256	4657	210	667	952	7.6/6.5	4.5/4.9	58.8/13.1	17.2/6.2
1969	77111	7675	69042	69	325	95.3	47405	33212	13900	29	251	4327	201	420	812	3.4/ -	-4.5/ -	-7.9/ -	-0.7/ -
1968	78762	7979	70356	64	363	92.6	48512	33376	14809	29	274	4183	210	453	818	2.4/ -	1.4/ -	4.6/ -	-1.0/ -
1967	75138	7722	67006	60	350	91.0	45751	31540	13896	26	263	4084	207	433	826	18.8/ -	9.5/ -	17.0/ -	7.6/ -
1966	84161	8512	75194	73	379	88.1	43829	29282	14229	27	256	3439	189	370	768	1.1/ -	14.5/ -	2.8/ -	8.9/ -
1965	80967	8502	71976	86	403	85.0	43282	28912	14055	31	241	3401	165	360	705	- / -	- / -	- / -	- / -

*Real wages are calculated by dividing nominal wages by the consumer price index.

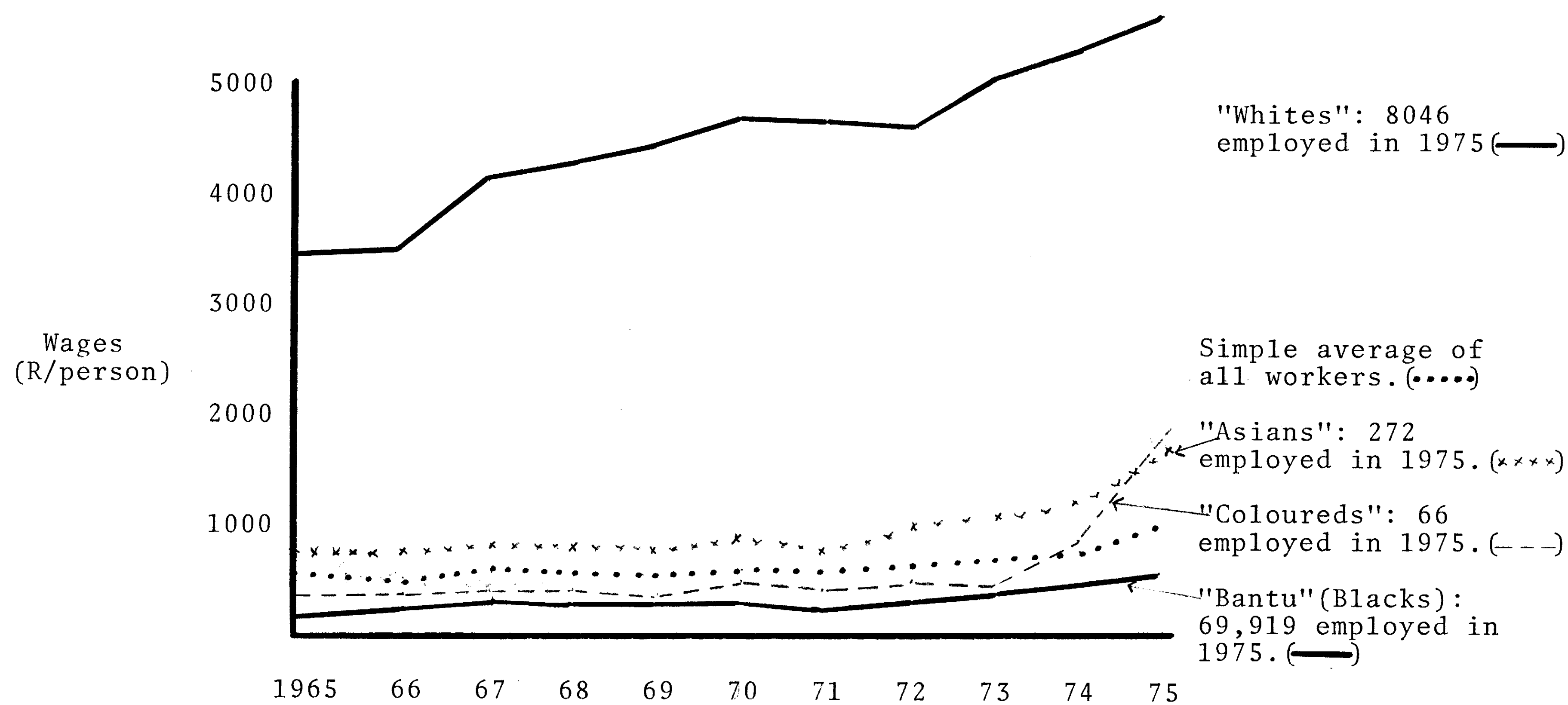
Source: Derived from South African Statistics, 1976

a) The term "Bantu" is used for all blacks in South African government statistical literature.

FIGURE 5

Real Annual Wages* Among Racial

Groups in Coal Mining, 1965-1975



1 Rand = 1.15 US$

* in R1970 (Constant Rands)

Source: Derived from South African Statistics, 1976, p.8.18; 11.7.

below) Since nearly 90% of the mining labor force is Black, the rapid percentage increase in total wages was a real 11.5% per year from 1970 to 1975. Table 15 displays the behavior of nominal wages among groups from 1973-1977.[2]

In 1977, the white South African miner earned $12,305 on average ($1977). His Black counterpart earned $1490 -- about one eighth the white wage. Coloreds -- those people of mixed Black/white ancestry -- earned $8803,[3] while "Asiatics" averaged $4065 per person in 1977.

This difference among mine workers, and especially the large premium paid white workers over other groups, reflects two realities: First, "management" in South Africa is synonymous with "white", and mine managers are better paid than miners the world over.[4] Second, white miners who perform the same tasks as Black (or other) miners, are paid more. This advantage is true for wages and benefits. Table 16 lists categories of labor charges which are applicable to white and Black miners in a typical gold mine.[5] Given the close bonds between gold and coal mining industries, and their competition for both Black and white labor, these categories are probably identical or very similar for coal mines.[6]

A growing political sophistication and job frustration resulted in "widespread mine rioting" in 1974 and 1975.[7]

TABLE 15

TRENDS IN NOMINAL WAGES IN SOUTH AFRICA, 1973-1977

Year and Racial Category	Number Employed	Salaries and Wages (Current Dollars)	Salaries and Wages Per Person	% Increase From Previous Year
1977 Total	95025	$265811	(a)	37.4
Whites	11063	136134	$12305	2.0
Blacks[b]	83080	123798	1490	13.8
"Coloureds"	484	4261	8803	162.2
"Asians"	398	1618	4065	13.9
1976 Total	79935	193343		28.0
Whites	8174	98619	12065	24.5
Blacks	71378	93419	1309	27.0
"Coloureds"	62	209	3357	6.5
"Asians"	321	1145	3568	17.1
1975 Total	78303	151031		47.6
Whites	8046	77949	9688	17.1
Blacks	69919	72044	1030	73.0
"Coloureds"	66	208	3153	103.4
"Asians"	272	829	3049	45.3
1974 Total	75006	102342		31.8
Whites	7450	61631	8273	17.1
Blacks	67249	40091	596	-
"Coloureds"	46	71	1550	-
"Asians"	267	547	2098	-
1973 Total	73329	77625		-
Whites	7308	51635	7066	-
Blacks				-
"Coloureds"	66021	25990	393	-
"Asians"				-

(a) An overall per capita wage is not quoted because it is of little relevance given the wide variation in wages per capita among racial groups.

(b) The South African statistical journals use the term "Bantu" for Blacks.

Source: Department of Mines, Republic of South Africa, Mining Statistics, various years.

TABLE 16

White versus Black Benefits in Gold Mines

White Labor Charges	Black Labor Charges
1-Wages and salaries	1-Wages and Overtime
2-Cost of living allowance	2-First-aid bonuses
3-Holiday leave pay & allowance, sick & accident leave and *ex gratia* payments	3-Pass fees: Mozambique & tropical areas
4-Red Cross fees & bonuses for possessing first-aid certificate	4-Black employees recruiting expenses
5-Transport & other allowances	5-Black employees accident insurance
6-Housing allowance and/or subsidy	6-Other charges: gratuities, welfare, education & recreation
7-Providence Fund: Miners Death Benefit Fund	
8-Providence Fund: contributions	
9-Retiring gratuities	
10-Unemployment Benefit Fund	
11-Accident insurance	
12-Government Miners Training School	
13-Refund of class fees & learners subscriptions	
14-Welfare, education & recreational facilities	
15-Pension Fund - mine officials	
16-Pension Fund - mine employees	
17-Pension Fund - additional benefits	
18-Death Benefit Fund - mine officials	
19-Death Benefit Fund - mine employees	

Source: Storrar, C.D., *South African Mine Valuation*, Chamber of Mines of South Africa, Johannesburg 1977, p. 136-137.

A result has been not only higher wages but large expenditures on housing, sanitization and kitchen facilities at some mine sites. These advances are still thought to be unsatisfactory by the more militant Black miners, who would support the formation of now-illegal Black unions.

The legalization of Black unions is probably not far off. As one South African economist claims, legal restrictions on Black labor unions will be

> ...in a matter of time, so completely obsolete as to call for really fundamental adjustment to economic reality.[8]

The head of Anglo-American Corporation's Gold & Uranium Division, when asked whether his firm would allow "a resemblance of a Black trade union on industrial mines" replied:

> We certainly would...I must say...that we don't consider it our business to bring trade unions into existence. Nowhere in the world does management do that. It must rise spontaneously from the men. But if men come to us with a good constitution, sound, and appear to have the support of a great number of workers, of course we would start talking to them.[9]

The president of the Chamber of Mines of South Africa portrays the economic necessity of change in mining labor practices in remarks to the 1978 Annual General Meeting:

> Many restrictive (labor) practices had their origins in the depressed economic conditions between the two world wars which were accompanied by an oversupply of White labour. In the future, however, the demand for skilled and semi-skilled labour will go well beyond the projected supply... It is clear that cost escalation in the absence of

> progressive relaxation of the restrictions on the more productive employment of labour can only lead to the destruction of the mining industry. Yet it is on mining that the country absolutely depends for the economic thrust on which solutions to the country's problems, political as well as economic, ultimately depend.[10] (Emphasis added.)

An important move toward eventual wage parity among races and legalization of Black trade unions is likely to come from the Recommendations of the Wiehan Commission, which "will be presented to Parliament soon."[11] The Wiehan Commission was appointed by the Minister for Labor and Mines, S.P. Botha, to critique the national policy of the "'reservation system', by which certain jobs can be reserved for whites." The backing of a state ministry provides political legitimization of the Commission's conclusions, and therefore gives official recognition and approval of recent trends toward wage parity and equal job opportunity. This development cannot help but sustain the momentum of the wage increases of recent years. One can only conclude that the enormous difference between Black and white wages and benefits will continue to shrink rapidly. Thus, the wage charge per ton of coal mined will continue to skyrocket.

The transition to this era of equal Black participation and renumeration will be accompanied by growing white labor unrest in the mines. In March, 1979, the white mine workers went on strike to protest the recommendations of the

Wiehan Commission. White miners oppose the elimination of the practice of reserving for white miners only the right to "handle explosives, ventilation, and hoist-shaft operation."[12] It is logical to assume that whites will protest for increased wages and benefits to counter this loss of exclusivity should the Wiehan recommendations be made law as is generally expected. The structural change now occurring in mining labor may therefore be a costly change indeed.

To combat increasing labor costs, producers will continue their attempts to increase productivity by using more capital-intensive mining methods, including strip-mining, continuous mining with pillar extraction, and long-wall techniques. One better realizes the boost in productivity which could theoretically result in light of the following understatement:

> In 1977 only 13 collieries out of 68 (total in South Africa) employed hand-loading techniques, producing about 8,500,000 saleable tons, representing 10% of total sales.[13] [Emphasis added.]

"Only" indeed! Clearly, as Black miners command higher wages hand-loading will become an impossibly expensive method.

A major increase in productivity is expected from the expansion of strip mining methods. In 1977, 15% of tons produced were extracted by strip methods, up from a negligible amount in 1963. Judging by the number of new strip mines opening in the near future (See Section 2 and Table 7), the proportion of strip mined production could exceed one-third by 1990. But the productivity increase will not be of a magnitude one might expect under the geological and political conditions of, say, the United States. The overburden in South Africa is, in general, extremely rocky and difficult to blast. In addition, the availability of stripping equipment and the financing for equipment purchases may be constrained by political events -- including further economic sanctions. Nonetheless, a steady rise in productivity from 1966-1976 is indicated in Table 17.

The average output per employee (miners, management, and others) has been steadily increasing in this period -- from 710 tons per employee per year in 1966, to 1080 in 1976, an increase of 4.3% per year. Crude though this measure is, the improvement is persuasive.

However, the 3.7% annual increase in gross productivity per employee during 1970-1976 was accompanied by a 6.8% annual increase in labor costs per employee. These rough measures suggest that increased productivity due to the adoption of more capital-intensive mining techniques is not keeping pace with labor costs.

In addition, an increase in the use of strip mining methods to compensate for increasing labor costs will accelerate increases in costs due to depletion. As rising

TABLE 17

Trends in Productivity and Labor Cost per Employee: 1966-1976

Year	Total Coal Production (10^3 tons)	Number of Employees	Tons/ Employee	% Increase Annually Previous 5 Years	Total Real Labor Cost (10^3R)	Average Real Labor Cost Per Ton	% Increase Annually Previous 5 Years
1976	86663	79935	1,080	3.7%	R83795	1.07	6.8%
1975	78217	75625	1,030	2.8%	64448	.87	1.9
1974	73969	71041	1,040	4.9%	54560	.77	-1.0
1973	71043	70582	1,010	4.7%	40398	.76	-1.0
1972	66646	72825	920	3.6%	49291	.74	-1.0
1971	66860	73896	900	4.9%	48593	.77	
1970	62809	72555	870		47405	.79	
1969	60329	73436	820		48512	.81	
1968	59995	75311	800		45751	.80	
1967	57326	74911	770		43829	.78	
1966	55901	78596	710				

Source: Derived from Mining Statistics, 1977, published by the South African Department of Mines.

wages encourage the move to strip mining, the focus of mining activity will shift to the shallower seams which are reachable by strip technology. As the pace of extraction from these seams quickens, increases in costs due to depletion will also accelerate. These depletion cost increases thus mitigate the cost-effectiveness of strip mining techniques.

Capital Costs

> It is realistic to expect that South Africa will continue to be exposed in the year ahead to international hostility, reflected in a continued decline in the availability of foreign capital, mounting pressure for economic sanctions and support for terrorist activity.[14]

Fear of foreign capital sanctions pervades South African literature. These fears are especially intense regarding the mineral extraction industries. As we have noted, the coal industry is rapidly increasing the capital-intensity of its operations. Political constraints on capital would, therefore, hit the coal mining sector hard in a critical period of rapid expansion of production. Industry officials claim that "...if the capital is not found, our indigenous energy resources may cease to be a natural asset."[15] Further, South Africa "can only remain relatively independent of external energy resources if (South Africa) continues to remain reasonably independent of external capital supplies."[16] This latter point suggests that South Africa places a national security premium on native supply of financing and equipment -- that South

Africa will tolerate the higher cost of sustaining the coal industry with indigenous capital to the degree made necessary by foreign capital sanctions.

Forecasts of capital cost increases are, unfortunately, not available in South African literature. Therefore, for the purposes of our discussion on future South African coal export costs, I use three scenarios based either on forecasts of U.S. capital cost increase in the coal mining sector, or on "naive" projections of capital costs based on reasonable guesses concerning future capital constraints. These scenarios are presented in Table 18.

The low-cost scenario uses the U.S. real machinery cost increase projections of Data Resources Incorporated through 1990.[17] These annual cost increases hover at around 2%. Scenarios 2 and 3, the medium and high cost scenarios, project annual cost increases of 5% and 10% respectively. It is my opinion that a 5% real yearly increase is not unlikely given trends in international public opinion regarding sales and financing to South African enterprises. It seems likely that negative global attitudes toward apartheid will push cost increases beyond possible rates of U.S. machinery cost increases reflected in Scenario 1. The high cost scenario is pure speculation and is presented to depict the general magnitude of cost increases that might occur with the advent of severe capital sanctions. The

TABLE 18

Projection of Real Capital Costs Per Ton of Coal Mined in South Africa: 1975 - 2000

Scenario 1: Low-Cost Case

Year	Cost Per Ton Low Grade	Cost Per Ton High Grade	% Real Increase
1975	$2.42	$7.47	1.5[a]
1976	2.46	7.58	1.5
1977	2.50	7.70	1.6
1978	2.51	7.74	0.5
1979	2.53	7.79	0.7
1980	2.55	7.84	0.6
1981	2.57	7.91	0.9
1982	2.61	8.03	1.5
1983	2.65	8.17	1.7
1984	2.70	8.33	2.0
1985	2.76	8.50	2.1
1986	2.82	8.68	2.1
1987	2.88	8.86	2.1
1988	2.94	9.05	2.2
1989	3.01	9.26	2.3
1990	3.08	9.48	2.4

(Continued)

a. Estimated by the author. Values for 1976 to 1990 from DRI, Coal Review, Nov., 1978, p. 6. (Using "TRENDLONG" implicit flight deflator assumptions supplied by DRI).

TABLE 18: Continued

Scenario 2: Medium Cost Case
(5% Real Increase Per Year)

Year	Low Grade	High Grade
1975	$2.42	$7.47
1976	2.54	7.84
1977	2.66	8.24
1978	2.80	8.65
1979	2.94	9.08
1980	3.08	9.53
1981	3.24	10.01
1982	3.40	10.51
1983	3.57	11.04
1984	3.75	11.59
1985	3.93	12.17
1986	4.13	12.78
1987	4.34	13.42
1988	4.55	14.09
1989	4.78	14.79
1990	5.02	15.53

(Continued)

TABLE 18 : Continued

Scenario 3: High Cost Case
(10% Real Increase Per Year)

Year	Low Grade	High Grade
1975	$2.42	$7.47
1976	2.66	8.22
1977	2.92	9.04
1978	3.21	9.94
1979	3.54	10.94
1980	3.89	12.03
1981	4.28	13.23
1982	4.71	14.56
1983	5.18	16.01
1984	5.69	17.61
1985	6.26	19.38
1986	6.89	21.31
1987	7.58	23.44
1988	8.34	25.79
1989	9.17	28.37
1990	10.09	31.20

implications for coal exports of the numbers present in Table 18 will be made clear in Section 7.

FOOTNOTES

Section 5

1. Petrick Commission Report, op. cit., paragraph 5.1.6.19.
2. Department of Mines, Republic of South Africa, Mining Statistics, various years.
3. Note that "coloured" wages more than doubled in 1977 over 1976.
4. This exclusivity is changing. See below.
5. Sturrar, C.D., South African Mine Valuation, Chamber of Mines of South Africa , Johannesburg, 1977, p. 136-137.
6. Section 2 above points out the interrelatedness of gold and coal mining.
7. Journal of South African Mining, "Report Gives New Insight on the Black Miner": An Analysis of the "Moodie Report".
8. Botha, J.J., "An Economic Boycott of South Africa," South African Journal of Economics, Vol. 46, No. 3, 9/78, p. 27.
9. Journal of South African Mining, Ibid.
10. Chamber of Mines of South Africa, Presidential Address by L.W.P. van den Bosch, 88th Annual General Meeting (of the Chamber), 6/27/78, pp. 8-9.
11. Business Week, "Pretoria's Turn Toward More Liberal Racial Policies, 4/23/79, p. 65.
12. Ibid.
13. Granville and Venter, op. cit., p. 53.
14. Van den Bosch, op. cit., p. 12. (See footnote 10 above)
15. Smith, Jan H., op. cit., p. 348.
16. Ibid.
17. Data Resources, Inc., Coal Review, Nov., 1978, p. 6.

Section 6: Transportation

We are interested in estimating trends in the costs of rail transport to Richards Bay, and of ocean transport to foreign ports. We use Western Europe as the destination for illustrative purposes. With these estimations of transport (and transport-related) costs, we will have compiled the cost estimates necessary to examine export price scenarios in the next section.

Rail

Rail cost estimates range between 1.5¢ and 2.5¢ per ton-mile.[1] A rough average of the trip length is 150 miles; this leads to an estimate of $2.25 to $3.75 per ton each trip to Richards Bay (about the same to Durban Bay).

Opinions regarding the trend of these costs vary. The IEA suggests that, due to favorable terrain and current satisfactory capacity, "rail transport costs from major producing regions to export harbours are to remain constant in real terms through the year 2000..."[2] This projection takes into consideration "Phase Three" of the national export "plan", which calls for exports increasing from 20 million tons per annum in 1980 to over 40 million in 1985. (See Section 7 on Exports.)

Not all observers agree with this assessment. R.L.

Cohen, of Anglo-American Corporation, believes the third phase "involves substantially higher costs for both mines and infrastructure."[3] Another observer adds that "(the) capacity of the rail line between the Transvaal Coal fields and Richards Bay is one of the crucial factors governing the amount of coal which can be exported."[4] He quotes a Richards Bay official as saying that "the line could probably handle at least 20 million tons per year."[5] However, since Cohen is not specific, and because the ICT information is more than two years old, I use the IEA assessment of "no real increases through the year 2000" as my assumption in the rough projections used in the next section.

Ports

The opening of Richards Bay harbor in 1976 was motivated by the signing of a low-ash metallurgical coal export contract with Japan by the TCOA.[6] The harbor, which is about 100 miles north of Durban Bay, the old export port on the Natal coast of the Indian Ocean, is running close to capacity at 12 million tons per year. By 1980 the capacity will reach 20 million tons.

It is unclear whether the third stage of export expansion will be accomplished by expanding Richards Bay once more, or by opening "other possible port sites on the Indian

Ocean..."[7] The ease with which Richards Bay is being brought to its capacity of 20 million tons per year suggests that, ceteris parabus, these new port developments will present few obstructions to reaching a capacity 40 million tons per year. As we have seen, however, coal exports are essentially "a matter of policy";[8] this policy will not, however, be constrained by any difficulties regarding port expansion.

In order to adequately consider future export prices, we need to estimate the costs per ton associated with an increase in the port capacity to, say, 40 million metric tons by the mid-80's. The costs of building the first stage of export capacity at Richards Bay was $42.6 million ($1975) for 12.6 million tons capacity[9] -- equal to $3.55 per annual ton. Using this figure, and assuming (a) 20 million tons of capacity is added in 1985, (b) all funds were raised by 5 or 10 years debt at either 10% or 15% per year, and (c) yearly payments are equal in nominal dollars, then the following matrix of cost per ton for the port capacity additions for 1985 in 1975 dollars is derived:

Port Capacity Cost Per Ton ($1975)

	10%	15%
5 years	0.97	1.40
10 years	0.58	0.87

To arrive at real annual costs for the period 1985-1990, these annual charges must be discounted at the appropriated interest rate. This is done in computing the desired price for exports in the next section.

Shipping

Ocean freight charges present more formidable predictive challenges. I assume for the limited purpose of this report, that real per ton freight rates remain constant at $12.00 through 1990. More importantly, I assume that the spread between coal freight costs to Western Europe from South Africa and the United States remains constant. This latter assumption is both more crucial and reasonable than the constant real cost assumption. Unless shipping sanctions are imposed on South Africa, they should pay a rate per ton-mile which approximates the charge to U.S. exporters.

FOOTNOTES

Section 6

1. Conversation with Alex Sargent, MIT Energy Lab, 2/2/79.
2. IEA, Steam Coal: Prospects to 2000..., op. cit., p. 132.
3. Cohen, R.L., Coal Division, Anglo American Corporation of South Africa, Limited, Letter to Prof. C.L. Wilson, MIT, 5/8/78, p. 2.
4. International Coal Trade, U.S. Bureau of Mines, vol. 45, no. 11, 11/76, p. 23.
5. Ibid.
6. Horsfall, D.W., "Coking Coal: South Africa's Needs and Resources Reviewed," in South Africa Mining and Engineering Journal, 1/78, p.51.
7. IEA, Steam Coal: Prospects to 2000, op. cit. p. 134.
8. Ibid.
9. International Coal Trade, U. S. Bureau of Mines, (Report on South African exports and Richards Bay) vol. 45, no. 11, 11/76.

Section VII: The Potential for South African Coal Exports

Government control over the price of domestically-consumed coal makes South African mining companies eager to sell coal for export. During 1977, the average price of bituminous coal exports was $23.83 per metric ton, up from $9.10 in 1970. The same type of coal sold for consumption within South Africa at $8.71 per ton in 1977, up from $1.98 in 1970.[1] But opposition to expansion of exports beyond the 20 million ton level increases as the government's perception of political and economic isolation becomes more critical and realistic. Nonetheless, expansion to 45, or perhaps 50 million metric tons of exports by the mid-1980's is likely. Commitment beyond this amount has not been made by either government or mining industry officials. The General Manager of Coal Operations for the General Mining and Finance Corporation -- the largest producer of coal in South Africa -- states that

> "...(South Africa) expects to maintain this (45-50 million ton per year) rate of exportation until the first decade of the twenty-first century.[2]

A representative of the second largest producer of coal, the Anglo-American Corporation of South Africa, Ltd., concurs:

> .....it would appear that a figure of 40-50 MTPA from RSA is reasonable (to the year 2000). To increase above this figure could give concern in some governmental areas regarding the future availability of coal for RSA needs.[3]

Regarding metallurgical coal exports, the International Energy Agency suggests:

> It is clear that no more exports of blend coking coal will be allowed apart from the current contract with Japan.[4]

Judging from these sentiments, the national mood is not consistent with the ambitious suggestion by the IEA, mentioned in the Introduction, that South Africa may "play the dominant role in the emerging steam coal market through the early 1990's."[5]

The caution which characterizes South Africa's projections of future coal exports reflects, as we have seen, not only external political realities, but also the likelihood of rapidly-rising real costs of production. I have constructed three sets of projections of possible real production costs for high grade export coal based on the conclusions of sections 4 through 6. The low cost case assumes operating cost increases in real terms of 10% per year, and capital cost increases of about 2% annually.[6] The medium, or "most-likely", case assumes 10% and 5%, respectively. (Also see Table 20). The high cost case presumes annual increases in operating and capital costs of 15% and 10%. Depletion costs in all three cases are based on production levels forecast by Granville and Venter,[7] and on the discussion in section 4 above. It is further assumed that South Africa can sell all the coal it produces at the prices projected. Finally, the use of washed (high-grade) coal is assumed to decline from its present share of 48% of production, to 40% in 1980, and 30% in 1985. This reflects the trends in new mine openings shown in Table 7.

The results appear in Tables 19-A through 19-C. Under the low-cost scenario, high grade coal reaches $27.98 in 1990.[8] In the "most likely" cost case, which reflects more closely an extrapolation of recent cost trends, high grade coal reaches $47.53 per metric ton. (See Table 19b) The high cost scenario, which is motivated by the possibility of more severe contraints on imported capital than now exist, suggests that coal will increase in real cost to $62.20 in 1990 from $13.77 in 1975. For illustrative purposes, the "most likely" case is focused on for the remainder of this discussion.

Under the "most-likely" cost scenario, it appears that U.S. coal exports may be much more competitive with South African coal sales to Western Europe than is presently the case. In 1978, the U.S. coal export price (f.o.b. Baltimore) averaged about $38.00 per metric ton.[9] South African coal sold for close to $22.00.[10] If we restate the cost components of South African high grade coal in 1978 (see Table 8-2) to 1978 dollars, and then escalate these

TABLE 19A

Low Cost Scenario for High Grade Coal: 1975-1990

($1975 per metric ton)

Assumption of Annual Real Cost Increases:

Operating: 10% per year
Capital: 2% per year
Depletion: See Text, Section 4
Transport: Constant to 1983, then add charge for port expansion. (See p.).

Year	Operating Cost	Capital Cost	Depletion Cost	Transport Cost	Minimum Desired Price(f.o.b.) Port, RSA)
1975	$3.30	$7.47	-	$3.00	$13.77
1976	3.63	7.62	.05	3.00	14.30
1977	3.99	7.77	.10	3.00	14.56
1978	4.39	7.93	.17	3.00	15.49
1979	4.83	8.09	.23	3.00	16.15
1980	5.31	8.25	.30	3.00	16.86
1981	5.85	8.41	.38	3.00	17.64
1982	6.43	8.58	.45	3.00	18.46
1983	7.07	8.75	.53	3.97	20.32
1984	7.78	8.93	.61	3.88	21.20
1985	8.56	9.11	.69	3.80	22.16
1986	9.42	9.29	.78	3.73	23.22
1987	10.36	9.47	.87	3.66	24.36
1988	11.39	9.66	.96	3.00	25.01
1989	12.53	9.86	1.05	3.00	26.44
1990	13.78	10.05	1.15	3.00	27.98

TABLE 19B

"Most Likely" Cost Scenario for High Grade Coal: 1975-1990

($1975 per metric ton)

Assumption of Annual Real Cost Increases:

Operating: 15% per year
Capital: 5% per year
Depletion: See text, section 4
Transport: Constant to 1983, then add a charge for port expansion (see p.)

Year	Operating Cost	Capital Cost	Depletion Cost	Transport Cost	Minimum Desired Price(f.o.b.) Port, RSA)
1975	$3.30	$7.47	-	$3.00	$13.77
1976	3.80	7.84	$.05	3.00	14.69
1977	4.36	8.24	.10	3.00	15.70
1978	5.02	8.65	.17	3.00	16.84
1979	5.77	9.08	.23	3.00	18.08
1980	6.64	9.53	.30	3.00	19.47
1981	7.63	10.01	.38	3.00	21.02
1982	8.78	10.51	.45	3.00	22.74
1983	10.09	11.04	.53	3.97	25.63
1984	11.61	11.59	.61	3.88	27.69
1985	13.35	12.17	.69	3.80	30.01
1986	15.35	12.78	.78	3.73	32.64
1987	17.66	13.42	.87	3.66	35.61
1988	20.20	14.09	.96	4.00	39.35
1989	23.35	14.79	1.05	4.00	43.19
1990	26.85	15.53	1.15	4.00	47.53

TABLE 19C

High Cost Scenario for High Grade Coal: 1975-1990

($1975 per metric ton)

Assumption of Annual Real Cost Increases:

Operating: 15% per year
Capital: 10% per year
Depletion: See text, section 4
Transport: Constant to 1983, then add a charge for port expansion (See p. 105)

Year	Operating Cost	Capital Cost	Depletion Cost	Transport Cost	Minimum Desired Price(f.o.b. Port, RSA)
1975	$3.30	$7.47	-	$3.00	$13.77
1976	3.80	8.22	$.05	3.00	15.07
1977	4.36	9.04	.10	3.00	16.50
1978	5.02	9.94	.17	3.00	18.13
1979	5.77	10.94	.23	3.00	19.94
1980	6.64	12.03	.30	3.00	21.97
1981	7.63	13.23	.38	3.00	24.24
1982	8.78	14.56	.45	3.00	26.79
1983	10.09	16.01	.53	3.97	30.60
1984	11.61	17.61	.61	3.88	33.71
1985	13.35	19.38	.69	3.80	37.22
1986	15.35	21.31	.78	3.73	41.17
1987	17.66	23.44	.87	3.66	45.63
1988	20.30	25.79	.96	3.00	50.05
1989	23.35	28.37	1.05	3.00	55.77
1990	26.85	31.20	1.15	3.00	62.20

components at 15% per year for operating costs, and 5% for capital costs, we reach a desired price per ton in 1990 of \$63.32 in 1978 dollars.[11] Assuming that the current shipping costs per ton from the U.S. and South African to Western Europe stay constant in real terms at their present levels of \$8 and \$12 respectively, then the U.S. f.o.b. price could rise to \$67.32 (\$1978) and command the same delivered price as will South African coals in Western Europe in 1990 under the "most likely" scenario -- that is, \$75.32 (\$63.32 + \$12). This implies that U.S. coal could increase in price from its current \$38.00 at a real 4.9% per year to reach \$67 in 1990 with South African coal in Western Europe.

The 4.9% estimate of the annual real increase in costs of U.S. coal through 1990 is high relative to cost increases projected elsewhere. Data Resource forecasts a <u>nominal</u> increase of 10.4% per year through 1990 under their "control" forecast.[12] This "control" forecast assumes yearly nominal cost increases of 9.1% for transporation, 4.8% for scrubbing, 7.1% for mining machinery, 7.8% for wages, about 1% annual <u>decline</u> in productivity, and a 10% rate of return to arrive at its yearly overall increase in costs of 10.4%. Adjusting for DRI's inflation estimates, the real annual cost increase reaches its lowest level in 1980 at 3.9%, then gradually increases to 5.7% by 1990. Applying the DRI real cost increases to the current U.S. export price, f.o.b.,

TABLE 20

DRI Real Cost Increase Forecast

"Control" Scenario

	Nominal Cost Increase	Implicit Price Deflation	Real Cost Increase
1977	10.4%	5.5%	4.9%
1978	"	6.6	3.8
1979	"	6.4	4.0
1980	"	6.5	3.9
1981	"	6.2	4.2
1982	"	5.6	4.8
1983	"	5.4	5.0
1984	"	5.1	5.3
1985	"	5.0	5.4
1986	"	5.0	5.4
1987	"	5.0	5.4
1988	"	4.9	5.5
1989	"	4.8	5.6
1990	"	4.7	5.7

Baltimore, of $38.00, a 1990 f.o.b., Baltimore price of $68.36 is calculated. This is about $1.00 above the price of $67.32 at which U.S. coal would compete on an equal cost basis with South African coal under the "most likely" case presented above. Based on this evidence, it is concluded that the great price advantage which South African export coal currently enjoys in deliveries to Western Europe would be nearly eliminated under the reasonable cost increase assumptions presented in this section.

FOOTNOTES

Chapter 7

1. Department of Mines of South Africa, Mining Statistics, 1970 and 1977, Table 12.

2. Ellis, S.P., General Manager, Coal Division, General Mining and Finance Corporation Limited, Letter to the author, 9/26/78.

3. Cohen, R.L., Anglo American Corporation of South Africa Limited, Letter to Professor C.L. Wilson, 5/8/78, p. 2.

4. IEA Coal Research, Published Plans and Projections for Coal Production, Trade and Consumption, by Hugh M. Lee, 12/1977, p. 57.

5. IEA, Steam Coal Prospects..., op. cit., p. 134.

6. Data Resources Incorporated forecasts annual nominal increases of 7.1% in mining machinery costs through the year 1990. Applying the implicit price deflator in Table 20 , which is also DRI's forecast, real machinery cost increases can be computed. They range between 0.5% and 2.4%, with the more rapid real increase occuring at the end of the period. I chose the 2% real increase for South Africa to approximate the increases expected by DRI in the U.S. Given fears of capital sanctions and the generally riskier environment in South Africa, it seems that this 2% estimate reflects a reasonable lower bound. See Data Resources, Inc., Coal Review, Nov. 1978, p. 6.

7. Granville and Venter, op. cit., p. 53.

8. High grade coal is the coal exported from South Africa. Little low grade coal leaves the country.

9. See, for example, Coal Week, Vol. 6, No. 15, 4/9/79, p. 6.

10. Ibid.

11. The general consumer price index for 1975 (1970 = 100) was 156.7, for 1976 = 174.1, 1977 = 193.8, 1978 = 213.2 (1978 derived by assuming a 10% inflation rate in 1978).

12. DRI, (See footnote (6)), Ibid.

Section VIII: Conclusion

The aim of this paper has been to describe and analyze the South African coal industry in an economic, geological and political framework. A broader purpose was to explore some of the obstacles an expanded world coal export industry will face in the remainder of this century. It is clear that political isolation and rapid changes in the structure of the South African work force will greatly diminish the present export advantage enjoyed by South Africa during the next decade.

The implications regarding competitive positions for other coal exporters, including the United States, are clear. Elimination of South Africa as lowest cost major coal exporter will improve the relative competitiveness of other producers. However, the extent of the absolute increase in export coal production is uncertain. It is therefore impossible to estimate at this time the impact of the conclusions presented in this study on the future volume of world coal trade. This study has demonstrated, however, that the future export levels of a major producer will be profoundly affected by national politics. It is suggested that observers of the coal industry proceed cautiously, therefore, in their attempts to estimate global growth in coal trade.

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9. Horsfall, D.W., "Coking Coal: South Africa's Needs and Resources Reviewed," South African Mining and Engineering Journal, Jan. 1978.

10. International Coal Trade, U.S. Bureau of Mines, (Report on South African Exports and Richards Bay), Vol. 45, no. 11, Nov. 1976.

11. ________________ "South Africa: Forecasts of Long and Short Term Growth of Coal Exports, Vol. 47, no. 5, May 1978.

12. ________________ "South Africa: Two New Coking Projects in South Africa: Vol. 47, no. 1, Jan. 1978.

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