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Tax Policy to Reduce Carbon Emissions in South Africa

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Abstract

Noting that South Africa may be one of the few African countries that could contribute to mitigating climate change, the authors explore the impact of a carbon tax relative to alternative energy taxes on economic welfare. Using a disaggregate general-equilibrium model of the South African economy, they capture the structural characteristics of the energy sector, linking a supply mix that is heavily skewed toward coal to energy use by different sectors and hence their carbon content. The authors consider a "pure" carbon tax as well as various proxy taxes such as those on energy or energy-intensive sectors like transport and basic metals, all of which achieve the same level of carbon reduction. In general, the more targeted the tax to carbon emissions, the better the welfare results. If a carbon tax is feasible, it will have the least marginal cost of abatement by a substantial amount when compared to alternative tax instruments. If a carbon tax is not feasible, a sales tax on energy inputs is the next best option. Moreover, labor market distortions such as labor market segmentation or unemployment will likely dominate the welfare and equity implications of a carbon tax for South Africa. This being the case, if South Africa were able to remove some of the distortions in the labor market, the cost of carbon taxation would be negligible. In short, the discussion of carbon taxation in South Africa can focus on considerations other than the economic welfare costs, which are likely to be quite low.

This paper—a product of the Sustainable Development Department and the Chief Economist Office, Africa Region—is part of a larger World Bank program of analytical work to develop country cases and to underpin the Africa Region's climate change strategy. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at dgo@worldbank.org.

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I. Introduction

For at least three reasons, Sub-Saharan Africa's response to climate change has concentrated on adapting to its adverse effects rather than mitigating further increase in greenhouse gases. First, all of Africa contributes less than 4 percent of global greenhouse gas emissions, so mitigation will not have major effects on climate change. Second, the stock of greenhouse gases in the atmosphere today is the result of emissions by rich countries. There is little reason why the world's poorest continent should now curtail its greenhouse gas emissions to compensate for these past excesses. Third, mitigation policies are costly and difficult to implement. Not only will they impose a cost on industries such as energy and transport that emit CO_2, the major greenhouse gas, but also, levying a carbon tax or limiting carbon emissions will require credible and effective institutions, which are arguably in short supply in Sub-Saharan Africa.

A possible exception may be South Africa. A middle-income country that produces 65 percent of Africa's and 1.5 percent of the world's carbon dioxide emissions[3] as a by-product of its extensive energy production and usage, South Africa has both higher levels of emissions and the capacity to tackle emissions of greenhouse gases. As an active participant in the Kyoto and Poznam processes, South Africa is also committed to mitigating climate change and has recently developed a Long-term Mitigation Scenario (see, for example, Winkler (2008)). Although all countries have the right to exploit their own natural resources, international environmental law and global citizenship require that countries contribute to alleviating climate change. Moreover, there is a policy risk associated with avoiding mitigation—when a carbon price does emerge from climate negotiations, there is a risk that South Africa will end up with stranded assets in the form of dirty coal-burning generators. Nevertheless, there are some questions about possible mitigation measures. The debate between a carbon tax and a cap-and-trade program will need to compare alternative taxes not only in terms of the welfare and economic impact, but also the capacity to recycle tax revenue to achieve further reform, and the impact on equity and the poor. To economize on institutions, the consensus seems to be in favor of a carbon tax rather than more complex cap-and-trade programs (Aldy et al. (2008), Summers (2007), Zedillo (2008)). But in the absence of a worldwide agreement, how high should the tax be? In principle, the tax should be set so that the marginal cost of carbon emissions equals the marginal benefit of the reduced greenhouse gases. Since the latter is still the subject of debate and analysis, there is little guidance on the appropriate level of the tax and very little information about its possible economic and welfare impact. Furthermore, South Africa currently has no carbon tax.[4] It may instead have to tax carbon-intensive products such as energy and transport, which would impose costs on the economy. Finally, even a pure carbon tax would be passed forward into the various

[3] World Development Indicators (WDI), 2008. The primary sources of information are the International Energy Agency (IEA)'s annual publications, *Energy Statistics and Balances of Non-OECD Countries* on energy use; and the U.S. Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) on CO_2 emissions. See also footnote 5.

[4] However, South Africa is one of the first developing countries to announce a partial carbon tax--2 cent/kWh on electricity from fossil fuels.

prices of energy (e.g., coal, natural gas, petroleum products) and embodied in the price of electricity, possibly hurting South Africa's competitiveness abroad and employment at home.

In this paper, we explore the implications of using tax policy to mitigate CO_2 emissions in South Africa under alternative scenarios. Using a general-equilibrium model of the South African economy, we simulate a "pure" carbon tax as well as various proxy taxes on commodities such as energy and energy-intensive sectors all of which are set to achieve the same level of carbon reduction. By energy, we mean energy inputs (such as coal, petroleum, and electricity) utilized in production by each sector. By carbon emissions, we mean fossil fuel emissions and not emissions from land-use change and forestry. Since, like most developing countries, South Africa is already replete with a number of distortions, such as taxes and subsidies in addition to labor market distortions that contribute to the high unemployment rate, we examine whether the introduction of a new tax exacerbates or dampens existing distortions. We find that a direct carbon tax imposes the lowest distortion compared with taxes on energy or energy-intensive sectors. For a carbon tax that reduces emissions by 15 percent, the cost is roughly 0.3 percent of household welfare, whereas a tax on energy-intensive sectors imposes a cost that is close to 10 times that amount.[5]

Next, we explore whether the revenue from the carbon tax or the alternative taxes on energy could be used to lower other distortionary taxes in South Africa. Not surprisingly, recycling revenue in this manner lowers the direct and indirect welfare cost of a carbon tax further; tax instruments that generate more tax revenue also provide the greatest adjustment in other tax rates. In the case of a tax on energy-intensive industries, the welfare cost with revenue recycling actually increases because of the extreme changes in output and the high taxes on energy-intensive industries needed to meet carbon emission reduction targets.

Finally, noting that South Africa's labor market also exhibits severe distortions, reflected for instance in the 25 percent unemployment rate, we look at the welfare cost if all these distortions were removed. We find that the welfare cost is significantly lower, particularly when labor flexibility in production is improved, indicating that the problem with carbon taxation may be its interactions with existing distortions rather than the cost of the tax per se. Put another way, if South Africa were able to remove some of the distortions in the labor market, the cost of using tax policy to reduce CO_2 emissions would be smaller.

We do not model the incentives for producers to adopt carbon saving technology for production directly. Instead, for a given initial production function, producers respond to price signals and shift out of taxed inputs to the extent possible. In the long run, one would expect a tax on carbon or a tax on energy to result in technology changes. If investment brings about greater economic flexibility, the tax on carbon needed to achieve a target level of emission reduction will also be smaller.

[5] Following standard analysis, we use equivalent variation to measure the welfare impact due to a policy change – see Simulation set 1 for further discussion.

Relationship to the literature. The issue of using taxation to address climate change has been surveyed by, among others, Stern (2008), Goulder and Pizer (2005), Aldy et al. (2003) and Bovenberg and Goulder (2002). The analytical framework used here derives from Sandmo's (1975) paper that showed how the cost of taxing an externality-creating commodity (such as a commodity with high CO_2 emissions), also known as a Pigovian tax, depends on the other taxes in the system. Since these taxes are typically there for revenue purposes, Sandmo extended the Diamond and Mirrlees (1971) result that revenue-raising taxes should fall on commodities with the lowest demand elasticity to show that the "optimal" tax is a weighted average of the inverse elasticity and the marginal social damage. In that sense, our paper extends the estimates of the marginal cost of public funds for revenue purposes (see, for example, Devarajan et al. (2002)) to the marginal cost of carbon taxation. Since, as mentioned earlier, the marginal social damage is still uncertain, we simulate all taxes to generate a fixed level of carbon reduction.

The analytical framework has mainly been applied in the context of developed countries. Using a dynamic general-equilibrium model of the United States, Goulder (1998) found that the marginal welfare cost of a Pigovian tax would be reduced if the revenue from the tax could be used to reduce pre-existing distortions. Assuming strong links between carbon taxes, capital accumulation and productivity growth, Jorgenson and Wilcoxen (1993) found that the expected fall of US GNP can be reversed and actually increased if the revenue is used to reduce high marginal tax rates on capital in the economy. In a partial-equilibrium application to developing countries, Shah and Larsen (1992) showed that welfare could be improved, and carbon emissions reduced, by removing subsidies and other distortions in the energy sector. In a general equilibrium analysis of a carbon tax in Thailand, Timilsina and Shrestha (2002) examined the economic impact and reduction of emissions from alternative carbon tax rates as well as the double dividend of revenue recycling through a lump-sum transfer or a reduction of direct income tax.

The welfare impacts from the two cases of revenue substitution are, however, very similar, mainly because a direct income tax in a static model with no factor accumulation is similar to a lump-sum transfer. Contributing to the very few analyses of developing countries, our general-equilibrium calculation compares the welfare costs of carbon taxation with alternative indirect taxes on energy, keeping the emissions target similar so that the social benefit of pollution control is comparable across taxes. We investigate the issue of revenue recycling by focusing on the reduction of pre-existing tax distortions that are more relevant to a developing economy. Our model builds on energy-environment CGE models of developing countries, including Robinson (1990), Lewis (1993), Blitzer and Eckaus (1993), Beghin et al. (1994), Yeldan and Roe (1994), Garbaccio, Ho and Jorgenson (1999), Xie and Saltzman (2000), and McDonald, Robinson, and Thierfelder (2008) as well as the partial-equilibrium study of presumptive environmental taxation of Eskeland and Devarajan (1996).

In response to South Africa's commitment to mitigating climate change and its Long-term Mitigation Scenarios (LTMS), there are a few studies recently undertaken to

project the country's emission trends and economic impacts of various policies over time. Van Heerden, Gerlagh, Blignaut, Horridge, Hess, Mabugu, and Mabugu (2006) fix the fossil fuel taxes to an equivalent carbon tax of R35 or 5 USD per ton of CO_2 in order to examine the decline in emissions, the increase in GDP, and a third potential dividend of reducing poverty when the taxes collected are recycled to reduce food prices. Pauw (2007), whose work underpins the LTMS, examines the direct and indirect impact of the policy scenarios designed to reduce CO_2 emissions (i.e. raising fuel taxes, changing production technology, investment costs, capital allocation by sector and other policy measures) on GDP, employment and welfare. Winkler and Marquard (2009) analyze the economic implications of a carbon tax, deriving lessons from other countries, reviewing findings from modeling works like Pauw (2007) and van Heerden *et al.* (2006), and the policy issues in designing a carbon tax. None of the studies mentioned compare the marginal cost of alternative taxes to meet a comparable emission target, using a public finance approach that is deployed in our study.

The study does not cover the practical design issues of a carbon tax and the experience is still relatively new. Some studies are beginning to document the lessons and what to avoid. Bruvoll and Larsen (2004) and Vehmas (2005) find that the carbon taxes dating to the 1990s in Denmark, Finland, Norway, and Sweden do not achieve cost-effective mitigation of emissions because they permit substantial variations in the tax per unit of carbon by fuels and by sectors. On the other hand, British Columbia, Canada imposes a carbon tax with uniform rate across fossil fuels (Government of British Columbia, 2008), but it is still too early to evaluate its impact. Moreover, there is no clear pattern to how the tax revenue from a carbon tax is used. Sweden began to recycle the carbon tax revenue in 2000 to reduce labor taxes (Government of Sweden, 2005). British Columbia uses the carbon tax to reduce taxes paid by both individuals and businesses. Norway's carbon tax, on the other hand, goes to the general budget (Daugberg and Pedersen, 2004).[6]

Section II of the paper presents an overview of the economic framework, the CGE model of South Africa, its distinctive features as well as how CO_2 emissions were incorporated. Section III discusses the simulation results and section IV draws general conclusions.

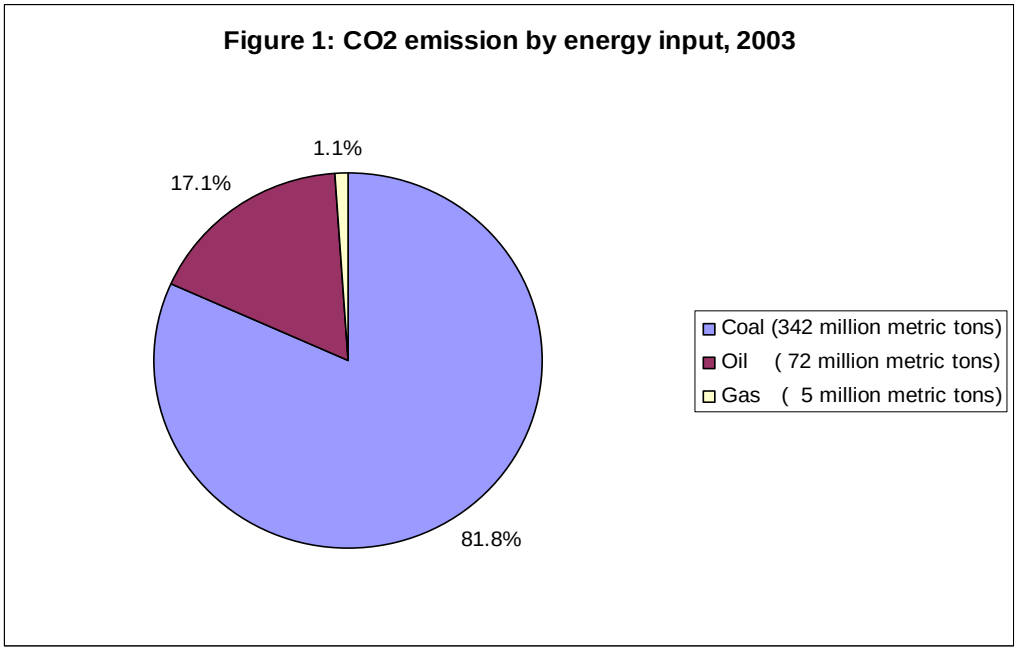
II. Overview of South Africa's Economic Framework

To examine tax policy and carbon mitigation strategies described in this paper, we employ and extend a computable general equilibrium (CGE) model of South Africa, a framework well-suited to analyze consumer and producer behavior and the impact of public policy embodied in taxes and public expenditures on the distribution of income and economic welfare. Extensions are made to better represent energy use, energy taxes, and CO_2 emissions in the South African economy, allowing energy demand and therefore

[6] For those interested in the practical experience and difficulties of the European Union's Emission Trading Scheme (ETS), Aldy *et al.* (2008) has a good summary.

carbon emissions to respond to changes in energy prices, including those caused by taxes. In what follows, we describe the model, including how the economy of South Africa is represented and how CO_2 emissions and a carbon tax are incorporated into the framework.

The economic structure of South Africa. South Africa is the largest middle income country in Sub-Saharan Africa, its gross national income accounting for about 40 percent of the region's total income.[7] It has a population of about 47 million and a per capita income of $ 5,390. Being more advanced, its economy is also more diversified than many developing economies. Agriculture accounts for only 4 percent of total value added while the service sectors are together the largest share of value-added (69 percent) followed by industry sectors (27 percent). The economic structure is represented by 43 sectors in the framework, three of which are energy sectors: coal, petroleum and electricity & gas (see Annex Table 1). Crude oil for domestic consumption is mainly imported and there is no tariff on crude oil.[8] The data in the model are from a 2003 social accounting matrix (SAM).[9]



Source: IEA (2006).

Energy use and CO_2 emissions in South Africa. CO_2 emissions depend primarily on energy use and the CO_2 coefficient or intensity of each energy input. Because of its heavy energy usage and reliance on coal, South Africa's energy-related

[7] The share is in terms of values in US dollars. Alternatively, the share is 32 percent in term of comparable purchasing parity power among countries. Figures are 2006 numbers from the WDI 2008 and calculated using the World Bank Atlas method.
[8] This is an extension of the initial data base which does not include the sector crude oil; we disaggregate crude oil imports from the category other minerals.
[9] The data construction was commissioned by the World Bank in 2002/2003 and developed by Claude Van der Merwe from Quantec. See Van Der Merwe (2002) for a description of the sources used.

CO_2 emissions are relatively high among developing countries, estimated to be 443.6 million metric tons in 2006 by the Energy Information Administration (EIA), ranking it 11th globally, placing it among developing countries behind China (6018) and India (1293), South Korea (515) and Iran (477), but just ahead of Mexico (436) and Brazil (377). Within Sub-Saharan Africa, Nigeria (101) is a distant second to South Africa.[10] In terms of per capita intensity, South Africa is comparable to United Kingdom and France.[11]

The pattern of CO_2 emissions in South Africa is due to a supply mix that is heavily skewed towards coal as the main natural resource for energy. Of the total energy consumption of about 5.0 quadrillion Btus, 75.4 percent is coal, 20.1 percent oil and the rest is accounted for by natural gas, nuclear, hydroelectricity and other renewables. Although crude is mainly imported, 40 percent of total oil consumption is now accounted for by synthetic liquids processed from coal and gas. As a result of this pattern of energy use, 85 percent of the energy-related CO_2 emissions is attributed to coal in 2003, the base year of our framework; only about 12 percent is due to oil and a very small amount (1 percent) is due to natural gas (Figure 1). In our framework, we also treat electricity as a significant energy input.

Table 1: Energy expenditures as a percent of value added in each production sector

Coke and Refined Petroleum Products	79.27	Health and Personal Services	6.94
Basic Non-ferrous Metals	57.02	Other Mining	6.47
Basic Iron and Steel	53.86	Wearing Apparel	6.37
Basic Chemicals	42.93	Plastic Products	6.33
Rubber Products	40.56	Coal Mining	5.93
Electricity, Gas, and Steam	37.50	Furniture	5.25
Transportation and Storage	35.32	Glass and Glass Products	5.03
Other Chemicals and Man-Made Fibers	27.29	TV, Radio, and Communication Equip	3.94
Water Supply	16.38	Business Services	3.66
Construction and Civil Engineering	12.39	Other Transport Equipment	3.50
Machinery and Equipment	12.01	Paper and Paper Products	3.40
Agriculture, Forestry, and Fisheries	11.18	Wholesale and Retail Trade	3.33
Catering and Accommodation	11.10	Motor Vehicles Parts and Accessories	3.25
Food	10.93	Other Producers	3.16
Professional and Scientific Equip	10.13	Other Industries	3.11
Metal Products Excluding Machinery	9.84	Footwear	2.96
Textiles	9.64	Wood and Wood Products	2.73
Communication	9.35	Beverages and Tobacco	2.58
Electrical Machinery	9.02	Government Services	1.91
Non-metallic Minerals	8.47	Printing, Publishing, and Recorded Media	1.62
Gold and Uranium Ore Mining	8.33	Financial Services	0.74
Leather and Leather Products	8.33		

Source: SAF SAM 2003, sectors ranked from most to least energy intensive.

[10] Figures in paranthesis are corresponding CO_2 emissions in million metric tons. The estimates compiled by EIA, IEA, and CDIAC – all U.S. government agencies –based on energy use and made in consultation with national statistical and energy related agencies and companies - are generally consistent with another. There are some slight differences in the latest and more preliminary numbers – for example, South Africa is ranked 12th in the IEA/CDIAC/WDI, just behind Mexico but ahead of Iran.

[11] See Figure 1 in the forthcoming 2010 World Development Report (WDR).

The relative importance of energy in each production activity may be characterized through its energy expenditure as a percent of the corresponding net output or value added, as shown in Table 1. Sectors with a high ratio of energy expenditures relative to value added include: refined petroleum products (79.27 percent), basic non-ferrous metals (57.02 percent), basic iron and steel (53.86 percent), basic chemicals (42.93 percent), rubber products (40.56 percent), gas, electricity & steam (37.50 percent), and transportation and storage (35.32).

Table 2: CO2 coefficients for energy inputs, 2003
In millions of metric tons of CO2 emissions per billion rand of energy input

Coal	34.25
Petroleum	0.84
Electricity & gas	0.00

Notes: The small amount of emissions from gas is attributed to petroleum, given that the SAM combines electricity and gas into one sector. Households and producers are assumed to have the same CO2 coefficient for energy consumption.

Source: Energy Information Administration (EIA) International Energy Annual, 2006, for emission data and SAF SAM 2003 for data on intermediate spending on coal and petroleum.

Table 2 shows the derived CO_2 coefficients that are consistent with the CO_2 emissions for each aggregate energy input (Figure 1) and the energy input expenditures in the 2003 SAM. The coefficients suggest how clean or dirty the production technology is for a particular energy source or input, the dirtiest being coal energy, the main energy input in South Africa.[12] In the SAM, electricity and gas are lumped together as a sector and input. Because the emissions arising from natural gas is very small, we combine its emissions into oil in our framework, so that electricity & gas sector mainly connotes electricity in terms of carbon content, thus isolating its key characteristic as energy in South Africa: electricity is relatively clean by itself, but it relies primarily on coal to generate the energy, emitting substantial amounts of CO_2 indirectly.

[12] Because of the lack of data, we do not adjust the energy expenditures by input and sector for relative prices and other factors in order to reflect more accurate energy quantities or equivalents. For a single country analysis, this is not as critical as in a multi-country comparison. Moreover, sectoral approaches to estimating energy quantities consistently understate the total level of CO_2 emissions because of data issues. For example, for South Africa in 2004, IEA reports CO_2 emissions of 421 million tons based on aggregate quantity of energy inputs and 343 million tons by the sectoral approach. For modeling purposes, the CGE database of the Global Trade Analysis (GTAP), version 6.0, from Purdue University, also provides emissions for South Africa by sector that total 299 million tons in 2001. Compared to the corresponding EIA number of 399 million metric tons based aggregate energy quantities, the GTAP numbers seem to be derived from EIA's sectoral approach. In Table 2, the derived coefficients are applied uniformly except in two sectors - basic iron and petroleum, where adjustments were made to make them closer to the CO2 coefficients from sectoral approaches. For basic iron, the CO2 coefficient for coal is 12.65 and for petroleum it is 0.42. For petroleum, which is mainly imported, the CO2 coefficient for coal and petroleum is zero.

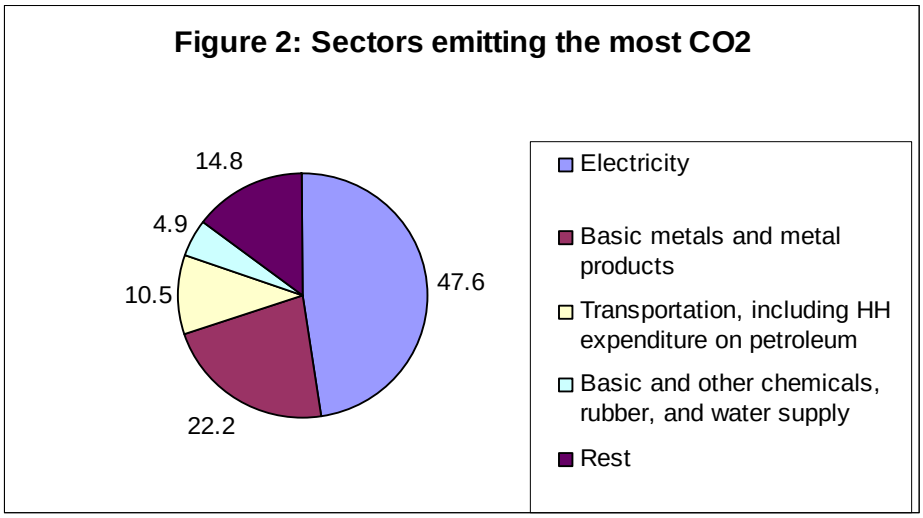
Table 3 CO_2 emissions by production activity and energy input (million metric tons)

Sector	Coal	Petroleum	Total CO2 Emissions	Percent of total CO2 Emissions
Electricity	198.83	0.20	199.04	47.6
Basic Iron and Steel	70.87	0.55	71.41	17.1
HH total	11.37	25.42	36.79	8.8
Transportation and Storage	0.72	17.76	18.49	4.4
Basic Non-ferrous Metals	9.90	1.64	11.54	2.8
Metal Products Excluding Machinery	9.34	0.33	9.67	2.3
Other Mining	7.03	1.08	8.11	1.9
Food	6.44	0.95	7.38	1.8
Other Chemicals and Man-Made Fibers	5.28	1.67	6.95	1.7
Water Supply	5.43	0.06	5.50	1.3
Basic Chemicals	0.94	4.10	5.03	1.2
Government Services	2.74	2.17	4.91	1.2
Agriculture, Forestry, and Fisheries	0.00	3.65	3.65	0.9
Health, Community, Social, and Personal Services	2.25	1.11	3.35	0.8
Rubber Products	2.54	0.46	3.01	0.7
Business Services	0.00	2.94	2.94	0.7
Wholesale and Retail Trade	0.00	2.71	2.71	0.6
Construction and Civil Engineering	0.00	2.45	2.45	0.6
Machinery and Equipment	1.65	0.67	2.32	0.6
Communication	0.00	2.31	2.31	0.6
Textiles	1.53	0.13	1.67	0.4
Non-metallic Minerals	1.09	0.19	1.28	0.3
Wearing Apparel	1.20	0.07	1.27	0.3
Beverages and Tobacco	0.63	0.13	0.77	0.2
Catering and Accommodation	0.50	0.22	0.73	0.2
Gold and Uranium Ore Mining	0.53	0.18	0.70	0.2
Paper and Paper Products	0.42	0.12	0.54	0.1
Coal Mining	0.00	0.45	0.45	0.1
Motor Vehicles Parts and Accessories	0.00	0.44	0.44	0.1
Leather and Leather Products	0.41	0.01	0.42	0.1
Other Producers	0.00	0.41	0.41	0.1
Electrical Machinery	0.00	0.38	0.38	0.1
Plastic Products	0.00	0.37	0.37	0.1
Wood and Wood Products	0.28	0.06	0.33	0.1
Other Industries	0.00	0.32	0.32	0.1
Financial Services	0.00	0.31	0.31	0.1
Professional and Scientific Equip	0.00	0.06	0.06	0.0
Printing, Publishing, and Recorded Media	0.00	0.04	0.04	0.0
TV, Radio, and Communication Equip	0.00	0.04	0.04	0.0
Other Transport Equipment	0.00	0.04	0.04	0.0
Furniture	0.00	0.04	0.04	0.0
Glass and Glass Products	0.00	0.03	0.03	0.0
Footwear	0.00	0.01	0.01	0.0
Coke, Refined Petroleum & Gas	0.00	0.00	0.00	0.0
Total	341.93	76.30	418.23	100.0

Source: CO2 coefficients from Table 2 and intermediate energy input by production sector from SAF SAM 2003.

The amount of carbon emissions by each production activity will depend on the type and amount of energy being used as inputs and the carbon emissions associated with each energy input. Table 3 shows the carbon emissions for different productive sectors in South Africa based on their energy expenditures and the CO_2 coefficients in Table 2.

Summarizing the information further in Figure 2, the sectors that generate the most carbon emissions in South Africa are the production activities that use the most coal or electricity, followed by public and private transportation due to the consumption of petroleum. The characteristic of the electricity sector is now apparent: although using electricity in various economic activities is fairly clean, producing it is another story. Because of its heavy reliance on coal as an input, the power sector is the largest emitter of CO_2 in South Africa, accounting for 48 percent of the total CO_2 emissions. Sectors that produce metallic products are also fairly dirty because of their use of coal to fire up furnaces, emitting about 22 percent of the CO_2 emissions as a group. The transportation sector combined with household use of petroleum accounts for 10.5 percent of total CO_2 emission. Households by themselves contribute about 9 percent. Other sectors with notable CO_2 emissions include the chemical sectors, rubber, water supply, other mining, and food manufactures. Although burning petroleum as an energy input is fairly dirty, next only to coal in terms of its CO_2 coefficient, the sector producing crude oil in South Africa hardly emits any carbon emissions because all crude oil is imported, its pollution being generated outside the country.[13]



Taxes on the purchase of energy commodities are relatively low in South Africa suggesting some potential for using tax policy to regulate carbon emissions.[14] Among energy inputs, a 15.4 percent sales tax is applied to purchases of refined petroleum, but basically none is applied to coal and electricity & gas (Table 4).[15]

[13] In the analysis, we ignore all possible taxes on carbon emissions originating from other countries.
[14] From the Energy Détente database, the taxation of gasoline is low in South Africa when compared to other countries.
[15] Sales taxes are ad valorem equivalent.

Table 4: Sales tax (percent) on energy commodities

Coal	0.0
Refined petroleum	15.4
Electricity & gas	0.1

Source: SAF SAM 2003

Modeling energy policies. The framework is modified from the standard specifications of a CGE model widely applied to developing countries by Löfgren, Harris, and Robinson (2001) and Dervis, de Melo, and Robinson (1982).[16] Different versions of the CGE model for South Africa have been used to analyze a value added tax (Go, Kearney, Robinson, and Thierfelder, 2005), oil price shocks (Essama-Nssah, Go, Kearney, Korman, Robinson, and Thierfelder, 2008), and a wage subsidy (Go, Kearney, Korman, Robinson, and Thierfelder, 2009).

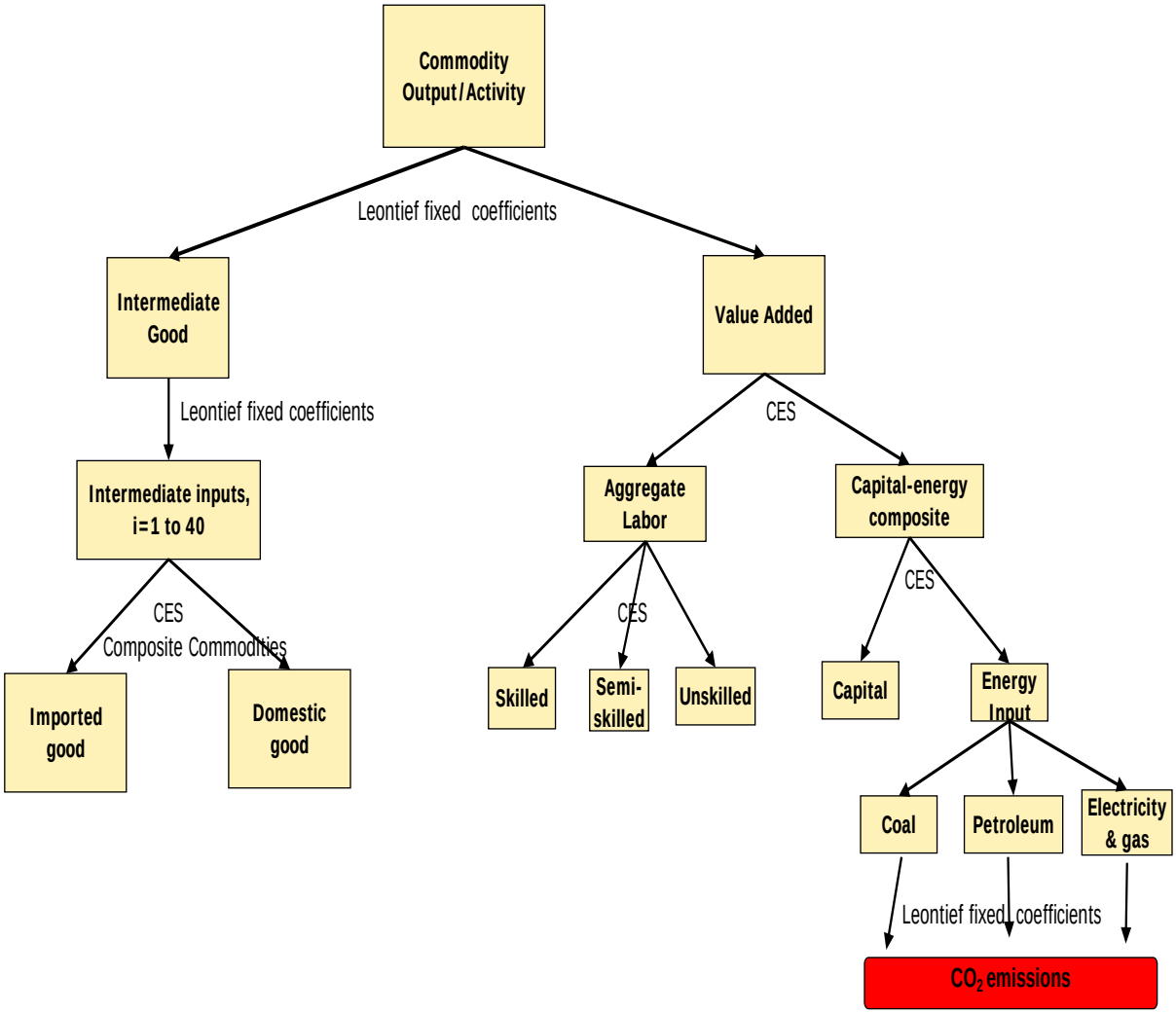
Following common modeling practice, production in each sector has a nested structure (Figure 3), combining different levels of inputs, each level being depicted by imperfect substitution through a constant elasticity of substitution (CES) function or by zero substitution through a Leontief technology of fixed coefficients. Output by activity consists of value added and intermediate inputs. Except for energy inputs, intermediate inputs are held in fixed shares to output (Leontief technology), each input a composite of imported and domestic goods. Value added is a CES combination of labor and a capital-energy composite. Three types of labor – skilled, semi-skilled, and unskilled – are aggregated into a single labor input.

Each sector potentially has three types of energy inputs, coal, petroleum, and electricity & gas, which are combined in an Armington (or CES) aggregation function into a single composite energy input. [17] In the model, the composite energy is treated as a primary input that is imperfectly substitutable with capital, implying that energy technology is to some extent embodied or associated with invested capital. The level of each energy input use is somewhat responsive to the relative costs of alternative energy inputs and to the net cost of production as reflected by the returns to capital. In the simulations below, we test the sensitivity of the results to alternative values of the elasticity of substitution between capital and energy and among energy inputs. We also examine the extreme case where energy inputs have zero substitution with other production inputs, suggesting no responsiveness to price changes in the production structure, specifying them as fixed input requirement per unit of output much like the Leontief input structure of other intermediate goods, following standard CGE specifications found in Löfgren et al (2001).

[16] The CGE model equations are solved simultaneously with the computer software package GAMS and the solver PATH.

[17] See McDonald, Robinson, and Thierfelder (2008) for a similar specification of production functions with energy inputs in a global model. The model adaptations used in this analysis are based on the model used in that paper.

Figure 3: Nested structure of production in each sector



CO_2 emissions are produced by each energy input, the amount of emissions being tied to the level of energy usage through a unique coefficient. Hence, to induce a reduction in CO_2 emissions, the economic cost of carbon may be raised directly by taxing the carbon emissions or indirectly by taxing energy inputs. A tax on carbon is feasible because the CO_2 coefficients are known. However, this implies a different tax rate for each sector, the tax rate being dependent on the energy and CO_2 intensity of that sector. The carbon tax per unit of energy input purchased for each production activity is the carbon tax rate times the CO_2 coefficient. Viewed another way and as a result of this specification, the price of energy inputs can differ by user whenever there is a carbon tax because the tax applied takes into account the CO_2 emitted per unit of energy good used. With this additional tax instrument, we can calculate the carbon tax rate needed to reduce CO_2 emissions by a given target.

Macro closure and labor market behavior: In the model, we assume that government's real spending, real investment, and aggregate foreign savings are constant. Private savings adjust in order to maintain a fixed total investment in the economy, so

that all changes affect household consumption. This is a standard approach in public finance analysis because it provides the welfare results of tax policy in isolation of other macroeconomic adjustments, such as changes in investment or government expenditure. Domestic savings (savings by institutions or households) are assumed to adjust and the economic and welfare effects are driven primarily by changes in net household income and consumption as the changes in energy taxes filter through the economy. In addition, revenue is fixed in the government budget, allowing the substitution of energy related taxes with lump-sum taxes (transfers) on household income or with pre-existing distortionary taxes such as sales and excise taxes, or import tariffs. The consumer price index (CPI) is the price numéraire.

One feature that characterizes the labor market in South Africa is the high rate of unemployment among low-skilled and semi-skilled workers. The unemployment rate was as high as 29.4 percent in 2001 but has declined to 26.7 percent in 2005 (Statssa, 2006). We have taken the interpretation due to Banerjee, Galiani, Levinsohn, and Woolard (2007) that this high unemployment is structural but in equilibrium – that is, the nonparticipation of the less-skilled who are jobless is caused by structural problems in South Africa as well as various vestiges of the apartheid system in the past, and not a voluntary choice. Accordingly, we model all the labor market categories in the reference case with aggregate employment fixed exogenously, and wages varying to clear the labor market with that employment level.

We consider how sensitive our results about the marginal cost of abatement are to various economic distortions prevalent in developing countries, particularly distortions in the labor market. To do so, we modify the labor market closures as described under set 2 of the simulations below.

The experiments are comparative statics with capital mobile across all sectors, except in coal, gold, and other mining, to mimic long-run equilibrium. No dynamics are introduced so that the model cannot look at the implications of adjustment costs of investment. Since the model is fairly neoclassical, the differences between the welfare results of a fully intertemporal model and a static one are minimal when the simulations are comparable - see, for example, Devarajan and Go (1998).

III. Scenarios and Results

30. Given a target reduction of CO_2 emissions, the economic cost or impact of various tax instruments depends on several sets of factors: i) the relative substitutability of energy inputs with capital or other intermediate inputs; ii) the relative substitutability among energy inputs; iii) various tax and non-tax related distortions in the economy. We devise four sets of simulations to test the sensitivity of the effects to these key factors.

Set 1 of Simulations: Sensitivity of the marginal cost of abatement by tax policy to relative substitution of energy inputs with capital

We examine three alternative taxes to reduce CO_2 emissions in South Africa by 15% as a target - i) a carbon tax; ii) a sales tax on energy inputs; and iii) a sales tax on energy-intensive sectors. As described previously, a single tax on carbon emissions will imply a different tax rate for each activity, depending on the supply mix of energy inputs for each sector and the intensity of CO_2 emission associated with each energy input. Since energy is a primary factor in the basic set-up, a carbon tax operates like a factor tax and there is incentive for producers to substitute away from the taxed sector to the extent possible, given the production technology. An alternative to the carbon tax, a sales tax is directed to the expenditures on energy inputs by each sector, but not tied directly to the emissions level. Like the carbon tax, a sales tax on energy is also a factor tax, raising the cost of energy to users. Finally, a sales tax on energy-intensive sectors such as basic iron and steel, transportation, basic non-ferrous metals, and metal products (excluding machinery) is the most indirect tax on carbon emissions among the taxes examined. Because these sectors are essentially intermediate inputs, the tax will have a cascading effect on the input cost structure. Except for the specific tax on carbon, all other taxes are ad-valorem taxes expressed as additional taxes from their existing tax levels in the economy.

The simulated 15% cut in emissions is a significant reduction when held against the actual performance of Kyoto signatories such as Canada. At 443.6 m tons of CO_2 emitted, this represents 9.4 tons per capita. Although it is a good starting point, it is still far from what is required if climate is to be stabilized this century, where the average per capita emissions for the globe may have to reach between 1 and 2 tons per capita. In simulation set 4, we consider alternative emission targets.

In this simulation, the additional revenue is returned to households through lump-sum transfers, thus maintaining revenue neutrality. Since there are several household groups, we make this as neutral as possible by effectively scaling the saving rates so that the aggregate household expenditure for each group is affected uniformly.

The magnitude of the economic impact of the taxes generally depends upon the assumptions about the relative substitution of energy inputs with capital and the relative substitution among energy inputs, given the pre-existing economic distortions operating in the economy. Energy being a basic intermediate good and because of the structure of energy supply/mix in South Africa, these elasticities will generally be low. Sensitivity of the results is provided by a reference case and a low elasticity or rigid case. In the reference case, the elasticity of substitution is set at 0.2 among energy inputs and 0.4 between energy and capital. For the low elasticity-rigid case, the value of the elasticity parameter is halved at 0.1 for energy inputs and 0.2 for capital and energy, thus bordering on the Leontief case of no substitution. The latter in effect provides a floor for various distortions that reduce the mobility of resources and which are not explicitly incorporated in the framework, such as imperfect competition arising from the market structure of industries. In both cases, the values are still generally low. We relax this assumption in one set of simulations below.

Table 5: Welfare Impacts of a 15% reduction in CO2 emission by tax policy:

Equivalent Variation, Percent Change from Baseline Household Expenditure

Household Income Deciles	Base value	tax on carbon emission by activities	sales tax on energy	sales tax on energy-intensive sectors	tax on carbon emission by activities	sales tax on energy	sales tax on energy-intensive sectors
		I. Reference case			**II. Rigid case**		
1st (poorest)	11.22	-1.38	0.23	0.80	-1.98	2.23	1.21
2nd	15.76	-0.77	1.82	3.37	-1.03	4.79	4.41
3rd	21.79	-0.62	1.23	-1.17	-0.66	3.95	-1.15
4th	28.41	-0.28	1.92	-0.33	-0.16	4.91	-0.14
5th	36.81	-0.41	0.92	-3.9	-0.31	3.29	-4.51
6th	47.1	-0.39	0.54	-4.77	-0.28	2.6	-5.59
7th	65.6	-0.37	-0.13	-5.29	-0.27	1.33	-6.28
8th	92.22	-0.44	-0.95	-5.15	-0.44	-0.29	-6.17
9th	135.95	-0.45	-1.84	-4.24	-0.43	-1.8	-5.07
10th - lower 5%	105.23	-0.35	-1.51	-3.36	-0.27	-1.26	-4.05
10th - next 1.25%	36.12	-0.14	-2.22	-4.39	0.23	-2.08	-5.21
10th - next 1.25%	42.62	-0.16	-1.76	-2.63	-0.06	-2.1	-3.25
10th - next 1.25%	48.22	-0.12	-1.31	-1.77	-0.11	-1.66	-2.32
10th – top 1.25%	99.27	0.02	-0.15	2.78	-0.45	-1.55	2.76
TOTAL	786.32	-0.33	-0.72	-2.76	-0.35	-0.19	-3.35

Source: CGE model simulations.
Notes:
Energy = coal, electricity & gas, and petroleum; energy intensive sectors = basic iron and steel, transportation, basic non-ferrous metals, and metal products excluding machinery.
In all scenarios, capital is activity specific in coal, gold, and other mining.

Table 5 shows the welfare impact (measured as standard equivalent variation in monetary equivalent of the change in utility) associated with the policy change. Although these welfare measures refer only to the cost side of the cost-benefit equation and disregard the social benefits associated with the changes in environment quality brought about by a reduction of carbon emissions, they are made comparable by keeping the target CO_2 emissions constant across experiments. We further express the welfare results as percent change from the base values for easy comparison. Moreover, equity implications are derived for household groups by income deciles. The total welfare change is a simple aggregation of the welfare results for the households in all income groups; although possible, no additional weighting scheme is attempted. Because of the inequality in South Africa, the highest income group is further divided into 5 income

subgroups for a total 14 household income groups. For each household group, utility is defined by a linear expenditure system (LES).

The welfare impact has an interesting pattern. All taxes will generally raise energy costs and reduce CO_2 emissions by their negative impact on production, thus lowering welfare in all cases (since the social benefit of reducing CO_2 emissions is not counted). In the reference case, the carbon tax shines as the most economically efficient among the taxes, its associated welfare loss being lowest. It benefits from being like a factor tax, affecting directly the carbon content in each sector, without the cascading effects of input taxes. This is followed by the sales tax, where welfare impact is twice that of the carbon tax. The sales tax on energy-intensive sectors is the worst. Its indirect and negative impact affects many economic activities since they are important intermediate goods.

In the rigid case, a lower economic flexibility prevents significant substitution and the wider dispersion of the higher energy cost throughout the economy. In this situation, it is difficult for producers to substitute capital for energy so energy-intensive sectors will contract more than when the production structure is more flexible. Likewise, non-energy intensive sectors will expand further. When the economy is less flexible, a sales tax on energy does better than other taxes in terms of its welfare impact. Some of the welfare change can be attributed to second best effects of tax changes in a distorted economy – output of high productivity, low energy sectors expand the most following a sales tax on energy.[18] Reducing the substitution elasticities does not seem to affect the welfare loss associated with a carbon tax, which remains low. This is because lower elasticities mean the economy's response, and hence the welfare losses, are also lower. The worst case continues to be a sales tax on energy-intensive sectors.

The equity impact of each tax is a different story. The sales tax on energy inputs has the best results as it imposes no burden on the lower income groups. The sales tax on energy intensive sectors places no burden on the lowest income groups, but unlike the sales tax on energy inputs, the sales tax on energy intensive sectors hurts some of the lower income groups. The carbon tax is generally regressive, imposing the highest relative burden on the lower income groups. The pattern is the same for both elasticity cases. Interestingly, in the rigid case and for both sales taxes, the welfare gains for low income households are greater than in the reference case and the gains extend to more households. This is because the income to capital, which goes to the richer households, declines much more than in the reference case, contributing to the larger decline in welfare of the richer household groups.

In summary, a carbon tax is the best option in terms of the consistency of its aggregate efficiency or welfare results in both low and higher elasticity cases. If a carbon tax is not feasible, a sales tax on the energy inputs would be the next choice, especially given its positive equity impact. Nonetheless, except for the sales tax on energy-

[18] As noted below in table 8, when factor market distortions are removed, a sales tax on energy-inputs is not the best tax in terms of welfare costs. This comparison suggests that the results reported in table 5 are due to second-best effects from the factor markets.

intensive sectors, the welfare changes are all *quantitatively* small, generally measuring much less than 1 percent from the base value of welfare. We examine the issue more carefully below along with the fiscal and economic results.

The macroeconomic and fiscal results of the various tax policies are shown in Table 6. Except for the sales tax on energy intensive sectors, the negative impact on GDP or consumption is generally less than 1 percent for both elasticity cases. Following the welfare results, the GDP and consumption effects of a carbon tax remain generally the same in both elasticity cases. Likewise, the impacts for a sales tax on energy are much less in the rigid case when compared to the corresponding numbers in the reference case. Although the percent changes are generally small, the annual losses in output could amount to about $330 million for the carbon tax case.

Table 6: Fiscal and Macroeconomic results by Tax Policy

	tax on carbon emission	sales tax on energy	sales tax on energy intensive sectors	tax on carbon emission	sales tax on energy	sales tax on energy intensive sectors
	I. Reference Case			**II. Rigid Case**		
Carbon tax per metric ton of CO_2 emissions	0.10			0.17		
Rand	96.25			165.22		
USD	12.72			21.84		
Additional tax rate		0.33	0.44		0.44	0.48
Ratio of additional tax revenue from meeting CO2 Emission target to total tax revenue	0.09	0.30	0.75	0.16	0.50	0.91
GDP (percent change)	-0.20	-0.41	-1.47	-0.20	-0.02	-1.76
Consumption (percent change)	-0.32	-0.66	-2.34	-0.31	-0.03	-2.80
Factor Adjustment (percent)						
Capital	0.67	1.32	3.04	0.90	2.10	3.70
Energy	4.81	10.54	7.31	4.80	9.86	7.20
Low-skilled labor	0.50	0.89	3.30	0.78	1.53	3.90
Medium-skilled labor	0.48	1.07	3.06	0.79	1.85	3.77
High-skilled labor	0.37	0.84	2.46	0.60	1.44	3.01

Source: CGE model simulations.
Notes: Factor adjustment is percent of total employed workers who must find another job as a result of the policy shock.
Energy = coal, electricity & gas, and petroleum; energy intensive sectors = basic iron and steel, transportation, basic non-ferrous metals, and metal products excluding machinery.

The degree of substitution possibility has the expected effects on the tax rates, being higher for the lower elasticity case. In order to attain a 15 percent reduction in

carbon emissions, the carbon tax is about $22 per metric ton in the low elasticity-rigid case and about $13 per metric ton in the higher elasticity case, all in 2003 US dollars. The revenue potential is reflected by the ratio of the additional energy tax revenue in question to total government revenue, showing high figures in particular for the low elasticity case and for the sales tax on energy-intensive goods.

Factor adjustments indicate the transition costs of using tax policy to target CO_2 emissions which leads to structural changes in the economy. As reported in Table 6, factor adjustments, measured as the proportion of the employed labor force that must change sectors of employment, are modest for a tax on carbon and increase as the tax instrument becomes less direct. In the rigid case, the adjustment costs are slightly higher than for the same tax instrument in the reference case. In the worst case, a tax on energy-intensive sectors in a rigid economy, the transition costs appear manageable –3.9 percent of low-skilled workers must find new jobs and 3.7 percent of capital is relocated.

For a technical explanation, we recall the results due to Sandmo (1975) regarding the optimal second-best taxation of commodities as applied to the case of externality-creating commodity *m*:

$$\theta_k = (1-\mu)\left(-\frac{1}{\varepsilon_k}\right) \quad k \neq m$$

$$\theta_m = (1-\mu)\left(-\frac{1}{\varepsilon_m}\right) + \mu\left(-n\frac{u_{m+1}}{u_m}\right)$$

If the Pigovian tax does not satisfy all the revenue requirement of government, then taxation of other commodities *k* in the first equation above follows the familiar result from Diamond and Mirrless (1971) where the highest tax $\theta_k (= \frac{t_k}{p_k})$ should generally be levied on commodities with inelastic demand or low elasticity ε_k. The second equation shows that correction for an optimal Pigovian tax rate θ_m, which is a weighted average of the inverse elasticity and the marginal social damage.[19] The marginal social damage of

[19] The latter is the sum of the marginal rates of substitution $(-\frac{u_{m+1}}{u_m})$ between good m as a private good and as a public good; it enters additively over n consumers with identical preferences and does not affect the other commodities in set k. The tax rate in the Pigovian case depends very much on the weight $\mu = -\frac{\lambda}{\beta}$, where λ is the marginal utility of income (or leisure) and β is the marginal effect (negative) of the tax requirement on social utility. μ is therefore interpreted as the marginal rate of substitution between private and public income; the lower μ is, the higher the tax requirement from the optimal Pigovian tax. As μ increases, the marginal social damage increases in value and when $\mu > 1$, subsidies are implied from the efficiency or first term. When $\mu = 1$, the existing Pigovian tax requirement is satisfied exactly and no additional distorting taxes or subsidies are needed at the margin.

climate change is of course beset with uncertainty regarding its magnitude and timing. Moreover, it is global in nature, encompassing many factors; ideally, there should be only one global price for carbon affecting all supply and demand decisions worldwide. We simplify the issue by focusing only on one country and by targeting a given level of emission reduction for all taxes in question, making the taxes comparable. We set aside what may be an optimal tax rate inclusive of the social gains from emission reduction. If the welfare cost of the tax per se is small, the overall welfare impact will likely be positive if the social gains in reducing carbon emissions can be measured and added. Doing so also means that standard public finance theory regarding the optimal taxation of commodities will apply to the results. The ratio of the deadweight loss to the revenue that the tax collects would be the product of the tax rate and the relevant elasticity. Because the elasticity for energy/fuel related activities which emit the most CO_2 are generally low, Summers (1991) has argued that the deadweight loss from a tax on those activities will tend to be small, which was confirmed by the results in Tables 5 and 6. There are two further corollaries to the low elasticity. First, the revenue effect will likely be strong. Second, just as a low elasticity case makes revenue generation compelling, it also means that a high tax rate is needed to attain any meaningful level of emissions reduction. If passed through to production decisions, the high tax rate will create greater distortions in the rigid case and may eventually raise the welfare cost.

Impact on various sectors.[20] Figure 3 illustrates the impact on the output of various sectors for a carbon tax in the reference case. In general, a higher energy cost resulting from a carbon tax will generally dampen the production of energy intensive activities, such as basic iron and steel, basic non-ferrous metals, metal products, electricity, coal mining, machinery and equipment, etc. Not all industries will be affected negatively, however. Although energy is now more costly to every sector, what matters is the relative or economy-wide repercussions as substitution in demand and supply interact to affect resource reallocation. In the end, sectors such as wood and wood products, agriculture, basic chemicals, paper and paper products, footwear, beverages and tobacco, textiles, food, etc. will benefit, because they are more intensive in the use of non-energy factors. The basic chemicals sector is not adversely affected because any petroleum input comes mainly from imports, implying a less direct and indirect carbon content in domestic production.

Second best effects arising from distortions in the sectors and factor markets will also have consequences on the aggregate welfare in the economy. In particular, there are sectoral differences in the productivity of labor and capital (see simulation set 3 below), which means that there will be welfare gains when a high productivity sector expands or a low productivity sector contracts, the net effect being dependent on the changes in the structure of output following the tax policy shock. These factor market distortions partly explain the case of the sales tax on energy in Table 5, where the welfare loss is lower when the economy is rigid compared to the flexible case (-0.19 versus-0.72). Output of

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[20] We only present two set of sectoral results so that the details do not distract from the main story or arguments. However, each experiment will have their own sectoral results and they are available as part of the generated outputs of a CGE model.

the high productivity sectors expand more in the rigid case than the flexible case, dampening the welfare losses from the tax policy shock in that scenario.

Figure 3: Percent change in output following a tax on carbon emissions with lump sum redistribution of tax revenue collected, reference case.

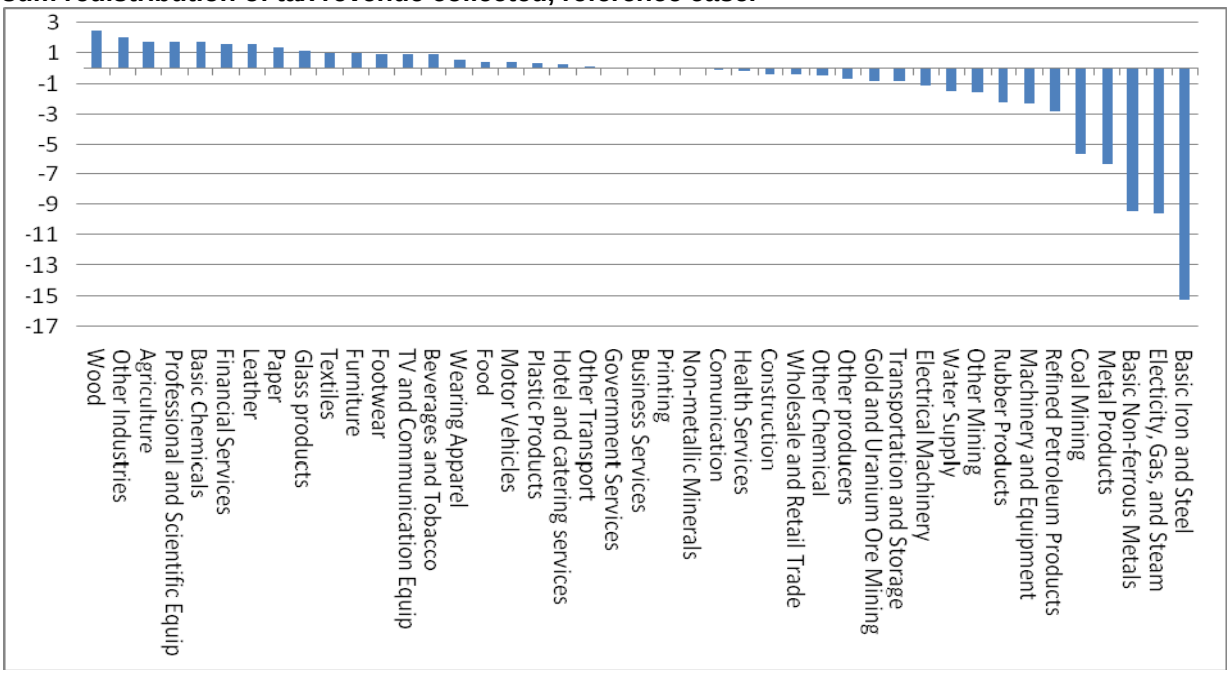
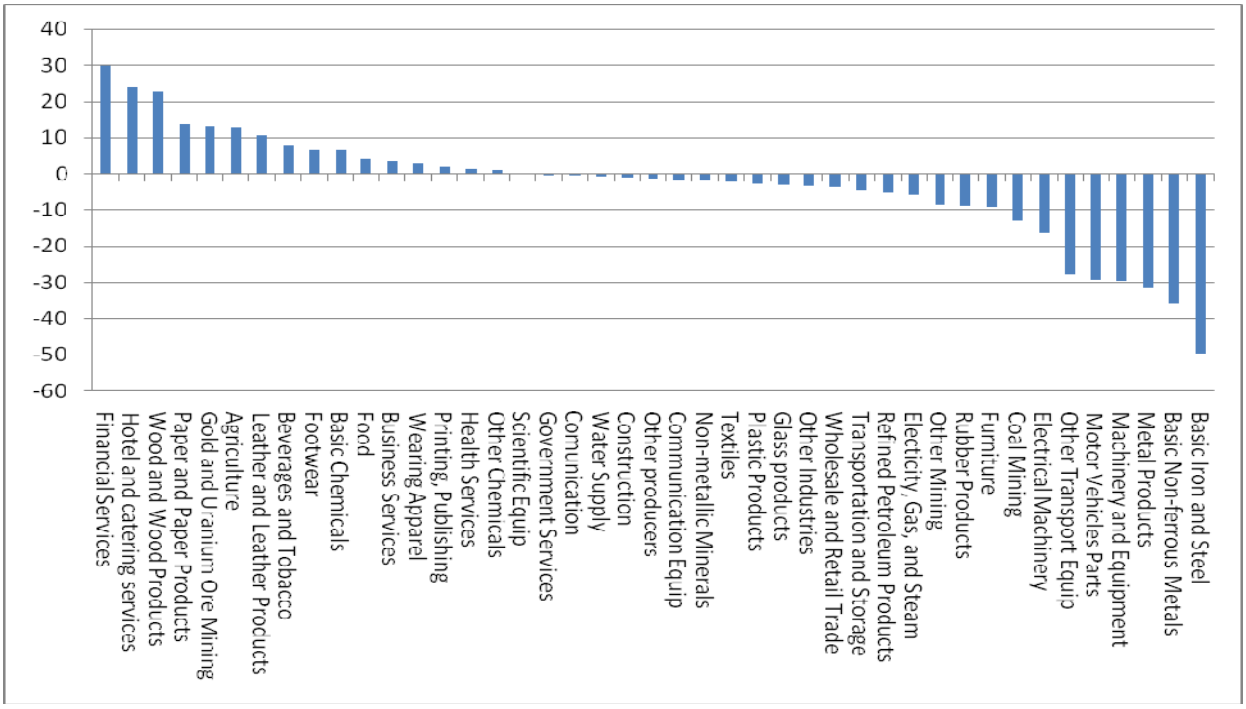


Figure 4: Percent change in output following a tax on energy-intensive sectors with lump sum redistribution of tax revenue collected, low elasticity or rigid case



Output changes are modest when there is a tax on carbon in the reference case – output adjustment range from a 3 percent expansion to a 15 percent decline, with the contraction concentrated mainly in a few very energy-intensive sectors (see Figure 3). Output adjusts most dramatically when there is a tax on the least direct instrument to target CO_2 emissions, a tax on energy-intensive sectors, in a rigid economy, see Figure 4. Output changes range from a 30 percent expansion to a 50 percent decline. As noted in Table 5, the overall welfare loss is highest because of various second-best effects, including factor productivity differences by sector, the distortions arising from taxing intermediate goods and their cascading effects in the cost structure, the high tax rates associated with low demand elasticities in order to reach the targeted reduction of carbon emissions, etc. In both cases, output declines the most for basic iron and steel, basic nonferrous metals and metal products.

Set 2 of Simulations: Sensitivity of the welfare impact to pre-existing tax distortions

Because of the revenue effects, the potential of a *double dividend* from environment taxation has received great attention in the literature, particularly for developed countries. That is, in addition to the social benefit of reducing the environment damages, there is an added benefit from *revenue recycling* if the revenue is used to substitute for other distorting taxes in the economy thus reducing the overall welfare loss from taxation in a second-best setting. In an extreme case, the welfare change turns positive. Do the prospects of revenue recycling apply to developing countries such as South Africa, allowing for significant and further tax reform? The results in Timilsina and Shrestha (2002) for Thailand suggest a weak double dividend, but the numbers are small and they do not compare alternative energy taxes or look at the relevant distortionary taxes prominent in a developing country. In our simulations, we look at the implications of revenue recycling for all three taxes by scaling uniformly all indirect taxes (production taxes, sales taxes, value added taxes, and import tariffs) that are not part of the policy experiment while maintaining revenue neutrality. The experiment is similar to Goulder (1998) but applied to the distortionary taxes more relevant in developing countries and for a target reduction of carbon emissions.[21]

Table 7 shows the prospects for tax reform from revenue recycling in South Africa. Recycling the revenue to reduce distortionary indirect taxes will lower the welfare cost of each tax by a significant amount, with one notable exception – the sales tax on energy intensive sectors. In the case of the carbon tax, recycling will lower the welfare loss to a very low 0.27 percent in both elasticity cases, about 30 percent less than without tax reform from revenue recycling. Tax substitution benefits the sales tax on energy inputs the most in the rigid case, its strong revenue allowing for a significant reduction of pre-existing tax distortions; its welfare change almost zero, very close to being a strong double dividend. As noted earlier, some of the welfare differences for this scenario can

[21] Goulder (1998) considers a reduction in factor taxes as a result of revenue recycling. Note, however, that with a double dividend, the tax structure may become unbalanced, highly or narrowly dependent on carbon/energy tax for revenue.

also be attributed to the pattern of output changes and second best effects from factor productivity differences by sector.

Table 7: Welfare Impacts with Tax Reform from Revenue Recycling
Equivalent Variation, percent change from Baseline Household Expenditure

Household Income Deciles	Base value	tax on carbon emission by activities	sales tax on energy	sales tax on energy-intensive sectors	tax on carbon emission by activities	sales tax on energy	sales tax on energy-intensive sectors
		I. Reference case			**II. Rigid case**		
1st (poorest)	11.22	-1.09	1.06	2.83	-1.56	3.42	2.88
2nd	15.76	-0.91	1.51	1.28	-1.35	3.88	1.09
3rd	21.79	-0.31	2.15	0.40	-0.18	5.47	0.06
4th	28.41	-0.26	2.05	-1.78	-0.19	4.96	-2.57
5th	36.81	-0.04	1.99	-2.48	0.29	5.17	-3.40
6th	47.1	-0.01	1.62	-3.43	0.34	4.51	-4.57
7th	65.6	0.01	0.94	-3.95	0.36	3.21	-5.24
8th	92.22	-0.16	-0.18	-4.76	0.03	0.97	-6.31
9th	135.95	-0.17	-1.16	-3.50	0.02	-0.74	-4.83
10th - lower 5%	105.23	-0.12	-0.95	-2.89	0.09	-0.37	-4.19
10th - next 1.25%	36.12	0.30	-1.11	-1.83	0.97	-0.23	-2.86
10th - next 1.25%	42.62	-0.13	-1.75	-4.16	-0.02	-2.24	-5.82
10th - next 1.25%	48.22	-0.30	-1.83	-5.26	-0.42	-2.75	-7.21
10th – top 1.25%	99.27	-1.10	-3.21	-9.92	-2.39	-7.27	-13.19
TOTAL	786.32	-0.27	-0.56	-4.07	-0.26	-0.05	-5.59
Adjustment to other taxes		-0.25	-0.70	-3.07	-0.44	-1.35	-3.74

Source: CGE model simulations.
Notes:
Energy = coal, electricity & gas, and petroleum; energy intensive sectors = basic iron and steel, transportation, basic non-ferrous metals, and metal products excluding machinery.

In all scenarios, capital is activity specific in coal, gold, and other mining.

Under revenue recycling, there is an equiproportionate change in the tax rates for all indirect taxes (production taxes, sales taxes, value added taxes, and import tariffs) that are not part of the policy experiments. Also, no revenue is recycled back to reduce base taxes on energy inputs or energy intensive sectors (instead those rates are held at base values, unless they are increased in the policy experiment).

Although the equity impacts follow the pattern of the previous results in the Table 5, there is further improvement for a sales tax on energy and a sales tax on energy intensive sectors. The reduction in other tax rates due to revenue recycling will generally benefit the poor. In the case of the sales tax on energy, welfare improvement is noted up to the 7th income deciles for the rigid case, thus in fact registering strong double dividends for most income groups except the top deciles.

The one clear exception is the sales tax on energy-intensive sectors, where the aggregate welfare losses are higher instead of lower when compared to Table 5. In this

case, the substitution of the taxes in question is basically trading one type of economic distortion for another. Following Diamond and Mirrlees' (1971) *production efficiency lemma*, an optimal commodity tax does not disrupt production efficiency, all distortions being focused only on consumer choice. Reducing pre-existing distortions arising from other indirect taxes (as afforded by revenue recycling) should therefore ameliorate the initial welfare cost of taxing the energy intensive sectors. However, the energy-intensive sectors that are taxed higher - such as basic iron and steel, transportation, basic non-ferrous metals, and metal products (excluding machinery) – are intermediate goods, causing production inefficiency with the higher taxes on those goods. The welfare impact is offset somewhat by the reduction of other indirect taxes and their associated distortions through revenue recycling. Being intermediate goods, their demand elasticities are low, signifying high potential for revenue recycling, actually generating the most revenue among the taxes in question, requiring in turn deeper cuts in other indirect taxes in the experiment that maintains revenue neutrality. Cutting other indirect taxes and the economic distortions associated with them will however encourage production and increase carbon emissions in sectors other than the energy-intensive sectors, forcing further and higher increases in the relevant energy tax in order to achieve the target 15 percent reduction in carbon emissions.

As noted in Table 7, other indirect taxes are reduced over 300% when the revenue from a sales tax on energy-intensive sectors is used to reduce other tax distortions – the tax rates become subsidies. The point of this extreme case is that the less directed the tax instrument, the less effective is revenue recycling, its revenue potential actually working against its effectiveness as a Pigovian tax and against the benefit of tax substitution in lowering pre-existing tax distortions.

Set 3 of Simulations: Sensitivity of the welfare impact to factor market distortions

We examine the sensitivity of the welfare results to a few key distortions existing in the factor markets in South Africa. The first is the sectoral differences in productivity for each factor, such as wage differences for labor of the same type across production sectors. The model incorporates such distortions by specifying fixed ratios of the marginal product of a factor in a sector to the average return of that factor, the standard way of introducing factor market distortions. Such differentials are not entirely due to differences in efficiency but also to factor segmentation such as lack of mobility, adjustment cost, etc. We examine their impact on the marginal cost of a new tax policy by specifying a "distortion free" base where these factors of proportionality are all one. The experiment is similar to the marginal cost of public funds analysis in Devarajan *et al.* (2002) but applied to a target level of emissions reduction instead of an additional unit of revenue. Revenue is returned to the households by lump-sum transfer similar to the simulations in Set 1. Since the impact on different household groups retains the same pattern found in the previous two sets of simulations, we only report the aggregate welfare impact.

As shown in Table 8, removing wage differences for labor of the same type across production sectors raises welfare losses slightly for the carbon tax and significantly for the sales tax in both elasticity cases. In the rigid case, sales tax is no longer superior to the carbon tax. The worst case remains the sales tax on energy-intensive sectors, registering a negligible improvement. Clearly, the lower welfare losses previously reported for the carbon and sales tax on energy were partly due to their interaction with labor market and pre-existing tax distortions, seemingly benefiting in the process. More specifically, the expanding sectors in the current experiment, which were previously the high productivity sectors in Figure 3, will no longer provide an additional welfare gain when factor productivity is equalized across sectors for each factor. Nevertheless, within the results of Table 8, the carbon tax is still clearly superior to the other taxes.

Table 8: Welfare Impacts of Labor Market Distortions or Specifications
Equivalent Variation, percent change from Baseline Household Expenditure

	tax on carbon emission by activities	Sales tax on energy	sales tax on energy-intensive sectors
I. Removing sectoral differences in productivity for each factor			
Reference case	-0.48	-1.40	-2.62
Rigid case	-0.69	-1.91	-3.33
II. Higher substitution elasticity among factors of production			
Reference case	0.04	0.91	-1.84
Rigid case	0.26	2.42	-2.17
III. Unemployment in the low and medium skilled workers			
Reference case	-0.90	-2.94	-9.01
Rigid Case	-1.01	-3.27	-11.14

Labor market segmentation or rigidity in South Africa is further reflected by a low elasticity of substitution among factors of production, particularly among unskilled and skilled labor. The relative complementarity among labor types is a key factor in preventing the additional employment of unskilled labor, with the scarcity of skilled workers acting as a constraint - see, for example, Go *et al.* (2009). To test this distortion, we raise the elasticity of substitution between labor and the capital-energy aggregate and between labor types all to 2.0 as a second experiment in Table 8. The carbon tax and the sales tax on energy will now result in welfare gains due to second-best effects, which essentially rechannel resources away from sectors with high carbon or energy intensity to sectors with relatively high productivity and low carbon/energy contents, such as other products, financial services, agriculture, wood products, basic chemicals, and leather, the resource reallocation being much stronger in the rigid case when the associated energy elastcities are low and for the case of a sales tax on energy. The results emphasize the critical role of labor market flexibility and its interactions with other pre-existing distortions as well as the introduction of the carbon or sales tax. Further tests (not shown) confirm that raising labor market flexibility as postulated will also lower

significantly the welfare cost of removing sectoral wage differences for each labor type (experiment I of Table 8) or introducing unemployment (as defined in experiment III below).

The third labor market distortion examined is the unemployment problem in South Africa. As an alternative to the base case in set 1, we allow for unemployment among low-skilled and semi-skilled formal workers, with sticky real wages, while the other labor markets clear in equilibrium, similar to the formulations in Go *et al.*(2009) and Lewis (2001). The unemployed are not fully represented in the utility function, so the specification is not ideal. However, there are high within-household income transfers in South Africa, so that the consumption of the unemployed is represented in the various household units – see Banerjee *et al.* (2007) and Moll (1993). The results in the third part of Table 8 show that welfare losses for various tax options will increase significantly when compared to the case in Table 5. With a lower welfare impact, the carbon tax is still better than other taxes.

With sticky real wages, a carbon tax will generate a 1 percent reduction in employment of either low-skilled and slightly more for medium-skilled labor, in either the rigid or reference case (Table 9). Employment losses are more dramatic with a tax on either energy or energy-intensive sectors. When there is a tax on energy-intensive sectors, employment can decline over 16 percent in the rigid case.

Table 9: Percent change in employment of low-skilled and medium-skilled labor with sticky real wages

	tax on carbon emission	sales tax on energy	sales tax on energy intensive sectors	tax on carbon emission	sales tax on energy	sales tax on energy intensive sectors
	I. Reference Case			**II. Rigid Case**		
Low-skilled labor	-0.96	-4.28	-13.46	-0.91	-5.62	-16.56
Medium-skilled labor	-1.33	-4.99	-13.81	-1.67	-6.93	-16.78

The three experiments in this set suggest that labor market distortions in South Africa matter very much. In particular, unemployment will likely raise the cost of carbon taxation significantly while effecting greater labor market flexibility will lower the marginal abatement cost. If labor market reforms are difficult to implement, the previous results of Table 7 still suggest that either a tax on carbon or a tax on energy inputs can reduce the pre-existing tax distortions significantly and substantially reduce the welfare cost of achieving a given target reduction in CO_2 emissions.

Set 4 of Simulations: Sensitivity of the carbon tax to the elasticity of substitution and alternative levels of emissions reduction

The carbon tax is lower in the reference case ($12.72) than in the rigid case ($21.84). We further investigate the effect of elasticity values on the carbon tax required to reduce emissions by 15 percent (Table 10). We also add the extreme case where energy inputs are part of the intermediate cost structure with zero substitution elasticity (a Leontief technology). In that extreme case, the carbon tax rises to about $127. The tax drops rapidly with higher values of elasticities. One possible interpretation of this result is that, if investment brings about a better and cleaner technology with better substitutability between capital and energy and among energy inputs, the required carbon tax will fall. This result suggests another use of the potential revenue of the carbon tax – to finance investment in new and alternative-energy technologies. Such analysis, however, will require a different and more dynamic analysis, including estimation of the possible cost structure of new and cleaner energy technology – which is beyond the scope of the present paper.

Table 10: Sensitivity of the carbon tax to the elasticities

Elasticity of substitution		
between capital and energy	**among energy inputs (coal, petroleum, electricity)**	**tax on carbon ($ per metric ton)**
2	0.5	$3.70
2	0.1	$4.36
1.2	0.1	$6.00
0.8	0.1	$8.72
0.4	0.2	$12.72
0.2	0.1	$21.84
0	0	$127.04

We also test the sensitivity of the effects of a tax on carbon to the target level of emission reductions, considering a 5, 10, 15, 20, and 25 percent reduction in CO_2 emissions. As seen in Table 11, the tax on carbon increases non-linearly, as targets increase, the tax needed to achieve them increases at an increasing rate. To achieve a 25 percent reduction in CO_2 emissions, the tax on carbon must increase $32. Likewise, welfare loss are non-linear, ranging from a decline of 0.04 percent to 1.15 percent, but the direction of change is the same. Even for a 25 percent reduction in emissions, the welfare costs are low, a decline of 1.15 percent.

Table 11: Sensitivity of the effects of a tax on carbon to the target emission reduction

	Emission Reduction					
	Base	5%	10%	15%	20%	25%
Welfare	786.32	-0.04	-0.14	-0.33	-0.65	-1.15
Carbon tax as a percent of total tax revenue	0.00	2.40	5.40	9.13	13.81	19.79
Carbon tax per metric ton (USD)	0.00	2.95	7.05	12.72	20.65	31.91
Carbon tax per metric ton (Rand)	0.00	22.29	53.32	96.25	156.21	241.38

In relation to South Africa's Long Term Mitigation Scenario (LTMS), its "Use the Market" scenario uses a starting carbon tax of R100 per ton, which is remarkably close to the calculated tax in the reference case (although the numbers in our study are in 2003 rand and US dollars). Hence, the emission target of 15 percent in this study could in effect be interpreted as an independent estimate of the emissions reduction possible for the LTMS, with the different simulations testing for the sensitivity of the carbon tax to various assumptions.[22]

IV. Conclusions

Political, social and economic considerations will affect South Africa's policies to reduce carbon emissions. In this paper, we have focused on one dimension and one instrument, namely the economic costs of the distortions created by different taxes applied to reduce carbon emissions. We find that the welfare costs of achieving significant reductions in CO_2 emissions are fairly small. In general, the more targeted the tax to carbon emissions, the better the welfare results. If a carbon tax is feasible, it will have the least marginal cost of abatement by a substantial amount when compared to alternative tax instruments. Furthermore, the welfare losses from a tax on carbon are small regardless of the elasticities of substitution in production. If the revenue generated can be used to reduce pre-existing tax distortions, the net welfare cost becomes negligible. If a carbon tax is not feasible, a sales tax on energy inputs is the next best option, which has a better equity impact and a better welfare result if the substitution elasticities are really low, given the existing distortions in the economy.

There are several points worth emphasizing. The simulations do not account for the social gains of emissions reduction and there are no dynamic or productivity gains including from benefits from clean technologies. Our approach is therefore conservative, by leaving out welfare gains. Even then, we find that the welfare cost is still small and manageable.

Moreover, a carbon tax may be relatively simple to implement among alternative policy instruments because the carbon content of individual fuels is fixed

[22] However, Pauw's "use the market" scenario also includes projections about the change in the structure of energy use and changes in investment and savings needed to achieve the higher investment levels. We do not include those changes.

stoichiometrically per unit of fuel and there are currently no ways to actually abate emissions (absent carbon capture and storage technologies). So tax rates can be fuel-specific and tuned to the actual carbon content. This is important because the analysis shows how much lower the welfare losses are for the carbon tax instrument.

The results confirm the conventional argument that the relevant deadweight loss will generally be small for energy related taxes. Moreover, labor market distortions such as labor market segmentation or unemployment will likely dominate the welfare and equity implications of a carbon tax for South Africa. This being the case, if South Africa were able to remove some of the distortions in the labor market, the cost of carbon taxation would be negligible. With the supply mix of energy being tilted towards coal, the adoption of a cleaner technology, possibly financed in part by the revenue potential of a carbon tax, is an important medium-term policy issue. Although mitigation-related public finance issues are the focus in the paper, adaptation measures will also be important for South Africa. In addition, South Africa interacts with other countries in southern Africa and there is potential to share power resources in the region. Finally, there may be carbon leakages as South Africa imports goods from neighboring countries with lower taxes applied to energy goods. All these are areas for further research.

In sum, the discussion of whether South Africa should tax carbon emissions can now focus on other considerations than the welfare costs, which are likely to be quite low.

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APPENDIX 1:
PRODUCTION SECTORS IN THE SOUTH AFRICA CGE MODEL

Aggregated Sector	Components	Percent of Total Output
Agriculture	Agriculture Forestry and Fishing	3.5
Fuels & Minerals	Coal Mining Gold and Uranium Ore Mining Other Mining	6.5
Food Products	Food Beverages and Tobacco	5.5
Textiles	Textiles Wearing Apparel Leather and Leather Products Footwear	1.5
Manufacturing	Wood and Wood Products Paper and Paper Products Printing Publishing and Recorded Media Coke and Refined Petroleum Products Basic Chemicals Other Chemicals and Man-Made Fibres Rubber Products Plastic Products Glass and Glass Products Non-metallic Minerals Basic Iron and Steel Basic Non-ferrous Metals Metal Products Excluding Machinery Machinery and Equipment Electrical Machinery TV Radio and Communication Equipment Professional and Scientific Equipment Motor Vehicles Parts and Accessories Other Transport Equipment Furniture Other industries	23.3
Utilities	Electricity Gas and Steam Water supply	2.4
Construction	Construction and Civil Engineering	4.5
Services	Wholesale and Retail Trade Catering and Accommodation Transport and Storage Communication Financial Services Business Services Health Community Social and Personal Services Other producers	39.6
Government Services	General Government Administration General Government Defense General Government Law and Order General Government Education General Government Health General Government Social Services General Government Economic Services	13.2

Government Revenue Structure

Source	Percent of Revenue Collected
Taxes on firms	20.5
Taxes on households	37.3
Taxes on production activity	15.7
Tariff revenue	2.2
Consumption based value added tax, net of rebates	15.4
Sales tax on consumption	8.9