Prospects for Coal Transport and Export in Botswana

by

Khaulani Fichani and **Walter C. Labys**

RESEARCH PAPER 2003-7

Khaulani Fichani
Natural Resource Economics Program
West Virginia University, PO Box 6108
Morgantown, WV 26506
E-mail: Kfichani@wvu.edu

Walter C. Labys
Professor of Resource Economics and Faculty Research Associate
Regional Research Institute
West Virginia University, PO Box 6108
Morgantown, WV 26506-6108
E-Mail: wlabys@wvu.edu

JEL Classification: C51, C61, F17, and Q41

Key Words: Long Run Marginal Cost Function, Econometric Models, Programming Models, International Coal Trade Model, Transport Networks, Botswana's Energy Policy

Abstract: Botswana has vast proven deposits of steam coal, which for a long time the government has wanted to develop but without much success. The main objectives of this study are: 1) to forecast possible coal exports from Botswana and the land routes for these exports, 2) to determine the competitiveness of Botswana's coal in world steam coal trade, and 3) to make recommendations on the appropriate policy for the exploitation of this coal. To accomplish these objectives, we construct a model of the global steam coal trade and apply this model to forecast the likely optimal size of mine, timing of capacity and choice of export port for the years 2005 and 2010 from a 2000 base forecast year. The results of our regional analysis suggest that Botswana's coal exports are competitive in Asia and Western Europe. These results are shown to be least sensitive to changes in rail transportation costs and marginal supply costs but more sensitive to changes in capital costs for mine development.

PROSPECTS FOR COAL TRANSPORT AND EXPORT IN BOTSWANA

1.0 Introduction

The objective of this paper is to analyze Botswana's potential as a world steam coal exporter. This requires constructing a model to appraise the policy options dealing with energy and infrastructure development that could encourage the development of Botswana's vast steam coal deposits. To the best of our knowledge, this is the first spatial and dynamic optimization model of the world steam coal trade that depends on econometrically estimated long run marginal cost functions. Previous models of the world steam coal trade have relied on short run marginal cost functions that result from the linearization of an engineering cost-based cumulative cost function. The included objective function minimizes the total discounted costs of annualized mine capital costs, variable costs of supply, and rail and maritime transportation costs, all subject to a given set of constraints. The geographic scope includes the two world markets of Western Europe and Asia. The net importing countries in Western Europe are Belgium, Germany, France, Italy, the Netherlands, Spain and the United Kingdom, and those for Asia are Japan and South Korea. The net exporting countries are Australia, South Africa, the United States, and Botswana. Model solutions for each of the net exporters includes optimal values for supply prices, quantity supplied, capacity additions, and trade flows over space and time.

This paper proceeds as follows: Section 2 provides a description of the model framework and describes the mathematical model used for the spatial and dynamic optimization. Section 3 presents the forecasting and sensitivity results dealing with policy applications. Finally, section 4 features conclusions.

2.0 The Proposed Model

Coal transport models have played an important role in analyzing a variety of coal issues and policies (Suwala and Labys, 2002; Yang, Hwang and Sohng, 2002; Gabriel, Kydes and Whitman, 1999; van den Bergh, Nijkamp and Rietveld, 1995; Labys, Takayama and Uri, 1991; Labys and Yang, 1991; Zimmerman, 1981; Labys and Yang 1980, and Macal, 1979). In recent years, there has been a reliance on spatial price equilibrium models that have built into them a project selection component using an approach developed by Kendrick and Stoutjesdijk (1978). Models of these types have been used by Suwala and Labys (2002 and 1998), and Lai and Chen (1996). These models range from linear to non-linear, mixed integer, and variational inequality (Nagurney, 1999 and 1987) models. At the international level, models such as those by Senf and Fruin (1986), Kolstad, Bivins and Abbey (1982), Dutton (1982) and the US Department of Energy (1982) represent an attempt to explain the world steam coal trade. Kolstad, Abbey and Bivins (1982), for example, not only forecast the international steam coal trade but also test U.S. government policy on a variety of issues such as eliminating import tariffs and quotas, and applying domestic subsidies to investments to deepen export ports to handle larger vessels.

There is a need for the Botswana government to employ a similar modeling approach to gain useful policy insights concerning obstacles that discourage the exploitation of the country's coal deposits. Such a model would also assist in policy decisions with respect to the provision of railway infrastructure along the routes identified by the model to be economical. The objectives of the proposed model are as follows:

1. to forecast the optimal size of export mine located on the Mmamabula coalfield in Botswana and the land routes for these exports for the years 2005 and 2010 from a base year of 2000 in the event there are railway lines to seaports at Walvis Bay in Namibia, Richards Bay in South Africa and Matola in Mozambique;
2. to forecast the competitiveness of these exports in the steam coal markets of Western Europe and Asia, and

3. to conduct sensitivity analysis of the optimal forecast values to determine their responsiveness to changes in capital costs for mine development, rail transportation costs, and changes in demand in the net importing countries of the model.

In order to build this model the following are required: a model optimization framework, capital expenditure cost equations for mine development, forecast quantities of domestic demands in the net exporting countries and import demands in the net importing countries, regressions for long run marginal cost functions in the net exporting countries, rail transportation costs and maritime transportation costs. The forecast maritime transportation costs along each major trading route are obtained by time series methods while those for rail costs are projections. The regressions for capital expenditure are exogenous to this model. These are obtained from the U.S. Bureau of Mines *Cost Estimating System* (1995). The specification and econometric estimation of country supply, demand, and long run marginal cost functions for net exporters together with their validation are presented in Fichani (2003). It is usual in models of this type to employ linear marginal cost functions derived from engineering cost data, which we have not been able to obtain. Instead we rely on econometrically estimated long run marginal cost functions for net exporters based on publicly available information about the coal industries of these net exporting countries.

2.1 Assumptions About the World Steam Coal Trade

The following main assumptions about the market behavior of the world steam coal trade are made:

1. All net exporting countries in the model start from a base year supply capacity of 2000 and can only increase supply by carrying out capital expenditure programs for capacity additions. The capacity added in this way is only available at five-year intervals, beginning with the first expansion period of 2005 to 2010.

2. We assume a perfectly competitive market in which the net exporters in the model respond to increases in exogenous steam coal demand by supplying steam coal after the necessary capital expenditure on capacity has been made. This is done through a cost minimization decision criterion in which the sum of the discounted capital costs, variable supply costs, rail transportation costs and maritime transportation costs are minimized over a give time horizon.
3. Each of the net exporters in the model has a minimum acceptable selling price (MASP) that is represented by its long run marginal cost function. The MASP is transmitted through to market prices in the markets of Western Europe and Asia after unit rail and maritime transportation costs have been added, and
4. Finally, we assume an increasing cost industry to reflect the positive slope of the steam coal industry aggregate supply curve and also to accommodate the non-negativity requirement on the slope coefficient for the long run marginal cost functions for each individual producer.

2.2 The Choice of Countries for the Model

The model divides the global steam coal trade into four geographic areas; North America, Southern Africa, Western Europe and Asia-Pacific, which includes Australia (see Figure 1 below). The Western European region is further divided at the country level to focus on the countries that have featured consistently among the major steam coal importers in the region. These are Belgium, Germany, France, Italy, Netherlands, Spain, and the United Kingdom. In the North American region, only the United States is included as it is generally taken to be the marginal producer of steam coal for exports due to its high mine-mouth production costs (e.g. see Abbey and Kolstad, 1983, and U.S. Bureau of Mines, 1993). As shown in Table 1, the countries selected represent a substantial portion of the export and import share of the seaborne steam coal trade (Dutton, 1982, the U.S.D.O.E. *International Coal Trade Model*, 1982 and Senf and Fruin, 1986).

Figure 1. The Seaborne Steam Coal Trade Among Countries of Supply and Demand

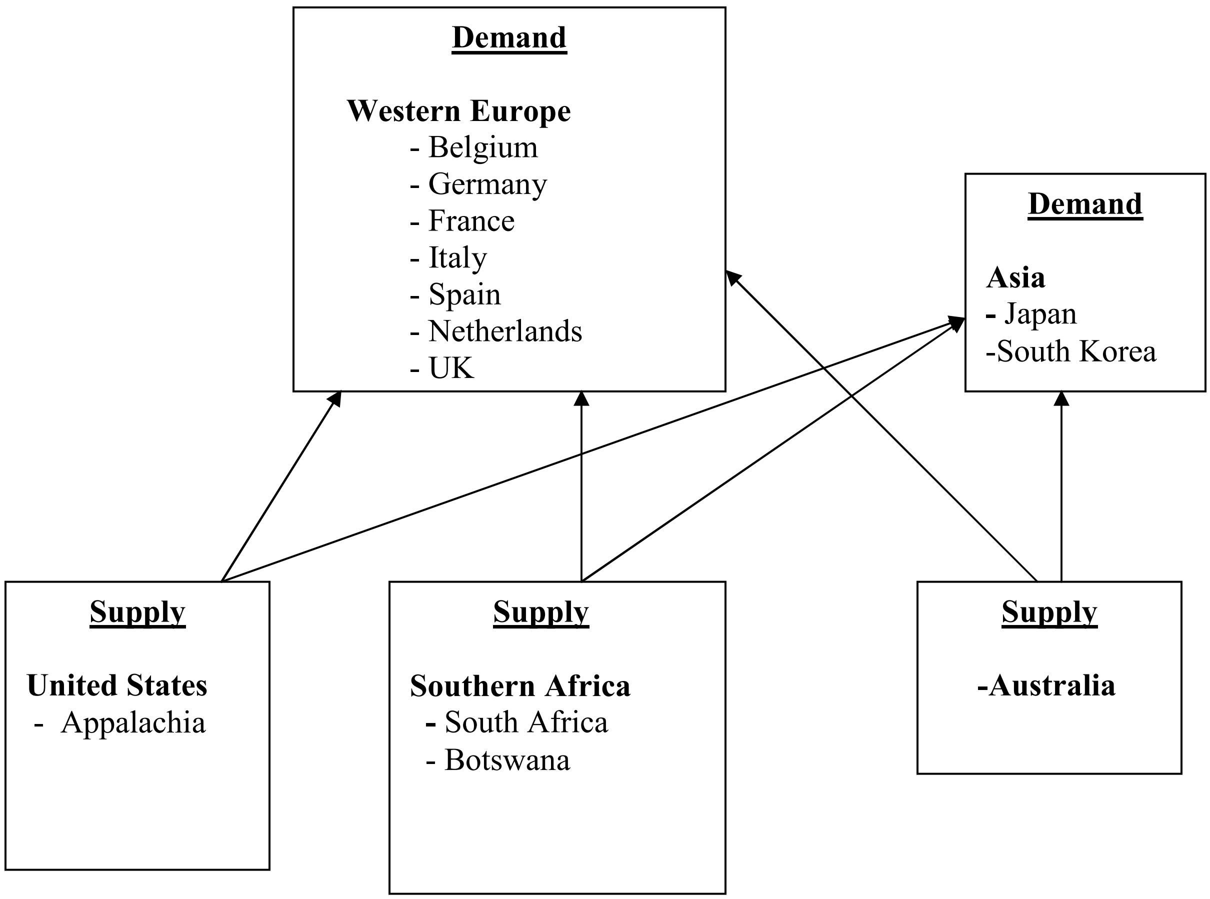

Table 1: Steam Coal Supply and Demand Patterns for Countries of the Model (000's metric tons)

Country	1980	1985	1990	1995	1996	1997	1998	1999	2000
Japan									
Demand	17496	35935	45044	63829	67073	69469	69998	74315	83391
Supply	11084	12460	8152	6261	6480	4275	3665	3906	3148
Imports	6412	23475	36892	57568	60593	65194	66333	70409	80243
South Korea	**4927**	**11300**	**11500**	**26734**	**27600**	**34652**	**35607**	**37342**	**42777**
Belgium									
Demand	8994	7490	8996	7657	7541	7608	7480	6081	7004
Supply	3982	4182	2357	637	560	427	312	364	375
Imports	5012	3308	6639	7020	6981	7181	7168	5717	6629
Germany									
Demand	46092	45641	44749	40231	44845	42660	42558	39839	37890
Supply	38456	37448	31976	27172	24385	24184	21708	20027	18515
Imports	7636	8193	12773	13059	20460	18476	20850	19812	19375
France									
Demand	33510	25175	19122	14872	16371	13440	17561	15167	15940
Supply	16076	13667	9378	8056	7755	6286	5375	5130	4442
Imports	17434	11508	9744	6816	8616	7154	12186	10037	11498
Italy - **Imports**	5820	11965	11797	11433	9971	8439	9436	10430	11817
Netherlands - **Imports**	3757	6879	12837	12234	11946	14749	16856	14532	17431
Spain									
Demand	11124	20290	21861	24331	19997	24525	23477	28092	28589
Supply	11505	15184	14603	13652	13674	13804	12300	11772	11317
Imports	-381	5106	7258	10679	6323	10721	11177	16320	17272
United Kingdom									
Demand	111982	94667	98236	70856	62040	53882	53624	47544	50846
Supply	120047	91438	92797	53956	49379	47419	40589	36809	31704
Imports	-8065	3229	5439	16900	12661	6463	13035	10735	19142
Total Imports	**42552**	**84963**	**114879**	**162443**	**165151**	**173029**	**192648**	**195334**	**226184**
Australia									
Demand	27373	34504	43367	45865	50616	51486	53616	55267	58808
Supply	29646	61571	93564	111352	110943	116794	131827	125904	133970
Exports	2273	27067	50197	65487	60327	65308	78211	70637	75162
South Africa									
Demand	79803	119870	119225	142985	145442	149781	147288	154017	150692
Supply	104515	162358	165492	202351	202829	216426	220806	221928	223394
Exports	24712	42488	46267	59366	57387	66645	73518	67911	72702
United States									
Demand	546581	645325	697253	743161	783995	837782	857406	858534	861484
Supply	592462	649381	760388	781448	808401	836721	868545	862342	842859
Exports [(a)]	24898	27562	35895	26541	27576	21682	22558	20443	13502
Botswana									
Demand	324	382	693	898	739	717	856	872	886
Supply	324	382	693	898	739	717	856	872	886
Exports	0	0	0	0	0	0	0	0	0
Total Exports	**51883**	**97117**	**132359**	**151394**	**145290**	**153635**	**174287**	**158991**	**161366**
Tot. Seaborne Trade	**95800**	**163600**	**199300**	**253000**	**274900**	**287400**	**296900**	**309800**	**347600**

Source: Compiled mainly from Coal Information 2001, International Energy Agency, Paris, p I.52
Notes: [(a)] US exports are reported exports less reported imports.

For a study such as this, it would have been useful to include the emerging exporters such as Colombia, Indonesia and China, but it was beyond our capacity to obtain meaningful data for these countries. The export growth potential of these countries is widely reported in mining industry journals. These reports project that even though China is becoming the marginal supplier to the world steam coal trade, it does not pose a threat to Australia's ranking as the leading steam coal exporter to markets in Asia. The reason cited for this is the concern about quality and security of supply, issues that favor Australia over China. In the Asian market, Australia's steam coal exports are projected to grow further in response to growing demand in the region. China would also need to invest in infrastructure for the domestic distribution of coal to meet rising domestic demand as well as exports. The political uncertainty in Indonesia, coupled with increasing domestic demand, creates an uncertain scenario for the growth of Indonesia's exports. In the region, the continued growth in electricity demand is credited for the growth in steam coal production and exports. In South America, Colombia's exports are projected to double from their current levels of about 37 million metric tons to 70.0 million metric tons by 2010. Colombia competes against South Africa for market share in the U.S. Gulf states as well as in Western Europe. The latter is also projected to increase its exports to 80 million metric tons by 2010.

Later in Table 8, we provide the relative competitiveness of f.o.b. prices for steam coal for the year 2000. In U.S. Dollars per mtce, this ranking is as follows: 1) Indonesia ($24.22), South Africa ($26.84), Colombia ($28.10), Botswana ($28.89), Australia ($31.10) and the United States ($38.08). In the Western European steam coal markets, coal from South Africa enjoys a cost advantage over Colombian coal (*South African Coal Report*, 2002). This model rationally excludes some exporters and importers and these are dealt with as the rest of the world. The question to ask, then, is whether or not Botswana coal can compete favorably against coals from Australia, South Africa and the United States in Western Europe and Asia?

We select model mines and their locations in each of the geographic regions. For the Southern Africa region, coal exports from South Africa derive from Witbank and are exported through Richards Bay, while those from Botswana are from Mmamabula and are exported through Richards Bay (and other possible routes to seaports at Matola in Mozambique and Walvis Bay in Namibia). For the United States, the model mine is assumed to be in Central Appalachia and coal is exported through the Hampton Roads port in Virginia. This assumption is valid and does not place exports from the United States at a disadvantage, as there has been consistently a premium in the range \$0.50 - \$2.50 per long ton of coal exported from U.S. Gulf ports destined for markets in Western Europe (*International Coal Review Monthly*). For Australia, we make the assumption that end-user prices and f.o.b. prices for steam coal are the same. In line with the maritime transportation costs data referencing, the export port is assumed to be mid-way between Gladstone and New Castle (IEA/OECD, 1984 and *International Coal Review Monthly*).

2.3 The Mathematical Model

The model is formulated as a dynamic variation of the spatial temporal and price allocation (STPA) model of Takayama and Judge (1971). The objective function minimizes the sum of the present values of annualized capital expenditure costs for mine capacity additions, variable supply costs, rail transportation and maritime transportation costs over a given time horizon. (see Table 2 for Variable Definitions). These discounted costs are minimized subject to resource availability constraints, port capacity constraints for the Southern Africa region, conservation of flow constraints for the transshipment ports in two of the three net exporting regions of the model (Southern Africa and the United States), and market demand constraints. The objective function is as given in equation 2.1 below.

$$\textit{Min Total Discounted Present Value Costs (PVC)} = \sum_{t=1}^{T} \delta_t (\phi_{kt} + \phi_{ft} + \phi_{st}) \quad (2.1)$$

where

$$\phi_{kt} = \sum_{\tau=1}^{t} \sum_{i=1}^{N} \sigma(Capex_{it}(H_{it})) \quad (2.2)$$

Equation 2.2 expresses the amortized capital costs in period *t* as the sum of the product of the capital recovery factor and the capital expenditure for capacity additions. The equation for capital expenditure costs, $Capex_{it,}$ (H_{it}) is taken from the U.S. Bureau of Mines *Cost Estimating System* (1995) and consists of three components 2.3-2.5, where Y_{it} is the capacity expansion in metric tons per day for a mechanized room and pillar mine with a production rate in the range 20000 – 25000 metric tons per day and operating on two production shifts using continuous miners. The variable H_{it} is converted to Y_{it}, which is in metric tons per day for computing the components of capital costs as shown below.

$Cost_{\mathrm{E}} = 2943 * Y_{it}^{0.901}$	equipment capital costs	(2.3)
$Cost_L = 405.8 * Y_{it}^{0.941}$	labor capital costs	(2.4)
$Cost_S = 390.7 * Y_{it}^{0.904}$	supply capital costs	(2.5)

The total capital expenditure cost is the sum of the three cost components. The cost estimate was updated to the base year 2000 from that of 1994 using mining cost indices for coal operations published by *Western Mine Engineering Inc.,* 2002. The labor component of the capital expenditure is normalized relative to wages in the United States.

$$\phi_{ft} = \sum_{i=1}^{N} \sum_{k=1}^{K} c_{ikt} q_{ikt} + \sum_{k=1}^{K} \sum_{j=1}^{M} c_{kjt} q_{kjt} \quad (2.6)$$

Equation 2.6 expresses transportation costs as the sum of rail plus sea freight costs.

$$\phi_{st} = \int_{0}^{q_{it}} (\alpha_{it} + \beta_i q_{it}) dq_{it} \tag{2.7}$$

where $$q_{it} = q_{i0} + \sum_{\tau=1}^{t} H_{it} \tag{2.8}$$

When the integral in equation 2.7 is evaluated and after substitution for equation 2.8, we obtain equation 2.9 below:

$$\phi_{st} = \alpha_{it}(q_{i0} + \alpha \sum_{\tau=1}^{t} H_{it}) + 0.5\beta_i (q_{i0} + \sum_{\tau=1}^{t} H_{it})^2 \tag{2.9}$$

Equations 2.7, 2.8 and 2.9 derive the variable cost of the supply function and demonstrate how the model acquires its quadratic cost structure. They show that the total variable supply cost for each producer and for a given period is obtained by integrating over the linear long run marginal cost function over the limits from zero to the cumulative quantity supplied by such producer.

$$\delta_t = \sum_{\tau=1}^{\theta} (1+\rho)^{-\theta(t-1)-\tau} \tag{2.10}$$

The discount factor for period *t*, where θ is equal to the number of years per time period and ρ is the discount rate, is given by equation 2.11 (Kendrick and Stoutjesdijk, 1978). The capital recovery factor (CRF) is given by:

$$\sigma = \frac{\rho}{1-(1+\rho)^{-T}} \quad \text{where } T \text{ is the life of project.} \tag{2.11}$$

The above objective function is minimized subject to the following constraining conditions:

Condition 1: This condition requires defining a set, *IK*, which matches producing countries to export ports to eliminate non-feasible links. The constraint says that for the set *IK*, exports should not exceed the available net supply, which is the difference between demand and base period supply plus sum of capacity additions to the present period.

$$-\sum_{k=1}^{K} q_{ikt} \geq D_{it} - q_{i0} - \sum_{\tau=1}^{t} H_{it} \quad \text{for all } i\text{, in } IK \text{ and } t \tag{2.12}$$

Condition 2: This equality states that at the transshipment nodes, coal inflows and outflows should balance out. This applies to the Southern Africa region and the United States. The condition does not exist for Australia as the long run marginal cost function is based on export prices that already include rail transportation costs to export ports.

$$\sum_{i=1}^{N} q_{ikt} = \sum_{j=1}^{m} q_{kjt} \quad \text{for all } k \text{ and } t \tag{2.13}$$

Condition 3: This inequality requires that the sum of supplies from transshipment ports must be greater than or equal to demand in region *j*..

$$\sum_{k=1}^{K} q_{kjt} \geq D_{jt} \quad \text{for all } j \text{ and } t \tag{2.14}$$

Condition 4: This inequality is relevant for those producers that may face a binding port capacity constraint. This applies to both existing and simulated ports in Southern Africa.

$$-\sum_{i=1}^{N} q_{ikt} \geq -V_{kt} \quad \text{for all } k \text{ and } t \tag{2.15}$$

Table 2: Variable Definitions

Variable	Definition
Sets	
I	Set of net exporting countries, i, in the model (Australia, South Africa, Botswana and the United States
K	Set of export ports, k, for the set of I exporting countries: Australia – Gladstone, South Africa – Richards Bay, United States – Hampton Roads and Botswana – (Matola, Walvis Bay and Richards Bay)
J	Set of import ports, j, in Western Europe (Antwerp, Rotterdam and Amsterdam) and Asia (Yokohama)
T	Time period for expansion, t, is 2005 and 2010 for the forecast from a base year of 2000 and 1995, 2000, 2005 and 2010 from a base year of 1990 for the simulation;
Endogenous Variables	
q_{it}	Domestic supply of steam coal at mine in exporting country I in period T (000s mtce)
q_{ikt}	Steam coal exports from mine I to port K in time period T (000s mtce)
q_{kjt}	Steam coal shipped form export port K to import port J in time period T (000s mtce)
H_{it}	Expansion capacity at mine I in period T (000s mtce)
Exogenous Variables	
Dit	Domestic demand in exporting country I, including exports to the rest of the world markets in time period T (000s mtce)
Djt	Total steam coal import demand by market J in time period T (000s mtce)
C_{ikt}	Rail costs from mine I to port K in time period T (in 2000 US Dollar / mtce)
C_{kjt}	Sea freight costs from export port K to import port J in time period T and for vessels greater than 100K tons deadweight (in 2000 US Dollar / mtce)

2.4 Forecast Demand, Supply and Long Run Marginal Cost Functions

The approaches to the econometric modeling of country demand and supply functions for mineral commodities can be found in the works by Labys (1999), Toweh and Newcomb (1991), Bozdogan and Hartman (1979), Mikesell (1979), and Fisher, Cootner and Bailey (1972). In this study, we estimate the country supply and demand functions under the context of a non-spatial time dependent econometric model of the world steam coal trade following similar approaches to those by Labson (1997) and Meyers, Devados and Helmar (1989). The purpose of this non-spatial econometric model approach is two-fold: 1) to model the domestic demand and supply functions for all countries to determine the forecast demands in the net exporting countries and also the forecast demands in the net importing countries of the model, and 2) to model the long run marginal cost functions for steam coal supply in the net exporting countries of the model. The model differentiates coal only on the basis of its heat content (Btu) and for this reason the coal supply and demand data are converted to metric tons of coal equivalent (mtce). Similarly, all price and cost variables are reported on a per mtce basis. A detailed description of the econometric modeling results can be found in Fichani (2003).

In Tables 3 and 4 we present the domestic and import demands in the net exporting and net importing countries of the model respectively, while Table 5 presents the transformed long run marginal cost functions in their quantity formulation. The long run marginal cost functions and forecast domestic and import demands are employed in the above model, which is solved using the GAMS MINOS 5.5 solver (Brooke et. al., 1998). The model solution results are presented in section 3 below. The data sources for this model appear later in Table 6.

Table 3: Actual and Forecast Steam Coal Demand and Supply Quantities in Net Importing Countries of the Model (000's mtce)

Historical Period				**Forecast Period**			
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Japan							
Demand	32 751	49 644	66 933	75 453	88 659	103 121	119 053
Supply	6 824	4 928	2 602	1 556	871	480	262
Imports	25 928	44 716	64 332	73 897	87 788	102 641	118 791
South Korea							
Demand [(a)]	76 554	54 501	39 597	52 740	61 140	70 878	82 167
Net Imp. Asia	**102 482**	**99 217**	**103 929**	**126 637**	**148 928**	**173 519**	**200 958**
Belgium							
Demand	6 977	6 897	5 238	6 709	8 398	10 511	13 155
Supply	1 611	436	296	144	68	32	15
Imports	5 365	6 460	4 942	6 565	8 330	10 479	13 140
Germany							
Demand	24 596	21 440	21 846	19 285	16 476	14 075	12 410
Supply	16 787	11 867	7 745	5 406	3 595	2 366	1 548
Imports	7 809	9 573	14 101	13 879	12 881	11 710	10 862
France							
Demand	14 509	11 088	12 336	10 016	7 923	6 149	4 709
Supply	8 443	6 946	4 006	2 905	2 093	1 501	1 073
Imports	6 067	4 142	8 330	7 111	5 830	4 648	3 636
Italy							
Demand	9 614	9 220	10 214	8 317	6 561	5 061	3 841
Netherlands							
Demand	8 001	7 338	8 057	7 308	6 281	5 391	4 628
Spain							
Demand	12 891	14 639	19 253	19 192	18 559	17 746	16 829
Supply	13 147	11 771	10 206	10 514	11 904	13 529	15 376
Imports	(256)	2 868	9 046	8 679	6 655	4 217	1 453
UK							
Demand	86 892	53 228	41 135	35 906	43 252	50 494	59 276
Supply	83 543	46 521	28 592	18 119	13 032	9 241	6 484
Imports	3 350	6 707	12 542	17 789	30 220	41 254	52 791
Net Imp. Europe	**39 950**	**46 308**	**67 233**	**64 843**	**72 533**	**83 004**	**93 583**
Model Imports	**142 431**	**145 525**	**171162**	**191 480**	**221 460**	**256 525**	**294 541**

Source: Fichani, K., Modeling the International Competitiveness of Botswana's Coal, 2003, Dissertation, West Virginia University, [On-line Abstract]. Available: http://etd.wvu.edu/templates/showETD.cfm?recnum=2870

Notes: [(a)] South Korea's demand estimates are projections based on 5.9% growth rate from 2000 as cited in Coal Information 2001, p I.140.

Table 4: Actual and Forecast Steam Coal Demand and Supply Quantities in Net Exporting Countries of the Model (000's mtce)

Historical Period				**Forecast Period**			
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Australia							
Demand	30 243	33 643	45 910	56 230	69 600	86 311	107 182
Supply	65 248	81 680	104 588	136 907	179 700	233 138	299 877
Exports	35 006	48 036	58 678	80 677	110 100	146 827	192 696
South Africa							
Demand	96 692	115 407	129 710	142 060	151 355	160 463	169 498
Supply	134 215	163 678	188 836	213 187	239 526	269 118	302 367
Exports	37 523	48 271	59 126	71 127	88 171	108 655	132 868
United States							
Demand	627 375	638 844	693 489	774 799	848 535	942 735	1 029 330
Supply	658 449	661 305	704 779	799 063	874 326	971 221	1 060 258
Exports	31 074	22 460	11 290	24 265	25 791	28 485	30 928
Botswana [(a)]							
Demand	800	800	800	800	800	800	800
Supply	800	800	800	800	800	800	800
Exports	0	0	0	0	0	0	0
Model Exports	**103 603**	**118 768**	**129 093**	**176 069**	**224 061**	**283 968**	**356 492**

Source: Fichani, K., Modeling the International Competitiveness of Botswana's Coal, 2003, Dissertation, West Virginia University, [On-line Abstract]. Available: http://etd.wvu.edu/templates/showETD.cfm?recnum=2870

Notes: [(a)] – Botswana's supply and demand are historical averages

Table 5: Transformed Long Run Marginal Cost Functions

Period 1991 – 1995:	
Australia:	$P = 50.90 + 7.06x10^{-5}Q^s$
South Africa:	$P = 15.54 + 6.51x10^{-5}Q^s$
Botswana:	$P = 15.54 + 6.51x10^{-5}Q^s$
U.S.A.:	$P = 42.97 + 7.32x10^{-6}Q^s$
Period 1996 – 2000:	
Australia:	$P = 32.31 + 7.06x10^{-5}Q^s$
South Africa:	$P = 5.01 + 6.51x10^{-5}Q^s$
Botswana:	$P = 5.01 + 6.51x10^{-5}Q^s$
U.S.A.:	$P = 32.19 + 7.32x10^{-6}Q^s$

Source: Fichani, K., Modeling the International Competitiveness of Botswana's Coal, 2003, Dissertation, West Virginia University, [On-line Abstract]. Available: http://etd.wvu.edu/templates/showETD.cfm?recnum=2870

Note: Botswana's long run marginal cost function is the same as that for South Africa.

2.5 The Choice of Land Routes for Botswana's Coal Exports

Two routes have been selected based on the detailed geographical analysis: 1) Mmamabula – Lobatse – Ghanzi – Gobabis - Walvis Bay in Namibia, and 2) Mmamabula – Ellisras – Pretoria – Matola in Maputo, Mozambique. The first route would use existing rail from Mmamabula to Lobatse, a distance of about 200km and a simulated railway line from Lobatse to Ghanzi, along the same corridor as the Trans-Kalahari Highway on the Botswana side, a distance of about 700 km and that from Ghanzi to Gobabis to join an existing railway line in Namibia. The total estimated length of this haul would be 1500 km. The second route links Mmamabula to the line that is currently being used to export steam coal from ISCOR's Grootegelug mine near Ellisras. The approximate total length of this haul is 1100 km. These routes are shown in Figure 2 below.

The routes from export to import ports are assumed to be the same as those for South Africa's coal exports to Western Europe and Asia. The Richard's Bay port is approximately equidistant from markets in Asia and Western Europe at 7400 and 7600 nautical miles respectively (*Western Mining*, 2002, Table 6 p. TR C4). A computation of the reduction in the sea voyage from using Walvis Bay instead of the East facing ports of Southern Africa shows that this would be about 20%. A port such as Walvis Bay would, therefore, compete favorably against as exporters from South America in the Western European steam coal markets.

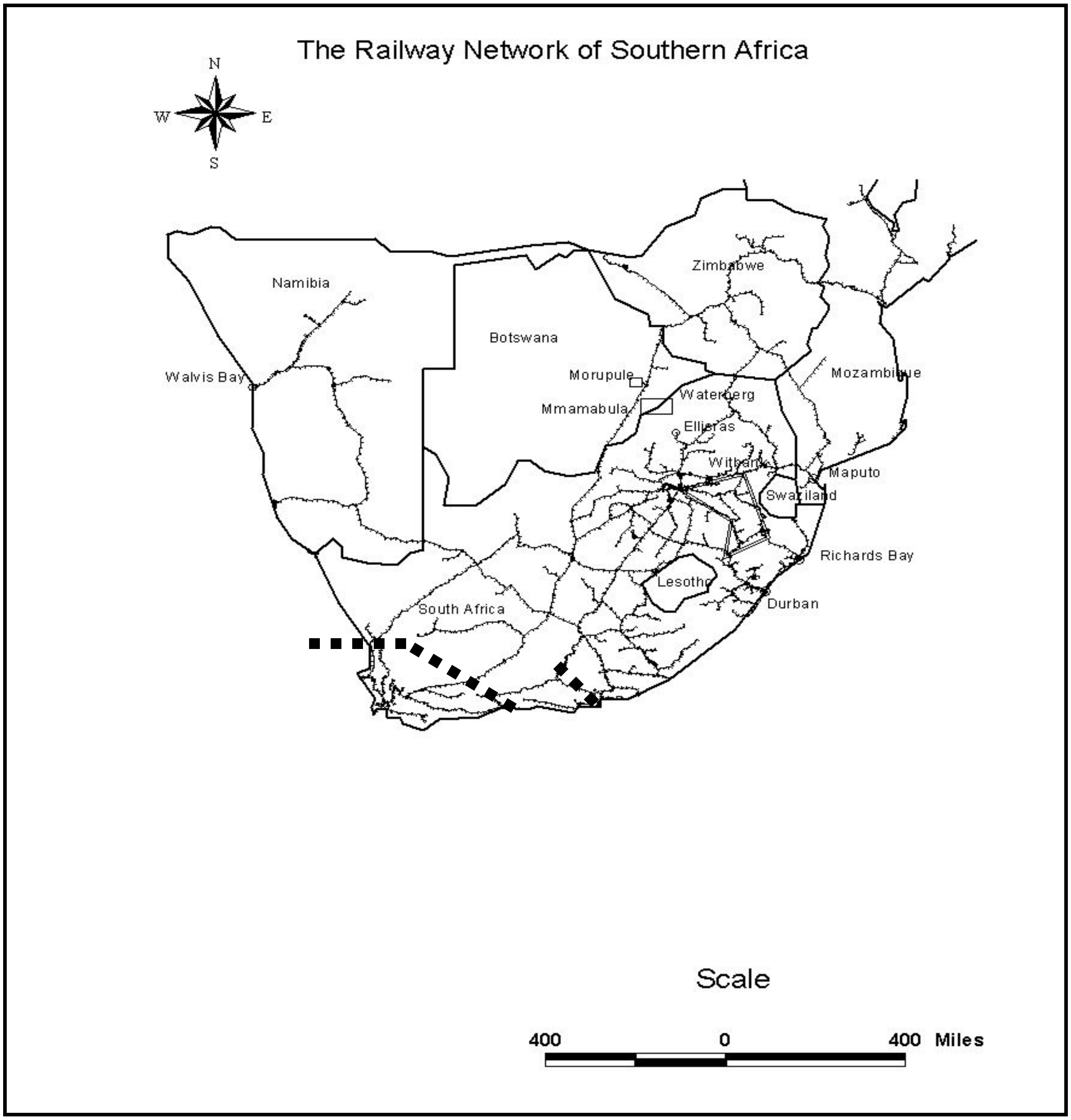

Figure 2. Simulated Railway Lines (bold dashed pattern) to Seaports with the Existing Railway Network of Southern Africa

Source: Compiled by author from GIS database files retrieved on April 19th, 2002 from: http://www.maproom.psu.edu/dcw/

Note: Coal deposits location is not geo-referenced and is therefore only illustrative.

Table 6: Model Variables and Data Sources

Data Variables	Source
Steam coal production, consumption, exports, imports	Coal Information, 1988, 1990, 1996 and 2001
End user prices for steam coal, natural gas and heavy fuel oil	1) Coal Information, 1988, 1990, 1996 and 2001 2) Energy Prices and Taxes, Quarterly Statistics, 2nd Quarter 2001
Maritime freight rates	Coal Trade Freight Report, Rodriguez and Sons Co. cited in International Coal Review Monthly
Rail transportation costs	Coal Information, 1988, 1990, 1996 and 2001
Macro data on real gdp, interest rates, exchange rates and CPI	International Financial Statistics, May 2001.
Hourly wage rates	International Labor Organization's Washington branch web site: http://us.ilo.org
Heat content of coals	US Energy Information Administration's web site www.eia.doe.gov

3.0 Policy Applications

We test whether or not Botswana's steam coal exports would be competitive in the world steam coal markets of Western Europe and Asia, if railway and port infrastructure existed for exporting this coal. Our forecasts trace the likely future development of Botswana's coal deposits beginning from the base year 2000 and extending to 2010 in five-year intervals. The model will also determine the cost competitive rail routes and seaports, thus providing policy makers with a valid justification for selecting such routes for development. The following additional assumptions are made for the base case forecast scenario:

1. Australia's future exports to Asia and South Africa's future exports to Western Europe do not fall below their year 2000 levels while they can take on any positive value in those markets in which these countries are marginal suppliers.
2. US exports are free to take on any value in both markets.

3. Botswana's exports are constrained by export port capacity, which is assumed to be 5.0 million mtce for Matola in 2005 and 20.0 million in 2010 for combined port capacity at Walvis Bay and Matola.

The first assumption preserves the existing export quantities, which may be protected from competition by the existence of long term contracts, but leaves future demand growth contestable. The last assumption assumes that if a decision to proceed with an export mine were made at the end of 2002, then in the remaining time, 2003–2005, from the first period of forecast, Mmamabula coal could be exported through Matola after the necessary investments on mine, rail and port capacity are made. While the model mine is a mechanized continuous room and pillar operation, the existence of strippable reserves at Mmamabula presents a possibility for developing an export steam coal mine by 2005. Due to the distance from Mmamabula to Walvis Bay, this route is assumed to be only available in 2010.

3.1 Results of the Base Case Forecast Scenario

The results of the base case forecast scenario are provided in Table 7 and these predict the following ranking among the four exporters for exports to Western Europe: 1) South Africa, 2) Botswana, 3) the United States and 4) Australia. In the Asian market, the forecast rankings are: 1) Australia, 2) South Africa, 3) Botswana and 4) the United States. Botswana's market share in Asia would be 12% in 2010. This translates into 10.772 million mtce 2010. The export port for this coal is Matola in Mozambique. In the Western European market, Botswana's market share would be 12% and 23% in 2005 and 2010 respectively, which translates into 5.0 million and 9.228 million mtce for these years respectively. All of Botswana's coal would be exported through the port of Matola in Mozambique.

In the Asian steam coal markets, Australia's forecast residual market share declines from its actual level of 89% in 2000 to 73% and 61% in 2005 and 2010 respectively while that for South Africa rises from 7% in 2000 to 27% for both 2005 and 2010 respectively. The United States is eliminated from this market, losing its 5% market share held in 2000. In Western European markets, both Australia and the United States are eliminated. South Africa's forecast market share is 88% and 77% in 2005 and 2010 respectively and during these years, the remainder of this market share is taken up by Botswana. These results were subjected to a sensitivity analysis for scenarios shown in Table 8.

Table 7: Forecast Results of the Base Case Scenario Showing Exporters' Market Shares

	Australia	South Africa	Botswana	USA
Asian Market				
Actual 2000	89.0	7.0	0.0	5.0
Base Case Forecast Scenario Shares				
: 2005	73.0	27.0	0.0	0.0
: 2010	61.0	27.0	12.0	0.0
Western European Market				
Actual 2000	17.0	76.0	0.00	7.0
Base Case Forecast Scenario Shares				
: 2005	0.0	88.0	12.0	0.0
: 2010	0.0	77.0	23.0	0.0

Source: Based on model simulations by the author.

Table 8 provides the forecast f.o.b. steam coal prices for the net exporters in the model together with those for some of the emerging exporters for the year 2000 only. The relative competitiveness ranking based solely on the f.o.b. prices for 2000 and with the export unit value expressed in year 2000 U.S. Dollar per mtce and shown in brackets are: Indonesia ($24.22), South Africa ($26.84), Colombia ($28.10), Botswana ($28.89), Australia ($31.10) and the United

States ($38.08). Over the forecast period, the competitiveness ranking of the ports for the net exporters in the model is as follows: 1) Matola, 2) Richard's Bay, 3) Walvis Bay, 4) Gladstone / New Castle and 5) Hampton Roads.

Table 8: Relative Competitiveness of F.O.B. Prices for Net Exporters (2000 U.S. $ /mtce)

Historical Period		**Forecast Period**	
Route	**2000**	**2005**	**2010**
Indonesia	24.22	na	na
South Africa			
: Matola	24.75	22.68	23.15
: Richard's Bay	26.84	23.92	24.39
: Walvis Bay	42.47	33.17	33.64
Colombia	28.10	na	na
Botswana [(a)]			
: Matola	28.89	26.45	26.92
: Richard's Bay	30.52	27.41	27.88
: Walvis Bay	33.09	28.93	29.40
Gladstone / Newcastle	31.10	40.32	41.17
Hampton Roads	38.08	55.83	56.37

Source: Based on model simulations by the author.
Notes: [(a)] Botswana's f.o.b. prices for 2000 are based on South Africa's f.o.b. prices.
Indonesia and Colombia are added for comparison in 2000 only

3.2 Model Validation

Two approaches are followed to validate the model. The first involves a comparison between historical and actual values. The second applies a response surface methodology whereby one can confirm with statistical significance the appropriate response properties of the model (see Myers and Montgomery, 1995, Kleijnen, 1974 and 1975, Ogawa, 1974 and Naylor, 1971). This approach has been applied mainly for industrial process optimization but an application to the modeling of commodity markets has been developed in Yang and Labys (1981). This approach normally involves employing analysis of variance based on some form of experimental design. The details of the latter method are presented in Fichani (2003), wherein we determine the response surface for Botswana's simulated optimal exports to changes in capital expenditure costs, variable supply costs, rail transportation costs and maritime transportation costs over a simulation period from 1995 to 2010 from a base year of 1990. In this paper, we present the results of the comparison of optimal and historical values for exports, trade flows, and the sensitivity results for scenarios depicted in Table 11 below.

The differences between the optimal and actual export values, expressed as a percentage of the actual values, are shown in Table 10. In 1995, these are: -7%, +24%, and –30% for Australia, South Africa, and the United States, respectively, while in 2000 these are: -4%, +24% and -27%. These results indicate, for instance, that the model underestimates Australia's exports by 7% and 4% in 1995 and 2000, a reasonably accurate result.

Table 9: Simulated Seaborne Steam Coal Flows Excluding Botswana (000's mtce)

Historical Period			**Forecast Period**	
	1995	**2000**	**2005**	**2010**
Gladstone to ARA [(1)]				
: Actual	4 427	6 674		
: Model	0	0	0	0
: Difference %	-100.0	-100.0		
Gladstone to Yokohama				
: Actual	41 496	55 948		
: Model	42 755	60 258	62 181	48 849
: Difference %	+3.0	+8.0		
Hampton Roads to ARA				
: Actual	14 176	2 838		
: Model	10 743	0	0	24 954
: Difference %	-24.0	-100.0		
Hampton Roads to Yokohama				
: Actual	4 889	3 085		
: Model	0	0	0	0
: Difference %	-100.0	-100.0		
Richard's Bay to ARA				
: Actual	19 090	30 059		
: Model	17 737	41 342	41 300	14 258
: Difference %	-7.0	+38.0		
Richard's Bay to Yokohama				
: Actual	5 581	3 877		
: Model	18 263	3 658	15 700	42 742
: Difference %	+327	-6.0		

Source: Based on model simulations by the author.
Notes: [(1)] Amsterdam, Rotterdam and Antwerp, which are taken as entry ports for steam coal imports into the modeled countries in the Western European region.

Table 10: Simulated Gross Steam Coal Exports Excluding Botswana (000's mtce)

Historical Period			Forecast Period	
	1995	2000	2005	2010
Australia				
: Actual	45 923	62 622		
: Model	42 793	60 358	62 222	48 849
: Difference %	-7.0	-4.0		
South Africa				
: Actual	48 271	59 126		
: Model	59 736	70 283	82 281	82 231
: Difference %	+24.0	+19.0		
U.S.A.				
: Actual	27 989	19 421		
: Model	19 643	14 163	14 271	39 287
: Difference %	-30.0	-27.0		

Source: Based on model simulations by the author.

Table 11: Scenarios for Sensitivity Analyses of the Base Case Forecast Results

Scenario	Rail Transport Cost	Mine Capital Cost	Steam Coal Import Demand
1	50%		
2	100%		
3	200%		
4		10%	
5		20%	
6		25%	
7			-20%
8			+20%

Source: Based on model simulations by the authors.

Next we determine how well the model predicts the temporal and spatial distribution of this trade by comparing optimal trade flow values with the actual values for 1995 and 2000. The temporal and spatial distribution of this trade is provided in Table 9 above. The model performs well in depicting trade flows between the major suppliers and demanders and does poorly in explaining trade links with low trade volumes. For instance, the percentage differences between the model's optimal trading volume between South Africa and Western Europe are -7% and

+38% in 1995 and 2000 respectively while that to Asia, which is not a major market for South Africa, these differences are +327% and –6% for 1995 and 2000 respectively. A similar observation is made for differences in Australia's exports to the Asian market where the errors are 3.8% and 8% in 1995 and 2000 respectively, while for exports to Western Europe, the errors are as high as –100% in both 1995 and 2000. Since the United States is a marginal supplier to both markets, by virtue of having the highest marginal cost function among these exporters, its exports volumes are quite erratic.

The results of the response surface methodology selects capital costs, rail transportation costs and their interaction factor to be the explanatory factors for the variability in Botswana's simulated steam coal exports; however, only capital costs are significant. The other cost components, which are variable supply costs, rail transportation costs and maritime transportation costs and their interaction with capital costs, have an insignificant effect on these exports (Fichani, 2003). The extent of the model's response to shocks in capital costs are close to what would be expected in reality.

3.3 Sensitivity Analysis of the Base Case Forecast Results

A sensitivity analysis was conducted to observe changes to the forecast optimal market shares, choice of export port, size of mine and timing of development for Botswana's coal deposits that would result from changes in rail transportation costs, capital costs for mine development and the level of import demand (see Table 11). The results of the sensitivity analyses are as follows:

1. In scenarios 1, 2 and 3, the optimal levels of Botswana's steam coal exports are least sensitive to rail transportation costs to the extent that a 200% increase in these costs still

results in Botswana's market share in Western Europe being at 12% or 5.0 million mtce, and 23% or 9.23 million mtce, in 2005 and 2010 respectively. In the Asian market, Botswana's market share declines marginally to 10% from 12% for the base case in 2010. The export tonnage in 2010 is 8.70 million mtce. The size of cumulative export mine capacity declines from 20.05 million mtce under the base case scenario to 17.97 million mtce in 2010.

2. In scenario 4, when capital costs are 10% above their base case levels, there is a 10% decline in Botswana's coal exports in 2010. This decline occurs for exports to the Asia market only. Scenario 5 shows that if these costs are 20% higher than in the base case forecast scenario, exports decline by 75% in 2010. Botswana loses its entire market share in Western Europe, while in Asia its share declines to 6% from the 12% it held in the base case forecast scenario. The export mine capacity is 5.0 million mtce in 2005 and 5.04 million mtce in 2010. In scenario 6, when capital costs are 25% above the level for base case forecast scenario, Botswana's steam coal is no longer competitive in both markets and the country is eliminated out of the model (see Tables 12 and 13 below).
3. In scenario 7, when the steam coal import demand is 20% lower than estimated, this does not affect the size of export mine at Mmamabula, which remains at 5.0 million mtce in 2005 and rises to 20.0 million mtce in 2010.
4. In scenario 8, a higher demand than that estimated expectedly shows that the simulated export port capacity for Mmamabula production would become a binding constraint on the size of mine to be developed. Also the port capacity constraint for South Africa means that the additional demand has to be met by other exporters not facing any of these constraints. The model demonstrates the role of marginal supplier that the United States

plays in this model. Its exports to Western Europe are 12.32 million mtce in 2010, which is the only time that the model selects U.S. exports.

5. The port of Matola offers the advantage of serving both the Asian and Western European markets and this is the port selected by the model.

Table 12: Distribution of Market Share in Asia Due to Changes in Botswana's Capital Costs (%)

	Australia	South Africa	Botswana	USA
Asian Market				
Actual 2000	89.0	7.0	0.00	5.0
Base Case Forecast Scenario Shares				
: 2005	73.0	27.0	0.0	0.0
: 2010	61.0	27.0	12.0	0.0
Capital costs up 10%				
: 2005	73.0	27.0	0.0	0.0
: 2010	61.0	29.0	10.0	0.0
Capital costs up 20%				
: 2005	73.0	27.0	0.0	0
: 2010	65.0	29.0	6.0	0
Capital costs up 25%				
: 2005	80.0	20.0	0.0	0
: 2010	71.0	29.0	0.0	0

Source: Based on model simulations by the author.

Table 13: Distribution of Market Share in Western Europe Due to Changes in Botswana's Capital Costs (%)

	Australia	South Africa	Botswana	USA
Western European Market				
Actual 2000	17.0	76.0	0.00	7.0
Base Case Forecast Scenario Shares				
: 2005	0.0	88.0	12.0	0.0
: 2010	0.0	77.0	23.0	0.0
Capital costs up 10%				
: 2005	0.0	88.0	12.0	0.0
: 2010	0.0	77.0	23.0	0.0
Capital costs up 20%				
: 2005	0.0	88.0	20.0	0.0
: 2010	0.0	77.0	0.0	23.0
Capital costs up 25%				
: 2005	0.0	100.0	0.0	0.0
: 2010	0.0	77.0	0.0	23.0

Source: Based on model simulations by the author.

4.0 Conclusions

The proposed model has proven successful in predicting the general trend in the temporal and spatial distribution of the steam coal trade as validated by relatively low percentage differences between the optimal and actual volume of steam coal exports for the historical years 1995 and 2000. The model predicts that Botswana's coal exports would have been competitive in Western Europe and Asia in the past and also in the future, in 2005 and 2010.

The results of the base case forecast scenario predict the following ranking among the four exporters for exports to Western Europe: 1) South Africa, 2) Botswana, 3) the United States and 4) Australia. In the Asian market, the forecast rankings are: 1) Australia, 2) South Africa, 3) Botswana and 4) the United States. The conclusions arising from this study are as follows:

1. The base case forecast results are sensitive to capital costs for capacity additions but are least sensitive to rail transportation costs;
2. Rail transportation costs at rates applying to South Africa's coal exports do not make Botswana's coal internationally uncompetitive;
3. The port of Matola is suitable as it serves both Western Europe and Asian steam coal markets, and
4. The results provide economic justification for the Botswana government to explore the means of providing railway infrastructure. Such an effort would involve initiatives by government, and under the Southern African Development Community's (SADC) protocol *Transport, Communications and Meteorology*, to present a case for this body to prioritize the development of both railway and port infrastructure for the region.

Further research in this direction would involve including country components for China, Colombia and Indonesia, as well as further refining the model's response to changes in transportation costs.

References

Abbey, D.S. and Kolstad, C. D., 1983. The Structure of the International Steam Coal Markets. *Natural Resources Journal*, 23 (4) 859-891.

Bozdogan, K. and Hartman, R.S., 1979. U.S. Demand for Copper: An Introduction to Theoretical and Econometric Analysis in: Mikesell, R.F. *The World Copper Industry: Structure and Economic Analysis*. (The John Hopkins University Press, Baltimore, Maryland), 131-163.

Brooke, A., Kendrick, D., Meeraus, A. and Raman, R., 1998. GAMS: A User's Guide. GAMS Development Corporation, Washington, D.C.

Clark, G.C., Lock, N.P. and Smith, R.A., n.d. The Coal Resources of Botswana, Department of Geological Survey, Lobatse, Botswana.

Dutton, C.M.J., 1982. Modeling the International Trade in Steam Coal. Energy Research Group, Department of Physics, Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, England.

Fichani, K., 2003. Modeling the International Competitiveness of Botswana's Coal. Dissertation, West Virginia University, *http://etd.wvu.edu/templates/showETD.cfm?recnum=2870*

Fisher, F.M., Cootner, P.H. and Bailey, M.N., 1972. An Econometric Model of the World Copper Industry. *Bell Journal of Economics and Management Science*, 3(2) 568-609.

Kendrick, D.A. and Stoutjesdijk, A.J., 1978. The Planning of Industrial Investment Programs: A Methodology. (published for the World Bank by the Johns Hopkins University Press, Baltimore).

Kleijnen, J. P. C., 1974. Statistical Techniques in Simulation: Part I. (Marcel Dekker Inc., New York, NY).

___ 1975. Statistical Techniques in Simulation: Part II. Marcel Dekker Inc., New York, NY.

Kolstad, C.D., Abbey, D.S. and Bivins, R.L., 1983. Modeling International Steam Coal Trade. Los Alamos National Laboratory, LA-9661-MS, UC-98f.

Lai, J. and Chen, C., 1996. A Cost Minimization Model for Coal Import Strategy. *Energy Policy* 24(12), 1111-1117.

Labson, B. S., 1997. Changing Patterns of Trade in the World Iron Ore and Steel Market: An Econometric Analysis. *Journal of Policy Modeling* 19(3), 237-251.

Labys, W.C., 1999. Modeling Mineral and Energy Markets. (Kluwer Academic Publishers, Boston / Dordrecht / London).

Labys, W.C. and Yang, C. W., 1991.Advances in the Spatial Equilibrium Modeling of Mineral and Energy Issues. *International Regional Science Review* 14(1), 61-94.

___ 1980. A Quadratic Programming Model of the Appalachian Steam Coal Market. *Energy Economics* 2(2), 86-95.

Labys, W.C., Nadiri, M.I. and Nunez del Arco, J., eds., 1980. Commodity Markets and Latin American Development: A Modeling Approach. The National Bureau of Economic Research Inc.

Macal, C.M., 1979. Analysis of Coal Development Issues with the Argonne Coal Market Model. Argonne National Library, Argonne, Illinois.

Meyers, W.H., Devadoss, S. and Helmar, M., 1987. The Iowa State University FAPRI Model in The International agricultural Trade Research Consortium: Agricultural Trade Modeling, the State of Practice and Research Issues. Economic Research Service, International Economics Division, United States Department of Agriculture, 44-56.

Mikesell, R.F., 1979. The World Copper Industry: Structure and Economic Analysis. (The John Hopkins University Press, Baltimore, Maryland).

Myers, R. H. and Montgomery, D. C., 1995. Response Surface Methodology: Process and Product Optimization Using Designed Experiments. (John Wiley and Sons, New York, NY).

Nagurney, A., 1999. Network Economics: A Variational Inequality Approach. (Kluwer Academic Publishers, Boston).

___ 1987. Computational Comparisons of Spatial Price Equilibrium Models. *Journal of Regional Science* 27(1), 55-76.

Naylor, T.H., 1971. Computer Simulation Experiments with Models of Economic Systems. (John Wiley & Sons Inc., New York, NY).

Samuelson, P. A., 1952. Spatial Price Equilibrium and Linear Programming. *The American Economic Review* 42(3), 283-303.

Senf, D. R. and Fruin, J.E., 1986. An Assessment of the Competitive Position of Great Lakes Ports in the International Steam Coal Trade. University of Minnesota, Staff Paper Series, Staff Paper P86-1.

South African Coal Report, 2002. 13(9), 9.

Suwala, W. and Labys, W.C., 2002. Market Transition and Regional Adjustments in the Polish Coal Industry. *Energy Economics* 24(3), 285-303.

___1998. Modeling Transition in the Polish Coal Industry. Instytut Gospodarki Surowcami Mineralnymi i Energia. (PAN, Cracow).

Takayama, T. and Judge, G. G., 1971. Spatial and Temporal Price and Allocation Models. (North Holland Publishing Company, Amsterdam / London).

___ 1964. Equilibrium among Spatially Separated Markets: A Reformulation. *Econometrica* 32(4).

Toweh, S.H. and Newcomb, R.T., 1991. A Spatial Equilibrium Analysis of World Iron Ore Trade. *Resources Policy* 17(3).

U.S. Department of Energy, 1982. Mathematical Structure of the International Coal Trade Model, prepared by George Washington University School of Engineering and Applied Science, Department of Operations Research and Oakridge National Library, Washington D.C., The Office.

United States Department of the Interior, U.S. Bureau of Mines, 1995. Economic Analysis Tools for the Minerals Industry (compact disk).

van den Bergh, J.C.J.M., Nijkamp, P. and Rietveld, P., 1995. Spatial Equilibrium Models: A Survey With Special Emphasis on Transportation, in: J.C.J.M. van den Bergh, P. Nijkamp and P. Rietveld, eds., *Recent Advances in Spatial Equilibrium Modeling*, (Springer) 48 – 76.

Yang, C.W., Hwang, M.J., and Sohng, S. N., 2002. The Cournot Competition in the Spatial Equilibrium Model. *Energy Economics* 24(2), 139-154.

Zimmerman, M.B., 1981. The U.S. Coal Industry: The Economics of Policy Choice. (MIT Press Cambridge, Massachusetts).