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A framework for environmental policy evaluation in the South African mining sector

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Kiel Working Papers

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A Framework for Environmental Policy Evaluation
in the South African Mining Sector

by

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ABSTRACT

This paper presents a Computable General Equilibrium (CGE) model for the analysis of environmental policies towards mining activities, and shows for the case of South Africa how it can be implemented numerically. The CGE model belongs to the class of static, trade-focussed models along the lines suggested by Dervis et al. (1982). A distinctive feature of the model is that it allows for substitution possibilities between primary factors and intermediate inputs such as energy and mineral resources. In the South African data base, two different types of households (black and other households) are distinguished in order to trace the distributional consequences of policy reforms which are of high priority given the income inequalities prevailing in South Africa.

Key Words: Computable General Equilibrium Model, Environmental Policy, Mining, South Africa

JEL-Classification: D58, Q32

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I. THE PROBLEM

For classical economists like Malthus and Ricardo, finite resources played an important role because they were expected to eventually constrain economic growth in the long run. After an extended period of limited interest in issues on resource economics, this view regained momentum with the appearance of the much-cited Limits-to-Growth study commissioned by the Club of Rome (Meadows et al. 1972) which was, however, criticized by economists as being overly pessimistic because of its neglect of substitution possibilities and technical progress (e.g. Nordhaus 1974). Since then, a growing consensus has evolved that the world is not under immediate threat of running out of nonrenewable resources but that the real problem are the environmental side-effects of resource extraction, i.e. the destruction of habitat and the emission of various pollutants such as heavy metals and sulphur dioxide (World Bank 1992).¹

This paper stylizes a modeling framework for the evaluation of policy measures which might reduce these environmental side-effects, and provides a data set for implementing the model for South Africa where

See Young (1992) for a detailed overview of the environmental side-effects of mineral extraction and processing.

mining is of critical economic importance. In doing so, four issues are of particular relevance. First, since a main objective of environmental policies is to induce a shift towards less resource-intensive activities, the model has to be *multi-sectoral*. Here, a Computable General Equilibrium (CGE) model is chosen. Second, it has to be checked whether *substitution* between resources and primary factors and *resource-saving technical progress* are likely to occur in response to policy changes. Both adjustments would lower the costs of stricter environmental regulations. Third, since property rights for nonrenewable resources tend to be fairly well established (ibid.), the issue to be analyzed is not primarily a suboptimal use of resources over time but rather a distortion in each single period which can be captured in a *static* framework. Finally, the *distributional effects* of policy reforms have to be taken into account given the racial inequalities prevailing in South Africa.

The remainder of the paper proceeds as follows. Chapter II explains the main features of the modeling framework. The data base for South Africa is documented in Chapter III. Chapter IV summarizes the conclusions of the paper.

H. THE MODELING FRAMEWORK

In discussing the modeling requirements, those characteristics which are of specific importance for the analysis of environmental policies towards mining will be treated in some detail (Section II. 1). The rest of the model will only be roughly surveyed (Section II.2) because it closely resembles the approach taken in previous CGE analyses along the lines suggested by Dervis et al. (1982).

1. Sectoral Responses to Environmental Policies

a. Substitution

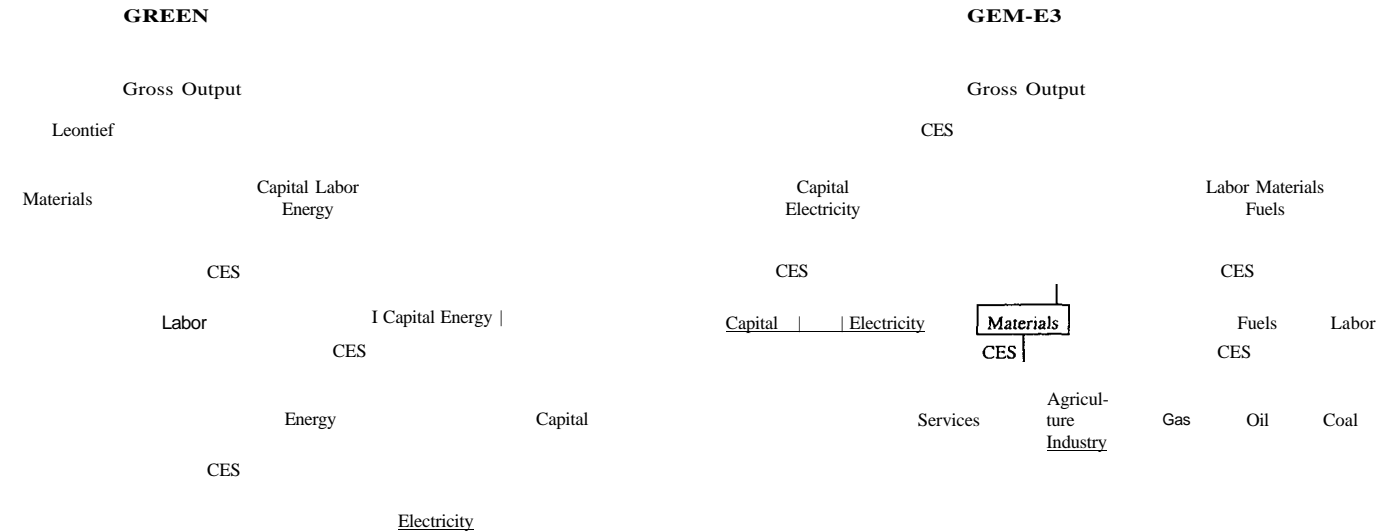
Almost all existing CGE models, while specifying Constant Elasticity of Substitution (CES) or Cobb-Douglas production functions to allow for substitution between capital and labor, retain the assumption originating with Leontief that intermediate inputs are used in fixed proportions to output (Jorgenson and Wilcoxon 1993). This assumption is, however, contradicted by empirical evidence, the most notable example being the price-induced energy conservation after the two oil price shocks. In a survey covering nine OECD countries, Schipper and Meyers (1992) concluded that between 1970 and 1989 energy-output ratios declined by

15-20 percent on average. The rapidly growing importance of recycling, which implies a reduced use of virgin materials per unit of production, also points towards the inappropriateness of fixed input coefficients. In the United States, for example, the rate of metal recycling has risen from 5 percent in 1975 to 23 percent in 1990 (McClain 1995).

The simplest way to overcome this weakness of conventional CGE models is to utilize a CES or Cobb-Douglas function which does not only include labor and capital, but also energy and materials as substitutable inputs.² Unfortunately, with more than two inputs, these functions have the property that the elasticities of substitution among all inputs must be the same (McFadden 1963). If this restriction proves to be too strong two possible alternatives remain. The first option is to employ a *nested production structure*. A well-known example of this approach is the OECD's GREEN[^]_{model} where the nesting hierarchy consists of four levels (see Figure 1). At the second level, for example, a CES function

- These inputs may be further disaggregated in order to distinguish, for example, between recycled and virgin materials or between fuels and electricity.

Figure 1 — Structure of Production in GREEN and GEM-E3



Source: Burniaux et al. (1992); Capros et al. (1997).

describes the relationship between energy and capital while at the next level another CES function combines the energy/capital bundle with labor. This specification relies on the assumption that labor is weakly separable from energy and capital, i.e. that the substitution elasticities between labor and capital and between labor and energy are equal. Similarly, in the GEM-E34 model for the European Union, weak separability between capital and electricity on the one hand and labor, materials and fuels on the other hand is assumed (Figure 1).

No separability restrictions are required when making use of the second option, a *translog cost function*, which provides a second-order approximation to the true production structure. The dual translog cost function⁴ can be written as

$$(1) \quad \ln C = a_0 + \sum_i a_i \ln w_i + \frac{1}{2} \sum_i \sum_j S_{ij} \ln w_i \ln w_j$$

where C are unit costs, a_i and S_{ij} are constant parameters and w_i (w_j) is the price of factor i (j). Differentiating (1) with respect to the logarithms of

General Equilibrium Model for Energy-Economy-Environment interactions.

The dual cost function is usually preferred over the primal production function because it only depends on factor prices which are more likely to be exogenous than the factor quantities appearing on the right-hand-side of the production function.

factor prices and using Shephard's lemma⁶ results in equations for the cost shares CS_i of each factor:

$$(2) \quad CS_i = \alpha_i + \sum_j S_{ij} \ln p_j / V$$

From the estimated parameters \hat{f}_{ij} the substitution elasticities can be calculated as

$$(3) \quad \sigma_{ij} = 1 + V / (CS_i - CS_j).$$

This specification allows for maximum flexibility in the sense that different substitution elasticities between any pair of factors are possible.

In order to check the plausibility of the different options it is helpful to look at existing estimates of factor substitution elasticities. Most of the evidence stems from the 1970s and 1980s when a central question was how costly it would be for economies to adjust to rising energy prices after the oil price shocks. Table 1 presents the results from several pooled cross-

6 Shephard's lemma states that $\partial \ln C / \partial \ln w_j$ equals the cost share of input i .

Table 1 — Substitution Elasticities between Capital, Labor, Energy and Materials⁸

\ Author(s)	Pindyck(1979)			Carrere and Deveziaux (1988)			Hesse and Tarka (1986)					Griffin and Gregory (1976)			Ozalalay c al. (1979)					
CountryX	<i>S_{CL}</i>	<i>S_{CE}</i>	<i>S_{LE}</i>	<i>s_{CL}</i>	<i>S_{CE}</i>	<i>S_U</i>	<i>SCL</i>		to		W	<i>SCL</i>	<i>S_{CE}</i>	<i>SLE</i>	<i>S_{CL}</i>	<i>S_{CE}</i>	<i>SLE</i>	<i>SLM</i>	<i>SME</i>	<i>s_{MC}</i>
USA	1.41	1.77	0.05	0.45	0.67	0.99						0.06	1.07	0.87	1.08	1.22	1.03	1.00	0.58	0.85
Canada	1.43	1.48	0.42	0.47	0.72	0.99														
Japan	1.15	0.74	1.15	0.54	0.78	0.98									1.14	1.18	1.05	1.00	0.05	0.88
Germany	0.71	0.66	1.23	0.51	0.73	0.96	0.80	0.30	-0.14	0.50	0.48	0.50	1.03	0.78	1.06	1.15	1.04	1.00	0.42	0.88
UK	0.64	0.36	1.10	0.21	0.56	0.99	0.77	0.26	0.36	0.35	0.64	0.39	1.04	0.84						
France	0.72	0.56	1.17	0.40	0.57	0.99	0.83	0.04	-0.12	0.48	1.61	0.41	1.05	0.82						
Italy	0.66	0.67	1.11	0.52	0.71	0.98	0.79	0.26	0.14	0.67	0.58	0.43	1.03	0.85						

^a All studies reported use pooled cross-country and time-series data. - ^bEL = electricity. - ^c NEL = non-electricity.

country and time-series studies. Pure time-series estimates are neglected because they mainly reflect short-term adjustments which are not of interest for the present purpose. With two exceptions, production factors are shown to be substitutes ($\sigma_{xy} > 0$) rather than complements ($\sigma_{xy} < 0$). Most estimated elasticities lie within a range of 0.5 to 1.5. The estimates neither suggest a particular nesting of the production structure, nor do they exhibit any other clear regularities. When looking at the only study where materials are included (Ozatalay et al., 1979)⁷ one might conclude, however, that a Cobb-Douglas framework is not too far of the mark. Given its simplicity, a Cobb-Douglas function will thus be used here in order to model the possibility that environmental policies induce a substitution between material inputs and other inputs.

b. Technical Progress

Input substitution is not the only possible response to changes in environmental regulation. A policy-induced price increase of a resource may also lead to the development of less resource-intensive production technologies within particular sectors. This case can be demonstrated

⁷ The other studies rely on the restrictive assumption that capital, labor and energy as a group are weakly separable from materials.

formally by integrating a time trend t representing technical change into equation 1:

$$(4) \ln C = a_0 + \sum a_i \ln x_i + a_p t + \sum \beta_{ij} \ln w_j + \sum \gamma_i P_i + P_{pp} t^2$$

Differentiating (4) with respect to log input prices yields the cost share equations

$$(5) \quad CS_i = a_i + \beta_{ij} \frac{P_j}{P_i} + \gamma_i + P_{pp} t$$

where the parameters β_{ij} indicate whether technical progress is factor-saving ($\beta_{ij} < 0$, i.e. the cost share of factor i declines), factor-neutral ($\beta_{ij} = 0$, i.e. the cost share of factor i remains constant) or factor-using ($\beta_{ij} > 0$, i.e. the cost share of factor i increases).

When differentiating equation (4) with respect to time in order to obtain the rate of productivity growth

another interpretation of the parameters β_{ij} becomes obvious. Now, they indicate how changes in input prices affect productivity growth. If, for example, technical progress is energy-saving an energy tax raises

Table 2 — Biases of Technical Change in Selected German, Japanese and US Industries

Country Sector	Germany (Unger 1986)				Japan (Kuroda et al. 1984)				USA (Hoffman 1989)			
	Labor	Capital	Energy	Materials	Labor	Capital	Energy	Materials	Labor	Capital	Energy	Materials
Coal mining									S	U	S	U
Oil and gas extraction									S	S	U	U
Metal mining									N	S	N	U
Total mining	N	N	N	N	S	S	S	U				
Petroleum and coal products	N	N	N	N	S	U	N	S	N	U	S	U
Iron and steel	N	N	N	N	S	N	S	U				
Non-ferrous metals	S	N	N	N	S	N	S	U				
Primary metals									N	N	U	S
Fabricated metals					S	S	S	U	S	U	U	N
Steel construction	S	U	N	N								
Machinery (except electrical)	N	N	N	S	S	U	U	U	N	U	U	S
Electricity	N	N	N	N	S	U	S	N	S	S	U	N

Note: N = factor neutral; S = factor saving; U = factor using.

productivity growth and thus leads to lower output losses than in a situation where only autonomous technical change (represented by the parameters a_p and P_{pp} in equation (6)) takes place.

Empirical evidence on the existence of biased productivity growth is limited to a few studies for industrialized countries. Sectorally disaggregated estimates of the bias parameters p_{ip} for Germany, Japan, and the United States are summarized in Table 2, with a focus on sectors in which energy and/or mineral resources are of particular importance. For these two inputs, as well as for capital, the findings are inconclusive whereas in the case of labor there is a tendency towards factor-saving technical progress in the United States and Japan. It can thus not be expected that stricter energy or resource policies systematically raise productivity and thereby ease possible trade-offs between economic and ecological objectives. For modeling, this implies that it is not necessary to specify technical change endogenously.

Another possibility is that environmental policies provide an incentive to reduce the environmental damage per unit of resource use. This kind of technical progress is likely to be the consequence of deliberately targeted policies such as SO^A -taxes, but its measurement is extremely difficult.

While the physical damage caused by the extraction and processing of resources at different sites is well documented (e.g. BGR 1997), it has not yet been possible to quantify the price responsiveness of emissions and habitat destruction. For the time being, modeling efforts therefore have to rely on the assumption that damage occurs in fixed proportions to resource use. As a consequence, it cannot be differentiated between policy measures directed at inputs, such as energy and resource taxes, and policies directed at emissions.

2. The CGE Model

Adjustments that go beyond sectoral production are captured by a CGE model of the Dervis et al. (1982) type. This class of models with its focus on external trade is well suited for the analysis of environmental policies towards mining activities because the sectors involved in extracting and processing energy and mineral resources tend to be highly export-oriented (see, for example, the case of South Africa described below). In the following, some main characteristics of the CGE model will be presented.

For the supply side, it has been shown above that substitutability between primary and intermediate inputs is the rule. Let sectoral output X_s be produced by means of a Cobb-Douglas function

$$(7) \quad X_s = A_s K^{\gamma} L^{\alpha} E^{\beta} M^{\delta}$$

where A_s is the technology parameter and $\gamma, \alpha, \beta, \delta$ are the partial production elasticities which under constant returns to scale add up to one. Since the existing evidence does not reveal a systematic productivity bias for energy and materials (see Table 2) the technology parameter is assumed to be exogenous. Then, factor demand as determined by the condition that real factor prices equal physical marginal products can be written as

$$(8) \quad FD_h = \frac{X_s}{\alpha_h} \frac{P_{X_s}}{W_h}$$

Equation (8) indicates that the demand for input h in sector s is an increasing function of the sectoral output price P_{X_s} relative to the input price W_h . Changes in this price ratio are thus a crucial determinant of the resource reallocation occurring as a response to energy and resource policies.

Sectoral output is either consumed domestically (D_s) or exported (E_s). As is now common in CGE analyses, a constant elasticity of transformation (CET) function aggregates domestic sales and sales abroad:

$$(9) \quad X_s = (D_s^\rho + E_s^\rho)^{1/\rho}$$

θ_s and e_s denote scale and distribution parameters, respectively. The transformation elasticity is defined as $r_s = 1 / (a_s - 1)$. Subject to the production possibility frontier given by the CET function, revenue maximization leads to export supply as a function of the export to domestic price ratio:

Analogously, it is assumed that domestic consumers demand a composite good (Q_s) which is a constant elasticity of substitution (CES) aggregate of imports (M_s) and domestic sales (X_s):

$$(11) \quad Q_s = C_s [\alpha_s M_s^{1-\sigma_s} + (1-\alpha_s) X_s^{1-\sigma_s}]^{-1/\sigma_s}$$

C_s and α_s are again scale and distribution parameters and $\sigma_s = 1/(1+r_s)$ is the substitution elasticity. Minimizing costs subject to the CES function gives import demand as a function of the domestic to import price ratio:

$$(12) \quad M_s = D_s \left(\frac{P_s}{P_M} \right)^{-\sigma_s} \quad 1 -$$

This is the so-called Armington-assumption (Armington 1969).

As extreme cases, the CET and CES functions encompass the neoclassical model where substitution and transformation is complete ($a_s \rightarrow \infty; T_s \rightarrow \infty$) as well as the structuralist model where the ratio between domestically sold and traded goods is fixed ($a_s = 0; r_s = 0$). The higher r_s and a_s , the stronger export and import volumes respond to changes in relative prices. There are two main reasons for assuming incomplete transformation and substitution in external trade. First, sales in the domestic market may be qualitatively different from exports or imports. Second, the high level of aggregation in CGE analyses implies that, within sectors, it is likely that the goods sold domestically and those traded are not the same. With imperfect transformability and substitutability, the law of one price which states that domestic relative prices of tradables are set by world prices no longer holds, i.e. there is some autonomy for the domestic price system. In addition, the specification can accommodate the two-way trade empirically observed for most sectors at higher levels of aggregation.

As a further deviation from neoclassical trade theory, the assumption of infinitely elastic export demand is relaxed. Although middle-income countries such as South Africa are not able to affect world prices for most of their traded goods, they may win (lose) world market shares by lowering (raising) domestic production costs relative to their foreign

competitors. To account for this phenomenon, an export demand function with a constant demand elasticity r^*_S

is utilized, where n_s is a weighted average of world prices for exports from all countries, PWE_S is the dollar price the home country receives for its exports, and \bar{E}_S a constant reflecting foreign demand for domestic goods when n_s equals PWE_S .⁹ While n_s is exogenously given for countries with negligible world market shares, PWE_S depends on domestic production costs, export incentives, and exchange rate policies. The export demand function thus allows for terms-of-trade effects of domestic policies. A resource tax, for example, may improve the terms of trade by raising the dollar export price at a given dollar import price.¹⁰

9 Given a negligible share of the home country in world markets, this is the demand curve the country faces if consumers in the rest of the world demand a mix of exports from the home country and from other countries so as to maximize a CES utility function.

¹⁰ On the import side, the neoclassical assumption of infinitely elastic supply is retained. This implies that the dollar import price is exogenously fixed.

The remaining demand components^H are modeled in a very simple way. Private households maximize a Cobb-Douglas utility function. This leads to a consumption function with fixed expenditure shares for individual goods. Choosing a Cobb-Douglas utility function implies unitary income and (uncompensated) own-price elasticities and zero cross-price elasticities, thereby ruling out substitution possibilities in private consumption. Government demand for final goods is defined using fixed shares of aggregate real government spending on goods and services. Exogenously given share parameters also determine the sectoral allocation of investment.

Having specified supply and demand, the income cycle is completed by mapping the flow of income from value added to the different institutions, namely firms, households, the government and the rest of the world. In a first step, total value added is distributed among the factors of production. A part of capital income remains in the corporate sector as retained profit, another part is repatriated by foreigners. The rest flows to domestic

^H All domestic demand components, including intermediate demand, are in terms of the composite (import + domestic) good Q_c .

households 12 who have to pay taxes and consume and save constant shares of their disposable income. The government receives revenues from a number of taxes, including resource and energy taxes. Any budget surplus is allocated to the savings pool which consists of corporate, household and government savings as well as capital imports.

In order to solve the CGE model, market clearing conditions for the product and factor markets as well as macroeconomic equilibrium conditions for the government budget, the balance-of-payments and the savings-investment balance must be specified. Supply and demand in product markets is equilibrated by the adjustment of sectoral prices. The aggregate supply of the primary factors labor and capital is fixed. Market clearing requires that total factor demand equals supply, the equilibrating variables being the factor prices. Both labor and capital are assumed to be intersectorally mobile because the interest here is in the longer term consequences of environmental policies.¹³ With real aggregate spending

If the distributional consequences of policy changes are of interest a disaggregation in the household sector is required. In South Africa, for example, a key issue is whether in particular the black population would suffer from stricter environmental regulation in the mining sector. Hence, the analysis must distinguish between black and other (white, colored, asian) households (see below).

In short to medium term analyses, it is often assumed that capital is sector-specific, especially in applications for developing countries.

set exogenously, equilibrium in the government's budget is achieved via adjustments in government savings. In the foreign exchange market, the CGE model determines an equilibrium relationship between the real exchange rate and the current account balance. Here, the nominal exchange rate is chosen to be endogenous. Finally, aggregate investment is the endogenous sum of private, government and foreign savings, i.e. the model is "savings-driven".

m. NUMERICAL SPECIFICATION FOR SOUTH AFRICA

The implementation of the theoretical model for a particular country proceeds in two steps. First, one has to construct a data set for a base year which records all nominal and real flows in the economy in a microeconomically consistent way. ¹⁴ The situation in the base year is assumed to represent a benchmark equilibrium of the economy. Second, the model parameters have to be specified in such a way that the model can replicate the benchmark data set.

For the requirements which a microeconomically consistent data base has to fulfill see St. Hilaire and Whalley (1983).

1. Data Base

The most convenient framework for organizing the data is a Social Accounting Matrix (SAM) which keeps track of the circular flow of income and expenditure in the economy.¹⁵ Table 3 presents an aggregate South African SAM for 1993. 1993 is chosen as the base year because the most recent Input-Output table has been published for this year. The Input-Output table contains a large part of the information needed to construct a SAM. Additional data sources are the South African national accounts and the balance-of-payments statistics.

In the SAM, the activities account shows producers' revenues from domestic sales and exports along the row, and expenditures on intermediate inputs, primary factors and indirect taxes down the column. The commodities account traces the domestic demand categories, the sum of which equals the value of domestic products sold on the domestic market plus imports. The factor accounts transform factor income into

A good introduction to SAMs and a number of examples of their uses is provided by Pyatt and Round (1985).

Table 3 — Aggregate Social Accounting Matrix for South Africa, 1993 (Million Rand)

^ \ ^ Expenditures Receipts ^~^~^	Activities	Commo- dities	Factors		Households		Govern- ment	Capital account	Rest of the world	Sum
			Labor	Capital	Black households	Other households				
Activities		624369							89772	714141
Commodities	329851				85379	145250	75411	63392		699283
Labor	210024									210024
Capital	136112								-7914	128198
Black households			72689	17812						90501
Other households			137335	35527						172862
Government	38154			12510	1934	18857				71455
Capital account				62349	3188	8755	-3956		-6944	63392
Rest of the world		74914		7914						74914
Sum	714141	699283	210024	128198	90501	172862	71485	63392	74914	

Notes: - In case of inconsistencies between data from different sources institutional saving rates were adjusted in order to balance the accounts.
- Flows from and to households are distributed among black and other households according to the shares shown in the 1988 SAM (CSS 1993), assuming that these shares have not changed until 1993.

Source: Appendix table; CSS (1993); South African Reserve Bank (1994).

income flowing to the various institutions. Incomes and expenditures in the household account are split up between black and other households. Here, the racial inequalities prevailing in South Africa become obvious. Representing three fourth of the population, the black majority receives only about a third of total household income. Any policy change in South Africa will thus at least partly be assessed with regard to its distributional consequences. The last three accounts contain the macroeconomic equilibrium conditions. They reveal a deficit in the government budget and a current account surplus, i.e. negative government and foreign savings.

The aggregate SAM does not show the sectoral disaggregation of production. In the model, twelve sectors are distinguished. Eight of them - coal mining, gold mining, other mining, petroleum and coal products, base metals, fabricated metals and machinery, electricity and recycling - are involved in the extraction and processing of energy and mineral resources. Four highly aggregated sectors - agriculture, other manufacturing, construction and services - complete the production structure.

Table 4 summarizes some main structural characteristics of the South African economy. The first column shows that mining and mineral processing accounts for over 20 percent of total output. Hence,

Table 4 — Structure of the South African Economy, 1993 (percent)

	Sectoral composition of gross output	Value added per unit of output	Exports/output	Imports/absorption	Imported intermediate inputs/total intermediate inputs
Agriculture	4.4	48.2	5.9	6.0	12.8
Coal mining	1.3	43.6	44.0	24.2	14.2
Gold mining	3.1	78.7	99.7	94.7	10.9
Other mining	2.8	47.2	68.0	26.5	15.5
Petroleum/coal products	3.0	23.5	8.9	37.4	24.4
Base metal products	3.0	45.5	57.4	28.2	15.1
Fabricated metal/machinery	8.1	37.0	8.7	18.4	13.5
Other manufacturing	20.5	30.7	11.8	15.1	7.6
Electricity	3.4	53.5	0.0	2.8	8.8
Construction	5.4	29.2	0.0	3.7	8.6
Services	43.2	62.7	3.9	4.3	10.8
Recycling	2.0	14.9	0.0	11.4	10.4
Sum/average	100.0	48.5	12.6	10.7	12.8

Source: Own calculations based on appendix table.

environmental policies in this area are likely to have significant economy-wide consequences. The importance of intermediate inputs in each sector is indicated by the per unit value added figures in the second column. High value added ratios, e.g. for coal mining, indicate small backward linkages, and vice versa. The last three columns provide information about sectoral trade orientation. Mining and base metal products are by far the most export-oriented sectors. They alone contribute about 60 percent to overall

export earnings. In terms of exports mineral activities are thus even more important for the economy than in terms of production. On the import side, both the share of imports in domestic absorption (indicating the degree of import "orientation") and the share of imported inputs in total intermediate inputs (indicating the degree of import "dependence") have to be considered. While import dependence appears to be fairly uniform across sectors, import orientation ranges from almost no imports for electricity, construction and services to an import share of over one third for petroleum and coal products.¹⁶

A further information the aggregate SAM does not provide is the sectoral distribution of labor income between black and other households. This information is of crucial importance because it determines the distributional consequences of policy reforms, given that capital income shares as well as expenditure shares are assumed to be constant. As Table 5 shows, the black population earns half or more of total income in the primary sectors (agriculture and mining) and construction, but only about a third in manufacturing and services. One might thus suspect that

¹⁶ The high share for gold mining is misleading because domestic absorption in this sector is extremely low.

Table 5 —Sectoral Labor Income by Household Type, 1993 (Million Rand)

	Black households	Other households	Share of black households in sectoral income
Agriculture	2412	1334	0.64
Coal mining	1084	898	0.55
Gold mining	5749	3493	0.62
Other mining	1996	2020	0.49
Petroleum/coal products	469	1027	0.31
Base metal products	1619	2857	0.36
Fabricated metals/machinery	4868	9202	0.35
Other manufacturing	8936	15928	0.36
Electricity	1160	2429	0.32
Construction	4355	4518	0.49
Services	39513	92753	0.30
Recycling	522	881	0.37
Total	72689	137335	0.35
<p>Note: Sectoral income is distributed among; black and other households according to the shares shown in the '988 SAM, assuming that these shares have remained constant until 1993. For petroleum and coal products, a sector which is not identified in the 1988 SAM, the shares of chemical products are taken.</p>			

Source: Appendix table; CSS (1993).

environmental measures directed at the mining sector, where the income share of black households is high, would have an adverse impact on the racial income distribution by lowering relative wages of black households. The overall distributional outcome does, however, also depend on where the resources which leave mining move to. If it is agriculture or construction that mainly benefits from a decline in mining output the distribution of labor income may remain largely unaffected because an expansion of these sectors would exert upward pressure on the wage ratio between black and other households.

Finally, the damage caused by the extraction and processing of minerals must be known in order to assess the ecological effects of policy reforms. The South African Department of Environment Affairs has carried out a survey on the waste generated by different production sectors. Table 6 summarizes the results of this survey for mining activities. It emerges that by far most of the waste is generated during mineral extraction, mainly in the form of tailings and overburden which may contain, among other things, sulphuric acid and heavy metals. The single-most important hazardous wastes of the South African economy are the acid cyanide-containing goldmine effluents. Waste streams in the petroleum/coal

Table 6 — Generation of Mining and Mineral Processing Waste in South Africa, 1990/91 (Thousand tons per annum)^a

Sector	Air emissions	Waste water	Solid/ liquid waste	Total	Thereof: hazardous waste
All mining and mineral processing	n.a.	n.a.	n.a.	412641	1435
Gold mining	0	1538	190188	191726	1013
Coal mining	0	0	45600	45600	0
Other mining	27	18	139268	139313	87
Petroleum/coal products* ³	n.a.	n.a.	n.a.	9508	0
Metal products ⁰	13	16	4873	4902	335
Electricity	1592	0	20000	21592	0
Total economy	1972	2182	414651	418805	1893

^a Carbon dioxide emissions are not included. - ^b The figure for petroleum/coal products has to be interpreted as a lower bound because in some instances it could not be identified whether waste was generated in this sector or in other parts of the chemical industry. - ^c In the case of metal products, a distinction between base metals and fabricated metals was not possible.

Source: Department of Environment Affairs (1992).

products and electricity sector are dominated by ash from coal processing plants and coal-fired power stations, respectively. The electricity sector also emits a significant amount of sulfure dioxide and nitrogenous oxides into the air. Slags containing various heavy metals are the main by-product in the metal products sector.

2. Calibration

In the calibration procedure, all parameters of the model are fixed and then held constant during policy simulations. Most of them, such as the sectoral shares in aggregate (private and public) real consumption expenditures, can be calculated directly from the data base. With respect to the data base, one has to consider, however, that all figures of the SAM and the Input-Output table are provided in value terms. In order to obtain separate information about prices and quantities, the common convention in CGE analyses is to set base-year prices to one, thereby equalizing nominal and real flows.¹⁷

¹⁷ An exception from this convention is frequently made for the factor markets in order to capture existing distortions which prevent factor prices from equalizing across sectors (see, for example, Devarajan et al. 1991).

On the supply side of the model, the choice of a Cobb-Douglas production function implies that two kinds of parameters have to be calculated: the production elasticities and the technology parameter. The former can be derived from the input demand equation (8). Under constant returns to scale, they add up to one. Once the production elasticities are given, the production function (7) can be solved for the technology parameter.

In foreign trade, one has to rely on external information about the trade elasticities. Here, the Global Trade Analysis Project (GTAP) data base is chosen as a reference point. The GTAP data for 30 regions include substitution elasticities between domestic and imported goods as well as between imports from different regions.¹⁸ The former correspond to the Armington elasticities reported in the first column of Table 7, which cover a range from 1.9 to 2.8. For the export transformation elasticities, a lack of adequate estimates was overcome by assuming symmetry between import aggregation and export transformation. The GTAP substitution elasticities between imports from different regions, which are set twice as high as the elasticities between imports and domestic goods, mirror the export demand

¹⁸ The GTAP model assumes that for each sector all agents in all regions display the same substitution elasticity.

Table 7 — Sectoral Trade Elasticities

Sector	Armington elasticity	Export transformation elasticity	Export demand elasticity
Agriculture	2.2	2.2	4.4
Coal mining	2.8	2.8	5.6
Gold mining	2.8	2.8	2.8
Other mining	2.8	2.8	5.6
Petroleum/coal products	1.9	1.9	3.8
Base metal products	2.8	2.8	5.6
Fabricated metals/machinery	2.8	2.8	5.6
Other manufacturing	2.2	2.2	4.4
Electricity	2.8	—	—
Construction	1.9	—	—
Services	1.9	1.9	3.8
Recycling ²	2.8	—	—

^a For recycling, no evidence is available. Since the sector is highly disaggregated, its Armington elasticity is assumed to be at the upper end.

Source: Dimaranan et al. (1997).

elasticities in the one-country model (see footnote 10). Here, GTAP figures are taken for all sectors except gold mining where South Africa is likely to face fairly unelastic demand and thus has considerable leverage in the world market. Altogether, the existing estimates of trade elasticities are so uncertain that policy simulations cannot do without sensitivity analyses. 19 Given the trade elasticities, the calibration of the external sector is completed by calculating the share and distribution parameters from the model equations (9) to (12).

IV. SUMMARY

This paper has introduced a static, trade-focused Computable General Equilibrium (CGE) model for the analysis of environmental policies towards mining activities, and has shown for the case of South Africa how to implement it numerically. Based on a literature survey, it has been concluded that the model must allow for substitution between primary factors and intermediate inputs but that there is no systematic productivity bias for energy and resources and thus no necessity to specify endogenous technical change. Since it has not been possible to quantify the price

The same is true for the production function.

responsiveness of emissions and habitat destruction caused by mining activities, the model relies on the assumption that damage occurs in fixed proportions to resource use.

The South African data base has been organized in a Social Accounting Matrix (SAM). The SAM distinguishes two different household types (black and other households) in order to trace the distributional consequences of policy reforms which are of high political priority given the racial income inequalities prevailing in South Africa. A crucial economic importance of mining activities is shown for South Africa, particularly in terms of export earnings. This implies that environmental policy measures are likely to have considerable economic-wide effects, thus making simulations in a multi-sectoral model relevant.

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Appendix Table — South African Input-Output Table, 1993 (Million Rand)

	i	2	3	4	5	6	7	8	9	10	II	12	11-12	Private Con- sumption	Government Con- sumption	Fixed Invest- ment	Inventories	Exports	Imports	Gross Prod- uction
1 Agriculture	3140	16	12	3	8	4	51	17292	15	4	569	0	21120	9765	501	293	-376	1828	-1879	31253
2 Coal Mining	1	937	6	68	934	524	4	270	1481	2	93	0	4320	1931	120	251	25	3959	-1606	9000
3 Gold Mining	0	0	778	0	0	0	0	60	0	0	0	0	838	292	91	208	-20	21709	-1333	21784
4 Other Mining	36	7	7	1360	4090	701	70	1010	0	318	45	0	7644	509	206	363	45	13684	-2326	20126
5 Petroleum/Coal Prod.	1502	332	105	547	7700	245	405	1693	185	814	5361	117	19007	8939	1506	1844	263	1929	-11810	21678
6 Base Metal Prod.	36	14	40	57	50	3443	5710	761	87	570	161	0	10929	782	261	556	124	12233	-3563	21322
7 Fabr.Metal+Machinery	535	1044	913	1206	281	588	15631	2954	404	2961	2369	440	29324	13000	4819	16287	1013	5020	-11885	57578
8 Other Manufacturing	5581	507	880	878	702	419	3347	48353	189	4996	12037	1664	79552	60047	5215	4454	2641	17187	-22923	146173
9 Electricity	289	450	1437	1098	672	1716	626	2547	5806	160	4055	167	19022	4999	732	109	8	107	-699	24278
10 Construction	156	5	211	103	0	0	0	0	822	8398	2839	0	12534	756	1914	28479	42	23	-1456	38291
11 Services	3349	866	479	1298	3436	1578	6220	13608	1523	4919	63368	8358	109001	127225	63383	5709	769	12091	-13620	308558
12 Recycling	168	674	609	1564	390	1291	2250	5662	161	779	1844	1169	16560	2385	-3337	283	22	0	-1813	14100
£1-12	14798	4852	5475	8183	18261	10509	34315	94211	10672	23921	92740	11915	329851	230629	74411	58837	4555	89772	-74913	714141
Remuneration	3746	1982	9242	4016	1496	4476	14070	24864	3589	8873	132266	1403	210024							
Gross Operating Surplus	11329	1941	7900	5478	3595	5230	7252	19950	9405	2306	61032	696	136112							
Net Indirect Taxes	1304	224	709	-10	1263	-10	3329	7102	612	3191	20353	85	38154							
Products Transferred From	76	0	0	2460	766	1852	7095	12214	0	0	6449	0	30911							
Products Transferred To	0	0	-1541	0	-3703	-734	-8483	-12108	0	0	-1283	0	-30911							
Gross Production	31253	9000	21784	20126	21678	21322	57578	146173	24278	38291	308558	14100	714141							

Source: CSS (1995).