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## Hazardous waste management in South African mining: a CGE analysis of the economic impacts

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# Kiel Working Papers

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**Hazardous Waste Management in South African Mining -  
A CGE Analysis of the Economic Impacts**

by

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## **Abstract**

There is no doubt that an improved hazardous waste management in mining and mineral processing will reduce environmental and health risks in South Africa. However, skeptics fear that waste reduction, appropriate treatment and disposal are not affordable within the current economic circumstances, neither from an economic nor from a social point of view. This paper mainly deals with the first aspect and touches upon the second. It investigates the short-run and long-run sectoral impacts of an environmental tax on hazardous waste in South African mining using an open-economy multisectoral general equilibrium model. The results bear out the expectation that the possibilities for shifting higher production costs are limited in an open economy. Moreover, the results show that the brunt of adjustment of an isolated approach towards hazardous waste management has to be borne by black workers.

**Key words:** Environmental management, mining and minerals processing, CGE analysis, South Africa

**JEL classification:** D58, Q2, O55

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## 1. Introduction

Mining activities, from exploration to extraction and processing, have recently come under increasing public scrutiny in South Africa as competition for environmental resources has intensified and the post-Apartheid government's attitude has shifted towards improved environmental quality and health (DME 1997: 51). However, for at least two reasons<sup>1</sup> a full internalization of negative externalities based on a careful study of abatement costs and damages is highly unlikely under the given circumstances.

First, the nature of environmental and health risks from mining makes them difficult to quantify and even more difficult to evaluate in monetary terms (Warhurst 1994: 13 ff.) For example, in coal and other mining operations, surrounding downwind areas, which are not owned by mining firms, are often subject to dust particles emanating from the mines. In addition, acid run-offs can pose hazards to mine workers, to fish and wildlife, and to consumers when they persist in water and food. Most of these risks are not immediately apparent to either producers or consumers and the nature of these risks varies widely among types of mineral being extracted, on whether mining is onshore or offshore, and on the methods and technologies of extraction used. The major form of environmental externalities in South African mineral extraction is solid waste generation (Table 1). The solid waste generated comprises mostly spoil and overburden which is regarded as relatively inert, and only potentially hazardous tailings and slags (DEA 1992a: 24f). These make up the bulk of the mining's solid waste stream, which in turn represents nearly 90 percent of the total South African waste stream. Only 0.007 percent of mining waste takes the form of air emissions, and only 0.4 percent is discharged with waste water. Air emissions are recorded only from the mining of platinum group metals. Although the quantity of waste discharged in waste water is small in comparison with the solid waste stream, the waste water stream is an important vehicle for hazardous

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<sup>1</sup> There are other reasons like market structure, absence of futures and risks markets and policy failures which may prevent a full internalization of environmental externalities in the mining sector (see Muzondo 1992: 5 ff.).

mining waste. As can be seen from Table 1, a small number of total waste streams in gold, platinum group metals, and antimony mining, and most of the waste in zinc refining have to be rated as hazardous with acid cyanide-containing goldmine effluents representing the largest hazardous waste stream in mining. However, it has to be kept in mind that environmental externalities in mining not only depend on the rates at which extraction takes place but also on the cumulative amounts of mineral ores already extracted. It is estimated that backlog in mining waste includes some 12 billion tons of overburden and depleted processed ores, and about 30 thousand tons semi-purified concentrates containing high concentration zinc, copper, cadmium or cobalt (DEA 1992a: 24 ff.). Thus, high environmental damages are incurred as a result of past and current mining activity.

Beside the problems associated with the measurement and evaluation of environmental damages, there is a second reason which prevents a full internalization of negative externalities in South African mining. While in many developed countries mining has been relegated to the status of an ugly old industry of little importance to the national wealth, the highly mineralized nature of many parts of South Africa has led to the creation of a mining industry which is quite important to the country's economy. Although the mining and quarrying industry accounted for only 8 percent of the country's GDP in 1995 primary mineral exports made up more than 40 percent of total export earnings. If the value of processed mineral products such as refined base metals, ferroalloys, iron and steel, and refinery products produced from coal were included, about 60 percent of South African export revenue would have come from mineral-based products. Moreover, the mining sector alone employed more than 4 percent of the country's total economically active population, most of them black workers (Scott 1997). Finally, given the strong regional concentration of extraction activities (DEA 1992a), on the one hand, and strong backward and forward industry linkages, on the other, the mining industry provides a strong impetus for both, regional and local economic development as well as upstream industries in the manufacturing and services sector and downstream industries in the metallurgical, engineering and durable consumer goods fields (Scott 1998). Giving up promising mining prospects for the sake of environmental purity is hence regarded as out of the question in South Africa (Wells et al. 1996).

Table 1 - Mining and industrial waste in South Africa, 1990/91 (Thousand tons per annum)<sup>a</sup>

Sector	Air emissions	Waste water	Solid/liquid waste	Total	Thereof:		
					Hazardous waste <sup>d</sup>	Potentially hazardous waste	Non-hazardous waste
1. Agriculture <sup>b</sup>	-	-	-	-	-	-	-
2. Coal mining	-	-	45,600	45,600	-	34,200	11,400
3. Gold mining	-	1,538	190,188	191,726	1,013	531	190,181
4. Other mining, of which	27	18	139,268	139,313	46	41	139,226
- Platinum group metals	27	18	45,137	45,182	18	28	45,136
- Phosphate	-	-	10,920	10,920	-	-	10,920
- Base metal	-	-	59,600	59,600	-	-	59,600
- Zinc	-	-	41	41	28	14	0
- Antimony	-	0	420	420	-	-	420
- Diamonds	-	-	23,000	23,000	-	-	23,000
- Asbestos	-	-	150	150	-	-	150
Total mining	27	1,556	375,056	376,639	1,059	34,773	340,807
5. Metallurgical and metals industries <sup>c</sup>	13	16	4,872	4,902	335	4,567	-
6. Non-metallurgical manufacturing industries	323	602	14,448	15,373	452	4,772	10,149
7. Services <sup>c</sup>	1,609	7	20,275	21,891	47	1,654	20,190
Total economy	1,972	2,182	414,651	418,805	1,893	45,766	371,147

<sup>a</sup>Excluding carbon dioxide emissions and sediments from waste water. - <sup>b</sup>Agriculture is not included in the survey. -

<sup>c</sup>Includes power generation. - <sup>d</sup>Includes highly, moderately and low hazardous waste.

Highly hazardous waste: contains significant concentrations of highly toxic constituents which are easily accessible, mobile, persistent in the environment and bio-accumulative;

Moderately hazardous waste: is highly explosive, flammable, corrosive or reactive, or is infective, or contains significant concentrations of constituents that are potentially highly toxic but only moderately mobile, persistent or bio-accumulative, or that are moderately toxic but are highly mobile, or persistent in the environment, or bio-accumulative;

Low hazardous waste: is moderately explosive, flammable, corrosive or reactive, or contains significant concentrations of constituents that are potentially highly harmful to human health or the environment.

Potentially hazardous waste: often occurs in large quantities, and contains potentially harmful constituents in concentrations that in most instances would represent only a limited threat to human health or the environment.

Source: DEA (1992a).

Given these caveats, this paper analyzes the economic impact of an environmental tax on hazardous mining waste in South Africa. There is now a consensus in the economic discussion that environmental objectives can be realized efficiently via price signals. Appropriate „eco-taxes“, whereby polluters are charged equal to their hazardous waste treatment costs allow the realization of any technologically possible environmental objective at minimum social costs. The analysis is based on a study by the Department of Environment Affairs on *Hazardous Waste in South Africa* which among others estimates hazardous and non-hazardous waste streams for different sectors (DEA 1992a) and assesses the economic impact of alternative policies towards hazardous waste management (DEA 1992b). This assessment is strongly based on a criterion of affordability. Thus, input-output-analyses were conducted to calculate the price-raising effects of alternative waste management policies (avoidance and technology standards). The analysis shows that the implementation of, e.g., best available technologies for controlling highly hazardous waste in all sectors of the South African economy - not just mining - would raise average prices by almost 4.5 percent, with the highest price increase realized in the paints and coatings sector whereas the price increase is lowest in mining (DEA 1992b: 70).

While being informative because the price effects calculated reflect cost-push effects as a result of the interindustry linkages, the model results of the DEA-study can not be used to evaluate the economic impacts of an enhanced waste management in South Africa since important structural and macroeconomic impacts are neglected. These economic impacts may be clustered along the following three categories:

- The environmental tax on hazardous mining waste will lead to an adjustment of factor demand and final demand and, therefore, to an environmentally more sound use of natural resources.
- Closely connected with the environmental impacts are the economic impacts of the environmental tax. Higher costs for waste management lead to changes in macroeconomic aggregates which have to be included in the analysis. Income and substitution effects will change the international competitiveness of individual sectors as well as the sectoral structure of the economy.



- The taxation of hazardous mining waste will yield higher tax revenues the use of which has to be included in the analysis.

In order to analyze these impacts a computable general equilibrium model is used. The general equilibrium framework makes it possible to capture explicitly all the major linkages between mining and mineral processing sectors and between them and the rest of the economy which are the driving forces behind the intersectoral allocation effects. It will be shown that both, factor price and foreign exchange effects are crucial in determining the final resource pull effects of an environmental tax. Missing any one of these effects can lead to misleading conclusions and wrong or inadequate policy recommendations.

The remainder of this paper is organized as follows. Section 2 gives a non-mathematical overview on the model used. In section 3, the most important structural features of the South African economy are discussed first and then some hypotheses on the sectoral impacts of an environmental tax on mining waste are derived. Subsequently, general equilibrium analysis is applied to identify factors which account for the short-run and long-run structural changes. Finally, in section 4, major results are summarized.

## **2. A General Equilibrium Model of South Africa**

Because the focus is on mining and mineral processing, the multi-sectoral, general equilibrium model gives emphasis to these sectors and their linkages to each other as well as to other broad groups of production sectors. Twelve sectors are distinguished, three mining sectors, seven manufacturing sectors, one *services* sector and one *agriculture* sector. A sectoral distinction is made in mining between three major mining sectors, *coal mining*, *gold mining*, and an aggregated sector *other mining* which is dominated by platinum group metals. In manufacturing *petroleum & coal products*, *base metal production*, and *fabricated metal & machinery* are separated from *other manufacturing* owing to the supposedly strong direct backward (forward) linkages to mining (all sectors) of the former (latter) sectors (see Appendix Table A3). The other sectors of the model are *electricity*, *construction*, and *recycling*.

A SAM for 1993, the base period of the study, has been constructed that integrates *national income, input-output, flow-of-funds, and balance-of-payments current accounts* into a comprehensive and consistent data set. The SAM and its components are presented in Appendix Tables A1 to A4. It is assumed to represent the initial (benchmark) equilibrium position of the South African economy and provides numerical values to several parameters of the analytical model.

The analytical model used belongs to a class of open-economy models developed by Dervis et al. (1982). One distinguishing characteristic of these models is the fairly firm rooting in microeconomic theory: Producers minimize costs subject to certain technology constraints, prices for outputs and inputs, and tax rates, while consumers maximize utility subject to a budget constraint. In our case the taxes on hazardous mining waste are the most important ones. The general mathematical structure of the model is described in Thiele (1998). The essential features of the model used here are the following:

- The production function is a combination of Cobb-Douglas for primary inputs (capital and two labor categories) and Leontief for secondary inputs. This implies that there are no substitution possibilities between primary and secondary inputs. Moreover, there is no possibility to substitute between individual secondary inputs.
- Domestic consumers have constant-elasticity-of-substitution (CES) utility functions over imports and domestically produced goods. Assuming that they minimize the cost of acquiring a given amount of a composite good, the demands for domestically produced goods and imperfect imported substitutes become derived demands. This leads to the import and domestic prices diverging, something which is crucial to the results derived below.
- On the export side, some domestic producers have constant-elasticity-of-transformation (CET) production possibility functions over exports and domestically sold goods. Under the assumption that they maximize revenues from exports and domestic supply, the production of export goods and goods for the domestic market also become derived supplies. Moreover, product differentiation between domestic tradables and imperfect foreign substitutes by world consumers is reflected in a down-

ward-sloping foreign demand curve for some domestically produced exports in the single country model.

- Capital is assumed to be fixed and sector-specific in the short-run but intersectorally mobile in the long-run. As a result, sectoral rental rates differ in the short-run but adjust to the economy-wide average rental rate in the long-run. There are two labor groups (black and others) both of which are mobile across sectors in the short-run as well as in the long-run. This means essentially that workers in each group receive the same wage in each sector.
- The level of savings abroad (the observable current account surplus in 1993) is assumed to be exogenous, while the exchange rate is determined endogenously. The level of investment is determined endogenously by the level of savings in the economy, the latter being the sum of private and public domestic savings with public savings including tax revenues from the environmental tax on hazardous mining waste.
- The GDP-deflator is held constant. The model focuses entirely on the real sector with money regarded as a „veil“ along traditional classical lines. This means that all real variables depend only on relative prices.

### **3. Impact Assessment of Hazardous Waste Management in Mining**

The model outlined above is the basis for the analysis of environmental taxes on hazardous mining waste. Lacking appropriate damage functions for the three mining sectors, the tax rates for the base solution were calculated from DEA-estimates on current waste treatment costs and estimates on the costs of best available waste treatment technology (BAT) were used to simulate increases in environmental taxes. DEA estimates that currently, total cost for hazardous waste treatment in South Africa average about 3.75 percent (DEA 1992b: 112). Of these, only 10 percent are involved with highly hazardous waste. The implementation of BAT is assumed to increase waste treatment costs eight-fold. This information is used in the model in the form of a tax-multiplier of 8. Thus, the environmental tax rates for the three mining sectors are increased from 0.375 percent in the base solution to 3.0 percent in the „counterfactual“.

The impact of general equilibrium effects is measured by comparing the changes in sectoral output, exports, imports, and domestic supply with changes of different domestic price vectors obtained as a counterfactual equilibrium. In investigating the economy-wide effects of the eco-taxes, an initial situation of static equilibrium for the South African economy is assumed which replicates the observed conditions in 1993 exactly, i.e. the model equations are satisfied.

### *3.1 Sectoral Characteristics of the South African Economy*

The data base is presented in Appendix Tables A1 to A4. Table 2 provides a summary of the most important structural features of the economy together with the crucial elasticities for determining the results of policy simulations. The first column shows that mining and mineral processing account for over 20 percent of total output.<sup>2</sup> Hence, significant economy-wide consequences are to be expected from any policy directed towards these sectors. 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 gold mining, indicate small backward linkages. By contrast, petroleum & coal products, construction, and recycling exhibit the lowest value-added ratios suggesting high backward linkages. The next three columns provide information about each sector's trade orientation. Mining sectors and base metal production are by far the most export-oriented sectors. Mining alone contributes about 46 percent to overall export earnings. If base metal products are included the export share is roughly 60 percent. In terms of exports mineral activities are thus even more important for the South African 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 sectoral intermediate inputs (indicating the degree of import „dependence“)

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<sup>2</sup> The three mining sectors account for roughly 9 percent of GDP at factor costs. The sectoral composition of GDP at factor costs of each sector can be computed as the sectoral share in gross output times the sectoral per-unit value added divided by the average per-unit value added.

Table 2 - Structure of the South African economy in the base solution (1993)

Sector	Sectoral composition of gross output	Value added per unit of output	share of exports in output	share of imports in absorption	share of imports in total intermediate inputs	share of final demand in absorption	supply elasticity	transformation elasticity	substitution elasticity	export demand elasticity
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Agriculture	4.4	48.2	5.9	6.0	12.8	0.36	0.33	-	4.00	∞
2. Coal mining	1.3	43.6	44.0	24.2	14.2	0.59	1.02	-	3.00	3.00
3. Gold mining	3.1	78.7	99.7	94.7	10.9	0.96	1.17	-	3.00	3.00
4. Other mining	2.8	47.2	68.0	26.5	15.5	0.66	0.73	-	3.00	3.00
5. Petroleum & coal products	3.0	23.5	8.9	37.4	24.4	0.43	0.42	2.90	3.00	∞
6. Base metal products	3.0	45.5	57.4	28.2	15.1	0.56	0.86	2.90	0.66	3.00
7. Fabr. metals & machinery	8.1	37.0	8.7	18.4	13.5	0.58	1.94	2.90	0.50	3.00
8. Other manufacturing	20.5	30.7	11.8	15.1	7.6	0.53	1.25	2.90	1.50	3.00
9. Electricity	3.4	53.5	0.0	2.8	8.8	0.24	0.38	0.70	0.50	∞
10. Construction	5.4	29.2	0.0	3.7	8.6	0.68	3.85	0.70	0.50	∞
11. Services	43.2	62.7	3.9	4.3	10.8	0.66	2.17	0.70	0.50	∞
12. Recycling	2.0	14.9	-	11.4	10.4	0.04	2.02	-	0.50	-
Sum /Average	100.0	48.5	12.6	10.7	12.8	0.58				

Source: Calculated from Appendix Table A2 and „guestimates“ (see text).

have to be considered. While import dependence appears to be fairly uniform across sectors, import orientation ranges from very low for less tradable goods from sectors like electricity, construction and services to an import share of over one third for petroleum & coal products.<sup>3</sup>

The last five columns give the crucial elasticities for determining the results of policy simulations generated by the model. Because production technology for sectoral value added is modeled by Cobb-Douglas production functions, the share observations obtained in the benchmark equilibrium data set provide us with a set of short-run labor demand and output supply elasticities. Given this technology specification, short-run price elasticities of supply are the highest in labor-intensive sectors with a large share of labor value added in total value added such as construction, services, recycling, and fabricated metals & machinery. Column (6) indicates the share of final demand in sectoral absorption and therefore gives an approximation of the price elasticity of demand. Thus, composite good price elasticities of demand are absolutely highest for sectors with close proximity to final demand. The foreign trade elasticities given in the last three columns roughly capture the extent of product differentiation due to differences in quality and degree of product heterogeneity. Lacking sector-specific foreign trade elasticities for South Africa, these elasticities represent what we believe to be „best guestimates“ given the peculiarities of the different sectors:

The problem to differentiate in domestic production between domestic supply and export supply exists only in the manufacturing sectors (because here, export-oriented sectors are lumped together with sectors which deliver mostly to the domestic market) and in the services sectors (because here, exports cover only a minor fraction of total production). Faini (1988) estimated a transformation elasticity of 2.9 with a standard error of 1.3 for a bundle of manufactured final goods in Turkey. This figure has been used as a central estimate for all manufacturing sectors (sectors 5-8). For traded services, elec-

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<sup>3</sup> The high import share for gold mining is misleading because domestic absorption in this sector is extremely low.

tricity, and construction, it was assumed that domestically sold and exported goods are less homogeneous and, therefore, the transformation elasticity is only 0.7.

Recycling is the only sector which exhibits no exports. Thus, no export demand elasticity needs to be estimated. By contrast, exports of manufactured products from South Africa compete with domestic supply on foreign markets - just in the same way as foreign supply competes with domestic supply on South African markets. In a single-country model, this implies a price elastic export demand for these products. Agricultural and mining products are relatively homogeneous. Insofar, the assumption of a perfectly elastic export demand function would be appropriate. However, South Africa was the world's largest gold exporter in 1993, ranked third in world coal exports after Australia and the United States, and is a major exporter of other mineral commodities implying that the small country assumption is hardly justifiable for these commodities. For all mining sectors, a decreasing export demand function has therefore been assumed. For agriculture, petroleum & coal products, electricity, construction, and services an infinitely elastic export demand function has been modeled because South Africa covers only a marginal share of world imports of these goods. In these sectors, export supply is either determined at exogenously given prices as the difference between domestic production and domestic demand (agriculture) or by the price elastic export supply (petroleum & coal products, electricity, construction, services). Lacking econometric estimates of export demand elasticities, uniform elasticities of -3.0 have been assumed for all sectors with price responsive export demand.

There are also no econometric estimates of sector-specific substitution elasticities for domestic supply and imports for South Africa. Therefore, the medium estimates used by Dervis et al. (1982) for the analysis of adjustment problems in Turkey are used here, too. It has to be noticed that we assume identical substitution possibilities for all categories of demand, i.e. intermediate demand and the different final demand categories.

### *3.2 Allocational Impact of Hazardous Waste Management in Mining*

We can now use our fully specified numerical model to examine the effects of an improved hazardous waste management in South African mining. The improvements in hazardous waste management are modeled as an environmental tax on hazardous waste

streams with the tax revenues used to finance advanced waste treatment technologies. Because we are primarily interested in the impact on resource allocation, emphasis will be given to a discussion on how and why individual sectors are affected differently. Moreover, the discussion will focus on the short-run effects with sector-specific capital whereas the long-run effects will be discussed only briefly.

A tax on hazardous waste in mining sectors initially increases production costs thereby driving a wedge between the domestic price of mineral commodities and the price of imported substitutes. This will induce domestic users to change their composition of the composite good, thereby reducing the demand on the domestically produced good and causing countervailing downward pressure on domestic prices. The resulting change in domestic prices depends on the cross-price elasticity of demand for the domestic good, which itself depends on the price elasticity of demand for the composite good and the elasticity of substitution in use between the domestically produced and foreign goods. Increasing prices will, *ceteris paribus*, lead to a large reduction in demand for domestically produced mineral commodities

- if it is easy to substitute them by imports (as indicated by high substitution elasticities);
- if the sectoral import share (import orientation) is low (implying that large quantities of the more expensive domestic good can be substituted by relatively small expansions of cheaper imports);
- if the demand for the composite good is relatively elastic with respect to the composite price (reflecting the minor importance of these goods as intermediates in domestic production).

Moreover, the adjustment of relative prices also depends on production characteristics as indicated by the elasticity of domestic supply. Low supply elasticities imply large reductions of the domestic price in the case of small shifts of the demand curve. Finally, export demand is also important in determining the final price effects of higher waste treatment and disposal costs, especially when the export share is large. The higher the elasticity of export demand, the smaller will be the domestic price change resulting from higher production costs. Higher production costs will lead to a fall in exports as domes-



tic output is withdrawn from foreign markets towards domestic use. The easier this substitution process, the smaller will be the price increase.

Returning to Table 2, from the demand characteristics of the mineral markets one would not expect large price increases in response to an environmental tax. All mining sectors exhibit high substitution elasticities and relatively high composite good demand elasticities. With the exception of gold mining, all sectors also have low import shares. Together, these characteristics imply large shifts of domestic demand towards imported substitutes and, therefore, downward pressure on domestic prices. Moreover, the shifting of additional costs to consumers is also limited by adjustments in export demand. Higher costs of production lead to higher export prices. At a given exchange rate exports will fall as export prices rise. This leads to an outward shift of the supply curve of the domestic good for domestic use following the decline in demand for exports. As a result, the net effect of the environmental tax on domestic mineral prices will be less than it would have been if there had been no feedback via the demand for exports.

These are the direct effects determining the initial domestic output price response of internalizing hazardous waste treatment and disposal costs. In order to estimate the final resource shifts in the economy, we must also take into account the economy-wide effects:

- First, there are the effects on investment demand resulting from the demand for waste treatment and disposal technology. Under the assumption that the composition of this technology is identical to the economy-wide capital composition the resulting investment demand will lead primarily to additional demand for fabricated metal & machinery and construction which together cover 76 percent of investment demand in the base solution (see Table A2 in Appendix). Thus, these two sectors are expected to expand their output and to attract additional labor from other sectors.
- Secondly, there are the effects on intermediate input costs. Other things being equal, those sectors with strong backward linkages to mining sectors are penalized the most. As can be seen from the input coefficients (see Appendix Table A3), mineral secondary inputs are generally not very important. The exception is petroleum & coal products where other minerals cover over one third of all secondary inputs. Obvi-

ously, an environmental tax on hazardous mining waste will not affect other sectors' intermediate production costs drastically.

- There is a relatively strong wage effect that will have a differential impact across sectors, depending on differences in relative factor intensities. Due to the environmental tax on hazardous mining waste, the average wage decreases by 0.4 percent, with wages for black and other employees decreasing by 0.5 percent and 0.3 percent respectively. This is because the environmental tax has a strong impact on economic structure. In general, higher environmental taxes decrease domestic wages. Since mining sectors are relatively intensive in the use of black labor (see Appendix Table A4) , black labor's wage rate decreases the most. Other labor which is intensively used in the manufacturing and services sectors is also released from the above-mentioned sectors, thereby decreasing other labor's wage rate.
- There is also a relatively strong exchange rate effect. Higher prices for domestically produced minerals will induce a shift towards imports and a reduction of export demand thereby causing a balance-of-trade deficit. In order to eliminate the trade deficit the Rand has to depreciate which will stimulate exports and restrict imports. Sensitivity analysis showed that the exchange rate response increases with decreasing trade elasticities. This is so because the rise in domestic export prices and import prices needed to stimulate exports and restrict imports in order to eliminate the balance-of-trade deficit is greater, the lower the export demand, substitution and the transformation elasticities. In the environmental tax simulation, the Rand depreciates by 0.7 percent.
- There are income effects associated with changes in the foreign terms of trade. However, the environmental tax on hazardous mining waste in South Africa improves the terms of trade only slightly.

These effects are reflected in Table 3, which reports the impacts on sectoral resource allocation, exports and imports. The results in the first seven columns have been derived under the assumption of fix sectoral capital stocks; they may be viewed as the

Table 3 - Sectoral impacts of hazardous waste management in South Africa<sup>a</sup>

Sector of the model	short-run (fixed sectoral capital stock)							long-run (capital intersectorally mobile)			
	X	p <sup>d</sup>	P <sup>v</sup>	R	E	M	D	X	E	M	D
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1. Agriculture	0.3	0.3	0.5	0.9	4.1	-1.5	0.1	1.8	16.4	-4.7	0.9
2. Coal mining	-2.6	2.1	-2.9	-2.5	-3.5	2.3	-1.9	-4.2	-5.7	3.8	-3.0
3. Gold mining	-2.2	1.4	-2.3	-1.9	-2.2	-0.4	-2.5	-5.2	-5.2	-0.9	-5.9
4. Other mining	-1.8	1.5	-2.8	-2.4	-2.2	1.6	-0.9	-4.4	-5.2	3.9	-2.4
5. Petroleum & coal products	0.2	0.5	0.1	0.4	0.7	-0.5	0.1	0.2	0.7	-0.6	0.1
6. Base metal products	0.7	0.3	0.5	0.9	0.8	0.4	0.6	2.2	2.9	0.4	1.4
7. Fabr. metals & machinery	0.6	0.0	-0.1	0.3	1.2	0.2	0.5	0.8	2.3	-0.0	0.6
8. Other manufacturing	0.3	-0.0	-0.1	0.3	1.1	-0.9	0.2	0.8	2.3	-1.4	0.6
9. Electricity	-0.2	-0.4	-0.7	-0.4	0.6	-0.7	-0.2	-0.4	0.4	-1.0	-0.4
10. Construction	1.3	0.0	-0.0	0.4	1.8	1.0	1.3	1.5	2.4	0.9	1.5
11. Services	0.1	-0.3	-0.3	0.0	0.7	-0.4	0.1	0.2	1.2	-0.6	0.1
12. Recycling	-0.1	-0.2	-0.4	-0.0	-	-0.5	-0.1	-0.2	-	-0.9	-0.2

<sup>a</sup>Percentage changes over initial solution; X is the gross domestic production, E is exports, M is imports, and D is domestically demanded domestic production; p<sup>d</sup> stands for the domestic output price, P<sup>v</sup> for unit value-added, i.e. factor enumeration per unit of output, and R for unit profit.

Source: Own computations from the South Africa CGE model.

short-run response of the South African economy to an enhanced hazardous waste management in mining. Columns (8) - (11) provide long-run results with capital being intersectorally mobile.

In general, the results bear out the expectation that an environmental tax on hazardous mining waste produces large indirect effects, and that the changes in relative prices create significant incentives to alter the resource allocation and the sectoral composition of foreign trade. As can be seen, electricity and recycling are the only sectors besides mining which contract outputs in the short-run. In the mining sectors this can be traced back to the direct effect of higher prices and the resulting decrease in both, domestic and export demand. By contrast, construction and, to a much lesser extent, base metal products and fabricated metals & machinery are seen to benefit most from the indirect effects. As indicated above, construction and fabricated metals & machinery dominate the production of investment goods and, therefore, benefit from the demand for improved waste treatment and disposal technology. For all other sectors, the impact on factor use, output and exports and imports is less clear.

What then determines the impact on resource allocation of environmental taxes in mining? In order to provide an answer to this question suppose first, we wish to predict output responses to the environmental tax on the basis of price information. Starting with the domestic output prices, one can check by comparing columns (1) and (2), whether price changes and output changes have the same sign. They do only in seven of the twelve sectors. In this case, it is necessary to examine, first, the change in per-unit value added which includes changes in intermediate input costs and, in the mining sectors, changes in environmental taxes.<sup>4</sup> Turning to a comparison of the direction of per unit value-added changes (column 3) and output changes eight price changes now correspond with output response. Generally, the per unit-value-added is lower than the output price due to higher intermediate input costs. However, except in the mining sectors where the environmental tax drives an additional wedge between output price and per

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<sup>4</sup> It is assumed that the environmental tax is initially paid by producers and shifted to consumers via higher prices.

unit value-added, the structure of changes of both indicators is nearly the same. This result can be explained by relatively low input requirements from mining in each of these sectors. In agriculture and in base metal products, lower secondary input costs for services in the former and lower secondary input costs for electricity, services and recycling in the latter outweigh rising costs for other secondary inputs. As a result the per unit value-added in these sectors increases even stronger than the output price. However, intermediate input costs effects brought about by interindustry linkages are generally not substantial and, therefore, do not drastically change the ranking of sectors if compared with the ranking by output price changes. Thus, the ranking by changes in per unit value-added still differs from the ranking by output changes. One can, therefore, conclude that neither output price changes nor changes in per unit value-added are good indicators of short-run resource pulls in general equilibrium. As can be seen by comparing per unit value-added changes in column (3) with per unit profit changes in column (4), wage effects are large enough to outweigh product price effects in four of the twelve sectors. Per-unit profits decrease in only five sectors as a result of the environmental tax. In all other sectors the adjustment costs of hazardous waste management can be shifted to labor and output can be expanded.

The sectoral changes in real import demand are generally less pronounced than the changes in sectoral output. On the one hand, these changes are determined by changes in domestic demand for the composite (imported and domestically produced) good. On the other hand, changes in import demand are determined by changes in the relative price of the imported good and the domestically produced substitute as well as their substitution elasticity. It has already been mentioned above that the environmental tax on hazardous mining waste leads to a devaluation of the Rand by 0.7 percent. This implies that the relative price between domestically produced and imported goods has fallen in all sectors except the mining sectors. It is, therefore, not surprising that there is a restructuring of domestic composite demand towards imports in the mining sectors and towards domestically produced goods in most other sectors (see columns (6) and (7)). In gold mining, base metal products, fabricated metals & machinery, and in construction, changes in domestic demand for the composite good overcompensate the substitution effect. As a result, import demand for gold decreases despite an increase in the relative

price for domestically produced gold because of the large reduction in overall demand for gold. In the other three cases, import demand increases because of the overall increase of demand for these goods. Generally, the restructuring is most pronounced in the primary sectors where substitution elasticities are much higher than in the rest of the economy.

The changes in exports reflect changes in domestic output prices caused by changes in domestic production costs. In general, sectors with decreasing domestic prices expand their exports and vice versa with the export response determined by the elasticities of export supply and export demand. This is best exemplified in the mining sectors where export demand decreases between 2.2 and 3.5 percent as a result of environmental taxes on hazardous waste. Given uniform export demand elasticities in all mining sectors, the extent of export reduction is solely attributable to different changes in domestic output prices. The export expansion is largest in agriculture (4.1 percent) and construction (1.8 percent). Both sectors are primarily inward-oriented, i.e. having low import and export shares (see Table 2) and both face a perfectly elastic export demand. Export supply in agriculture is determined by domestic supply and demand conditions. Thus, a relatively large increase in agricultural production combined with a relatively small increase of domestic demand causes a relatively high expansion of exports. In construction, the export supply response is restricted by a low export transformation elasticity of 0.7. However, the high labor intensity of the sector causes a strong output response as the sectoral production wage decreases and - despite a small change in the relative price between exports<sup>5</sup> and domestic goods - induces a large export response, although from a very low initial level. In all other sectors exports increase, too, as the depreciation of the Rand improves the competitiveness of South African exports on the world market.

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<sup>5</sup> At given world market prices, the change in the relative price for exports and domestic supply is given by the change in the exchange rate (0.7 percent) minus the change in output price as indicated in column (2).

These short-run results of enhanced hazardous waste management in mining have been derived under the assumption of sectorally fixed capital stocks. In the long-run, the short-run differences in sectoral profit rates will lead to a reallocation of capital and labor from sectors with lower than average profit rates to those with above-average profit rates. The results of this factor reallocation are shown in columns (8) - (11) of Table 3. Generally, these results bear out the expectation that the quantity responses are larger if beside labor capital is also mobile across sectors. Yet, they are less pronounced in labor intensive sectors, as might be expected.

#### **4. Summary and Conclusions**

This paper has addressed specific questions within the much broader discussion on environmental policies towards mining in South Africa (DEA 1992a, b; DME 1997; Wiebelt 1998). The short-run and long-run impacts of environmental taxes on hazardous mining waste on resource allocation and sectoral foreign trade in South Africa have been analyzed numerically using a computable general equilibrium model of an open economy. It has been shown that environmental taxes on hazardous mining waste change the structure of relative prices thereby inducing substitution processes in production, consumption, and foreign trade. These substitution processes are determined by several parameters. Most importantly, the extent of international competition in affected industries will determine the scope for shifting tax payments to forward and backward related sectors.

After the abolishment of sanctions in the post-Apartheid era the Republic of South Africa is exposed to stiff competition on commodity markets from abroad. This implies that domestic production factors, particularly labor, remain as the sole destination for tax shifting. In this context, environmental taxes can be shifted only in two ways: either wages must decrease or labor employment is reduced to the extent that labor's marginal product equals the real wage, i.e. unemployment is increased. Given the full-employment assumption in the model simulations real wages decrease as a result of environmental taxes in mining activities. Moreover, since mining sectors are relative intensive in black labor employment, black employees have to bear the brunt of adjustment.

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Appendix Table A1 — 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	71455	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: Thiele (1998).

Appendix Table A2 — South African Input-Output Table, 1993 (Million Rand)

	1	2	3	4	5	6	7	8	9	10	11	12	Σ 1-12	Private Consumption	Government Consumption	Fixed Investment	Inventories	Exports	Imports	Gross Production
1 Agriculture	3146	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	822	8398	2839	0	12534	756	1914	28479	42	23	-1456	38291	
11 Services	3349	866	479	1298	3436	1578	6220	16945	1523	4919	63368	8358	109001	127225	60046	5709	769	12091	-13620	308558
12 Recycling	168	674	609	1564	390	1291	2250	2325	161	779	1844	1169	16560	2385	0	283	22	0	-1813	14100
Σ 1-12	14798	4852	5475	8183	18261	10509	34315	94211	10672	23921	92740	11915	329851	230629	75411	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	-4283	0	-30911							
Gross Production	31253	9000	21784	20126	21678	21322	57578	146173	24278	38291	308558	14100	714141							

Source: Thiele (1998).

Appendix Table A3 - Input-Output - Coefficients

Sector	Agriculture	Coal mining	Gold mining	Other mining	Petroleum / coal products	Base metal products	Fabr. metals & machinery	Other manufacturing	Electricity	Construction	Services	Recycling
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1. Agriculture	.100675	.001721	.000559	.000152	.000359	.000171	.000879	.118300	.000628	.000116	.001844	.000000
2. Coal mining	.000017	.104148	.000273	.003366	.043076	.024588	.000070	.001846	.060996	.000060	.000303	.000000
3. Gold mining	.000000	.000000	.035699	.000000	.000000	.000000	.000000	.000411	.000000	.000000	.000000	.000000
4. Other mining	.001142	.000342	.000778	.067583	.188665	.032875	.001215	.006911	.000006	.008311	.000144	.000000
5. Petroleum / coal products	.048060	.004814	.036896	.027198	.355202	.011504	.007039	.011585	.007618	.021247	.017374	.008319
6. Base metal products	.001155	.001574	.001839	.002848	.002313	.161466	.099167	.005206	.003569	.014880	.000522	.000000
7. Fabr. metals & machinery	.017101	.115985	.041896	.059922	.012951	.027556	.271482	.020210	.016623	.077329	.007677	.031211
8. Other manufacturing	.178565	.056342	.040382	.043620	.032358	.019652	.058135	.330793	.007768	.130460	.039012	.118027
9. Electricity	.009258	.049969	.065940	.054560	.030979	.080499	.010872	.017422	.239137	.004184	.013141	.011838
10. Construction	.004989	.000532	.009667	.005126	.000000	.000000	.000000	.000000	.033868	.219328	.009201	.000000
11. Services	.107160	.096239	.021974	.064511	.158483	.074003	.108029	.115921	.062731	.128448	.205367	.592795
12. Recycling	.005377	.074901	.027953	.077712	.017970	.060555	.039080	.015907	.006618	.020335	.005977	.082883

Source: Computed from Appendix Table A2.

Appendix Table A4 — 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

Note: Sectoral income is distributed among black and other households according to the shares shown in the 1988 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.

Source: Thiele (1998).