UNITED NATIONS UNIVERSITY
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World Institute for Development Economics Research

Working Paper No. 2012/46

The Economic Implications of Introducing Carbon Taxes in South Africa

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May 2012

Abstract

South Africa is considering introducing carbon taxes to reduce greenhouse gas emissions. We evaluate potential impacts using a dynamic economy-wide model linked to an energy sector model. Simulation results indicate that a phased-in carbon tax that reaches US$30 per ton of CO_2 by 2022 achieves the ambitious national emissions reductions targets set for 2025. Relative to a baseline with free disposal of CO_2, constant world prices and no change in trading partner behaviour, the preferred tax scenario reduces national absorption and employment by 1.2 and 0.6 per cent, respectively, by 2025. However, if South Africa's trading partners unilaterally impose a carbon consumption tax then welfare and employment losses exceed those of a domestic carbon tax. Border tax adjustments improve welfare and employment while maintaining the same emissions reductions. The mode for recycling carbon tax revenues strongly influences distributional outcomes, with tradeoffs between growth and equity.

Keywords: carbon tax, growth, employment, income distribution, South Africa

JEL classification: D58, H23, O13, O44

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This working paper has been prepared within the UNU-WIDER project 'Development under Climate Change', directed by Channing Arndt and James Thurlow.

UNU-WIDER gratefully acknowledges specific programme contributions from the governments of Finland (Ministry for Foreign Affairs) and Sweden (Swedish International Development Cooperation Agency—Sida) for the Development under Climate Change programme. UNU-WIDER also acknowledges core financial support to UNU-WIDER's work programme from the governments of Denmark (Ministry of Foreign Affairs, Danida), the United Kingdom (Department for International Development), and the governments of Finland and Sweden.

ISSN 1798-7237 ISBN 978-92-9230-509-3

Acronyms

BTA	border tax adjustments
CES	constant elasticity of substitution
CGE	computable general equilibrium
CTL	coal-to-liquid
GDP	gross domestic product
GHG	greenhouse gases
GTL	gas-to-liquid
LES	linear expenditure system
RSA	Republic of South Africa

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Typescript prepared by Liisa Roponen at UNU-WIDER

1 Introduction

South Africa is amongst the world's most carbon-intensive economies. An abundance of coal resources and subsidized coal-fired electricity has led to a reliance on energy-intensive mining and heavy industry as the historical drivers of economic development. Notwithstanding this legacy, the South African government has recently targeted ambitious reductions in greenhouse gas (GHG) emissions. Emissions reductions at the scale envisioned imply a structural transformation of the South African economy. To achieve this, the government is considering introducing a carbon tax (RSA 2010). Not surprisingly, this raises concerns about eroded export competitiveness, job losses in carbon-intensive sectors, and higher energy prices for low-income households (Arndt et al. 2012). These concerns underpin resistance to a carbon tax from various interest groups (Resnick, Tarp and Thurlow 2012).

Given that global climate change negotiations seem to have stalled and that there is, as a consequence, no immediate international pressure on South Africa to limit emissions, it is worthwhile to reflect on why the country would pursue mitigation policy. There are at least two reasons. First, Sokolov et al. (2009) estimate that without global mitigation, there is a 50 per cent chance that global temperatures will rise by five degrees or more by 2100. The chance of a rise of less than two degrees is nil. As Weitzman (2011) notes, the consequences of such extreme global warming are deeply uncertain and may be profoundly negative. Despite this uncertainty, there is broad consensus that low-income countries will be affected first. Africa is vulnerable, given its underdevelopment and location in the tropics. While South Africa is better equipped to adapt to climate change, its neighbouring states are less robust. Overall, there are strong reasons to believe that Africa's long-run interests, including those of South Africa, favour effective global mitigation. Not only would implementing a carbon tax support the emergence of global policy, but it would also serve to cement South Africa's position as a leader on the continent.

A second reason for introducing a carbon tax is that other nations, notably Australia and the European Union but also China, are taking climate change seriously. Even the United States has shown some willingness to enact mitigation policies—the House of Representatives passed a 'cap and trade' bill (effectively a carbon tax) in 2010, but this failed to gain approval in the Senate. It is possible that, over the coming decade, mitigation policies could be implemented in a number of leading countries. For these policies to be effective, this 'coalition' of mitigating countries will have incentives to expand membership. They may also find it logical and politically expedient to limit the 'carbon leakage' that arises when carbon-intensive supply-chains are relocated to non-coalition countries. Border tax adjustments (BTA) that impose taxes on the carbon content of imports (and rebate domestic exporters) are one potential instrument for achieving this objective.

South Africa therefore has a long-run incentive to support global mitigation and a short-run incentive to be part of the coalition of mitigating countries. Pre-emptive mitigation policy, such as a carbon tax, would allow South Africa to avoid being disadvantaged in global markets. It would also initiate the transformation to a 'greener' economy and avoid having to rapidly reduce emissions in the future. Whether or not this is a good idea depends, in large measure, upon the economic impacts of a carbon tax. In this article we explore these economic impacts and consider alternative carbon tax designs.

We are not the first to explore these issues in the South African context. Two recent studies use computable general equilibrium (CGE) models to evaluate the potential effects of a carbon tax (Pauw 2007; Devarajan et al. 2011). Devarajan et al. find that carbon taxes reduce national welfare but are more efficient than other tax instruments on energy use or pollution. Through detailed sensitivity analysis, the authors show that their results depend crucially on labour market rigidities and technology substitution possibilities. One limitation of the study is that the authors do not distinguish between different energy technologies or capture South Arica's long-term electricity investment plan, which largely determines the future energy mix and includes a shift towards renewable energy. The study might therefore overstate the responsiveness of electricity production and prices to the carbon tax. In contrast, Pauw distinguishes between energy technologies and bases long-term electricity investments on a partial-equilibrium energy model. Pauw finds smaller welfare reductions when a carbon tax is introduced, although less detailed attention is paid to labour market rigidities.

Perhaps the main limitation of these studies is the lack of a time dimension. They use static CGE models, which exclude changes in investment behaviour in response to energy prices. Their static models also allow a costless reallocation of capital across industries and so understate adjustment costs. In a real world dynamic setting, capital typically becomes immobile after investment, implying that new investment is needed to shift production and employment towards less carbon-intensive activities. Moreover, neither study allows industries to invest in less energy-intensive technologies. Efficient mitigation policies are implemented over time allowing the carbon-intensive capital stock to depreciate away and providing clear signals to investors and innovators to take carbon emissions into account. For these reasons, South African emissions targets focus on 2025. Considering the path to achieving these emissions reductions forms an important part of the analysis.

To address these limitations, we develop a dynamic CGE model of South Africa. Following Pauw (2007), our model contains detailed energy technologies and is calibrated to investment projections from an energy sector model. Our dynamic specification allows non-energy industries to endogenously invest in more energy-efficient technologies in response to higher energy prices. The model is calibrated to a purpose-built database that reconciles energy and economic data. We simulate various policy options, including carbon taxes; foreign and domestic BTAs; and various revenue recycling options. Under all policy variants, a carbon tax of R21 (US$3) per ton is introduced in 2012, rising linearly to R210 (US$30) per ton by 2022, which is sufficient to meet national emissions targets. As with Devarajan et al. (2011), we conduct sensitivity analysis on labour market rigidities.

The remainder of this paper is structured as follows. In the next section we describe the structure of energy use and emissions in South Africa and outline the country's long-term electricity investment plans and its implications for future emissions. Section 3 describes the model and Section 4 presents the simulation results. The final section summarizes our findings and identifies areas for further research.

2 Energy use and carbon emissions in South Africa

2.1 Sources of GHG emissions

South Africa has committed to reducing its GHG emissions by 34 per cent by 2020 and 42 per cent by 2025 relative to a 'business-as-usual' baseline (RSA 2010). Such ambitious targets reflect South Africa's ranking as the world's thirteenth largest GHG emitting country in absolute terms in 2007, with per capita emissions nearly twice the global average (World Bank 2012).

Arndt et al. (2012) compile an emissions profile for South Africa using information from national supply-use tables and energy balances. Table 1 describes the sources of carbon dioxide (CO_2) emissions from burning primary fossil fuels (i.e., coal, crude oil and natural gas).[1] Had South Africa burned its entire fossil fuel supply in 2005 it would have generated 523.6 million metric tons of CO_2 emissions. However, more than a quarter of coal is exported, implying that the CO_2 emissions of net domestic supply are lower at 387.8 million tons. Despite these exports, coal still accounts for 87.8 per cent of net emissions, followed by crude oil at 9.7 per cent.

More than three-fifths of domestic coal supply is used to generate electricity. In 2005, coal-fired power plants generated 92.9 per cent of total electricity supply, followed by nuclear (4.9 per cent) and hydropower (1.8 per cent). This reliance on coal-fired plants explains why 53.1 per cent of South Africa's total emissions are from electricity generation. Coal is further used to produce liquid fuels, where it generates an additional 31 per cent of total emissions. Natural gas is used to produce electricity and liquid fuels, although the quantities are relatively small and it contributes little to total emissions. The remaining 16.2 per cent of coal and 68.4 per cent of natural gas that are not transformed into electricity or liquid fuels are used directly by industries and households.

Table 1
Carbon dioxide emissions from fossil fuel use, 2005

	Total	Coal	Crude oil	Natural gas
Domestic production (CO_2 mt)	479.8	472.8	0.0	7.0
Plus imports	43.8	3.6	37.6	2.5
Total supply	523.6	476.4	37.6	9.5
Less exports	137.1	137.1	0.0	0.0
Less change in stocks	-1.3	-1.3	0.0	0.0
Domestic supply	387.8	340.6	37.6	9.5
Direct domestic use	387.8	340.6	37.6	9.5
Electricity	205.8	205.3	0.0	0.5
Petroleum	120.2	80.1	37.6	2.5
Other industries	52.0	45.5	0.0	6.5
Households	9.7	9.7	0.0	0.0

Notes: Includes CO_2 emissions from burning primary fuels but excludes other GHGs.

Source: CGE model data (see Arndt et al. 2012).

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[1] We use standard carbon emissions factors equal to 1.93 tons of CO_2 per metric ton of coal, 2.33 per metric ton of crude oil, and 0.056 per gigajoule of natural gas.

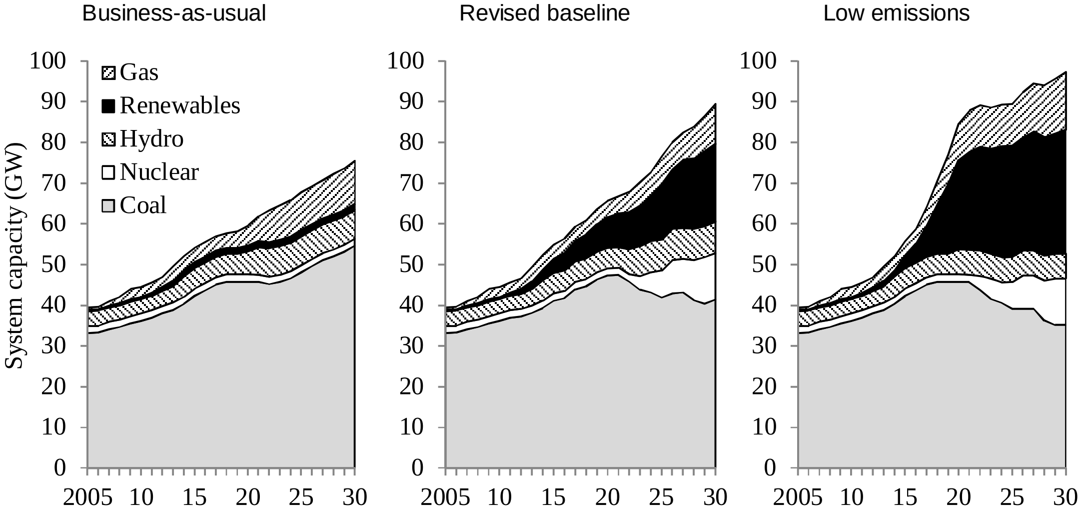
Table 1 showed the emissions associated with the *direct* use of primary fuels. However, all industries generate emissions *indirectly* by using carbon embodied within intermediate inputs. Arndt et al. (2012) estimate carbon intensities for products and find that indirect carbon use accounted for two-thirds of total emissions in 2005, of which approximately a quarter is carbon embodied within imported goods and services. Not surprisingly, energy products are found to be the most carbon intensive, with electricity and petroleum generating 3.29 and 0.66 tons of CO_2 per 1000 Rand (US$160) of final demand, respectively. Carbon intensity is also relatively high for the more export-intensive heavy industries, such as wood products (0.37) and metals (0.40). Carbon use tends to be lower in services, such as government (0.08) and finance (0.03). Unlike heavy industries, services have smaller trade and transport margins, which account for 7.1 per cent of national emissions. Services do, however, use carbon indirectly, especially in the form of electricity. The carbon intensity of electricity generation therefore has economy-wide implications beyond the energy and heavy industrial sectors.

2.2 Long-term electricity investment plan

South Africa recently announced its electricity sector investment plan for 2010-30 (DOE 2011). The plan draws on a PLEXOS energy sector model, which estimates least-cost investment options subject to various constraints, including demand forecasts, portfolio risks, domestic production quotas, and emission targets. Figure 1 shows results from three simulations that satisfy the same demand forecast.

The 'business-as-usual' scenario is unbounded by carbon taxes or emission targets. Under this scenario, CO_2 emissions in the electricity sector rise from 237 million tons in 2010 to 381 million tons in 2030. The total cost of the 'business-as-usual' plan (in

Figure 1
Electricity system capacity in the energy sector model scenarios, 2005-30



Source: Authors' calculations using DOE (2011).

present value terms) is estimated at R0.79 trillion (US$108 billion), which is equivalent to a third of gross domestic product (GDP) in 2010.[2]

The least carbon-intensive investment plan in DOE (2011) still fails to achieve the national emission reduction targets. In the ‘low emissions’ scenario, total CO_2 emissions only reach the targeted 42 per cent decline from baseline by 2030 rather than 2025. Even this delayed achievement incurs a substantial financial cost to the economy, with the ‘low emissions’ investment plan costing R1.25 trillion (US$171 billion). This implies that, given domestic production quotas and demand forecasts, meeting the national emissions targets in the electricity sector will cost the economy *at least* an additional R0.46 trillion (US$63 billion) or 19 per cent of GDP in 2010. Much of this additional cost is due to greater use of renewable energy, which has lower load factors and therefore requires more installed system capacity in order to deliver the same electricity output as coal-fired and nuclear alternatives.

At least some of the additional investment costs will need to be passed onto consumers through higher electricity tariffs. However, recent tariff increases suggest that any sizable pass-through will face political economy constraints (see Büscher 2009; Resnick, Tarp and Thurlow 2012). Therefore, it is not surprising that the South African government has endorsed a more modest investment plan.[3] The total cost of this ‘revised baseline’ scenario is well below the cost of the ‘low emissions’ scenario. However, total CO_2 emissions in 2025 are only 19 per cent below the baseline and so fall far short of the 42 per cent target. This implies that if future electricity production follows the revised baseline scenario, as is expected, then any remaining emission reductions would need to occur outside of the electricity sector. This special dispensation or ‘ring fencing’ poses an important constraint because the electricity sector currently produces more than half of total emissions. For this reason, we initially calibrate our economy-wide model to replicate the revised baseline, and then use this as our reference scenario for evaluating the effects of carbon taxes on reducing the remaining emissions.

3 Model specification and calibration

Our CGE model is well-suited to evaluating tax policy. It captures the functioning of a market economy in which the interactions of producers, households, government and rest of the world are mediated via prices and markets. Macroeconomic and resource constraints are respected, which is crucial for large-scale policy changes. The model contains detailed information on sectors and households and so provides a ‘simulation laboratory’ for quantitatively examining how carbon taxes influence production, trade and employment patterns as well as income distributions. In this section we describe our model’s specification and its underlying data sources.

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[2] The present value calculation uses an eight per cent discount rate for the period 2010-30.

[3] This ‘policy-adjusted scenario’ (DOE 2011) is an outcome of government and private sector consultations.

3.1 Consumer and producer behaviour

Drawing on Statistics South Africa (StatsSA 2006), the model disaggregates households into 14 representative groups according to their per capita incomes. Each representative consumer is assumed to maximize welfare (utility) subject to a budget constraint. For this we employ a linear expenditure system (LES) of demand:

$$P_j \cdot H_{jh} = P_j \cdot \gamma_{jh} + \beta_{jh} \cdot \left((1 - s_h - td_h) \cdot Y_h - \sum\nolimits_{j'} P_{j'} \cdot \gamma_{j'h} \right) \qquad (1)$$

where *H* is consumption of good *j* by household *h*, *γ* is a minimum subsistence level, *β* is the marginal budget share, *P* is the market price of each good, *Y* is total household income, and *s* and *td* are marginal savings and direct tax rates. The LES functions allow income elasticities to vary across household groups based on estimates from Case (2000).

Similarly, producers maximize profits subject to input and output prices. A constant elasticity of substitution (CES) function determines output quantity *A* from sector *j*:

$$A_j = \alpha_j \cdot \left(\delta_j \cdot L_j^{-\rho_j} + \left(1 - \delta_j\right) \cdot \overline{K}_j^{-\rho_j} \right)^{-1/\rho_j} \qquad (2)$$

where *α* reflects total factor productivity (TFP), *L* and *K* are labour and capital demands, and *δ* and *ρ* are share and substitution parameters. Our production functions permit technologies to vary across industries. Maximizing profits subject to Equation 2 gives the factor demand equations:

$$\frac{L_j}{\overline{K}_j} = \left(\frac{r \cdot Z_j}{W} \cdot \frac{1 - \delta_j}{\delta_j} \right)^{1/\left(1 + \rho_j\right)} \qquad (3)$$

where *W* is the labour wage and *r* is a fixed economy-wide capital rental rate adjusted by a sector-specific distortion term *Z*. The factor substitution elasticity is a transformation of ρ. Higher elasticities mean that producers can more readily substitute between labour and capital when relative prices change. Although not shown, our South African model differentiates between four education-based labour categories.

Leontief technology determines intermediate demand. Fixed input-output coefficients $io_{jj'}$ reflect the quantity of good j' used to produce one unit of good j. These technical coefficients are drawn from StatsSA (2010) and Arndt et al. (2011). The producer price *PA* is the sum of factor and intermediate payments per unit of output

$$PA_j \cdot A_j = W \cdot L_j + r \cdot Z_j \cdot \overline{K}_j + \sum\nolimits_{j'} P_j io_{jj'} \qquad (4)$$

3.2 International trade and carbon taxes

Imperfect substitution exists between domestic goods and goods supplied to and from foreign markets. A constant elasticity of transformation (CET) function determines the relationship between the quantity of domestically supplied goods *D* and exported goods *E*:

$$A_j = \pi_j \cdot \left(\sigma_j \cdot D_j^{\mu_j} + \left(1 + \sigma_j\right) \cdot E_j^{\mu_j}\right)^{1/\mu_j} \tag{5}$$

$$PA_j.A_j = PD_j \cdot D_j + PE_j \cdot E_j \tag{6}$$

where *PD* and *PE* are domestic and export prices. Similarly, a CES function defines the relationship between domestically produced goods *D* and imported goods *M*:

$$Q_j = \tau_j \cdot \left(\varphi_j \cdot D_j^{-\lambda_j} + \left(1 + \varphi_j\right) \cdot M_j^{-\lambda_j}\right)^{-1/\epsilon_j} \tag{7}$$

$$\left(1 - ts_j\right) \cdot P_j \cdot Q_j - tc \cdot cd_j = PD_j \cdot D_j + PM_j \cdot M_j \tag{8}$$

where *Q* is the composite supply good, *PM* is the import price, and *ts* is the sales tax rate. The parameter *tc* is the carbon tax value that is multiplied by the quantity of carbon *cd* embodied within primary fossil fuels, i.e., *cd* is a direct measure and so is only non-zero for coal, crude oil and natural gas. By imposing carbon taxes on the composite good *Q*, we assume that exported fossil fuels are exempt but imports are not. Import substitution and export transformation elasticities are from Dimaranan (2006).

Minimizing $PA_jA_j - PD_jD_j - PE_jE_j$ and maximizing $PQ_jQ_j - PD_jD_j - PM_jM_j$ subject to Equations 5 and 7, respectively, gives the ratios of *D*, *E* and *M* in Equations 9 and 10.

$$\frac{D_j}{E_j} = \left(\frac{\sigma_j}{1 - \sigma_j} \cdot \frac{PD_j}{PE_j}\right)^{1/(\mu_j - 1)} \tag{9}$$

$$\frac{D_j}{M_j} = \left(\frac{\varphi_j}{1 - \varphi_j} \cdot \frac{PM_j}{PD_j}\right)^{1/(1 + \lambda_j)} \tag{10}$$

Import prices *PM* and export prices *PE* are determined by world prices *pwm* and *pwe* and by the exchange rate *X*. World import prices are adjusted for import tariffs *tm*. Although not shown, the South African model also includes transaction costs on imported, exported and domestically supplied products. Transaction costs generate demand for trade and transport services and are subject to carbon taxes.

$$PM_j = \left(1 + tm_j\right) \cdot pwm_j \cdot X + tb \cdot ci_j \tag{11}$$

$$PE_j = \left(pwe_j - tr \cdot \left(cd_j + ci_j\right)\right) \cdot X - tb \cdot ci_j \tag{12}$$

Domestic BTAs *tb* are based on indirect carbon measures, i.e., on the carbon within the intermediate inputs used to produce the final product. A domestic BTA causes import prices to rise depending on their carbon content, which is calculated assuming that domestic and import technologies are similar (see Arndt et al. 2012). A domestic BTA also causes export prices to rise through rebates. When trading partners introduce their own carbon tax with a BTA equal to *tr*, then South Africa's import prices remain unchanged but export prices fall (i.e., foreign exporters receive rebates but domestic exporters are taxed in foreign markets). Foreign BTAs affect all exported products based on their direct and indirect carbon content (i.e., *cd* + *ci*).

The current account balance is the difference between total export earnings and import payments and, while not shown, net foreign factor payments and transfers. Our macroeconomic closure allows the exchange rate *X* to adjust to maintain a fixed level of foreign savings *F* (i.e., foreign capital inflows).

$$\sum_j pwe_j \cdot E_j + \bar{F} = \sum_j pwm_j \cdot M_j \tag{13}$$

3.3 Government and investment demand

Assuming all factors are owned by households, total income *Y* is given by

$$Y_h = \sum_j \left(\omega \cdot W \cdot L_j + \theta \cdot r \cdot Z_j \cdot \bar{K}_j\right) + st_h \tag{14}$$

where *st* are social transfers from the government, and coefficients ω and θ determine the distribution of factor earnings to individual households. The South African model also includes enterprises that earn the returns to capital and use these profits to pay corporate taxes, save and pay dividends to households.

The government is treated as a separate institution. Total revenue is the sum of direct and indirect taxes, including carbon taxes and BTAs, as shown on the left-hand side of Equation 15:

$$\begin{aligned}\sum_h td_h \cdot Y_h + \sum_j ts_j \cdot P_j \cdot Q_j + \sum_j tc \cdot cd_j \cdot Q_j + \sum_j tb \cdot ci_j \cdot \left(M_j - E_j\right) \\ = \sum_j P_j \cdot \bar{G} \cdot g_j + \sum_h st_h + B\end{aligned} \tag{15}$$

Revenues are used to purchase goods *G* and make social transfers *st*. Any remaining funds are (dis)saved, as shown on the right-hand side of Equation 15. Our macroeconomic closure for the government assumes that consumption spending is equal to base-year quantities *g* multiplied by an exogenous adjustment factor *G*. The recurrent fiscal balance *B* adjusts to equalize total revenues and expenditures.

Our savings-driven investment closure implies that total investment adjusts to the level of total savings. This is shown below

$$\sum_h s_h \cdot Y_h + B + \bar{F} \cdot X = \sum_j P_j \cdot I \cdot i_j \tag{16}$$

where *i* is fixed base-year investment quantities multiplied by an endogenous adjustment factor *I*.

3.4 Factor and product market equilibrium

Total labour supply LS is determined by upward-sloping supply curves that depend on the prevailing wage *W*, the base-year wage *w*, base-year labour supply *ls*, and a wage-supply elasticity ε. In equilibrium, total labour supply LS must equal the sum of all sector labour demands L:

$$LS = ls \cdot \left(\frac{W}{w}\right)^{\varepsilon} = \sum\nolimits_{j} L_j \tag{17}$$

Unlike labour, which is mobile across industries, capital is sector-specific. Both factor demand *K* and the rental rate *r* are fixed (see Equation 3) and the distortion term *Z* adjusts to equate capital demand and supply in each sector.

Finally, product market equilibrium requires that the composite supply of each good Q equals private and public consumption and investment demand. Market prices *P* adjust to maintain equilibrium. Producers' abilities to pass-through carbon taxes to consumer prices are moderated by demand's response to higher prices.

$$Q_j = \sum\nolimits_{h} H_{jh} + \bar{G} \cdot g_j + I \cdot i_j \tag{18}$$

Together, the above 18 sets of equations simultaneously solve for the values of 18 sets of endogenous variables (i.e., *A*, *PA*, *L*, *W*, *Z*, *D*, *PD*, *E*, *PE*, *M*, *PM*, *Q*, *P*, *X*, *Y*, *I*, *H* and *B*). The consumer price index (CPI) is our numéraire.

3.5 Investment and capital accumulation

Our recursive dynamic model has distinct within- and between-period components. The above equations specify the within-period component. Between-periods, exogenous variables and parameters are updated based on externally determined trends (i.e., labour supply *LS*, government consumption *G*, foreign capital inflows *F*, and technical change α) and on previous period results (i.e., capital accumulation *K*).

While not shown in Equations 1-18, each variable has a time subscript *t*. Sector-level capital stocks *K* are determined endogenously based on previous period investment. As shown below, the quantity of new capital *N* is based on the value of investment and the capital price *PK* (i.e., market prices *P* weighted by investment shares *i*). New capital is allocated to sectors after applying a depreciation rate υ and according to a capital allocation factor *SK* (0<*SK*<1; $\sum SK = 1$) (see Dervis, de Melo and Robinson 1982).

$$N_t = \sum\nolimits_{j} \left(P_{jt} \cdot I_t \cdot i_j\right) \cdot PK_t^{-1}$$

$$\bar{K}_{jt+1} = \bar{K}_{jt} \cdot (1 - \upsilon) + SK_{jt} \cdot N_t$$

$$SK_{jt} = SP_{jt} + SP_{jt} \cdot \left(\frac{SR_{jt} - AR_t}{AR_t}\right)$$

SP is a sector's current share in total capital stocks, SR is a sector's profit rate (i.e., $r \cdot Z_j$), and AR is the average profit rate. New capital is allocated in proportion to a sector's share of current capital stocks adjusted by its own profit rate relative to the national profit rate. Sectors with above-average profit rates receive a greater share of investible funds than their share in the existing capital stocks. This 'putty-clay' specification implies that new capital is mobile but installed capital is sector-specific.

3.6 Energy-saving investment behaviour

Between periods non-energy producers can respond to changing energy prices by investing in more or less energy-intensive capital and production technologies. This is shown below

$$\frac{io_{jet+1}}{io_{jet}} = 1 - \left(1 - \frac{P_{et}}{p_e}^{-\rho_e^k}\right) \cdot \frac{SK_{jt} \cdot N_t}{K_{jt}}$$

where the change in intermediate demand io for energy commodity e depends on changes in energy market prices P relative to base-year energy prices p. A sector's responsiveness to changes in energy prices depends on the share of new investment $(SK_{jt} \cdot N_t)$ in the sector's existing capital stock K. This specification implies that new investment (or newer 'vintage' capital) is required for a sector to adopt less energy-intensive technologies. Slower growing and less profitable sectors will find it more difficult to adjust to higher energy prices.

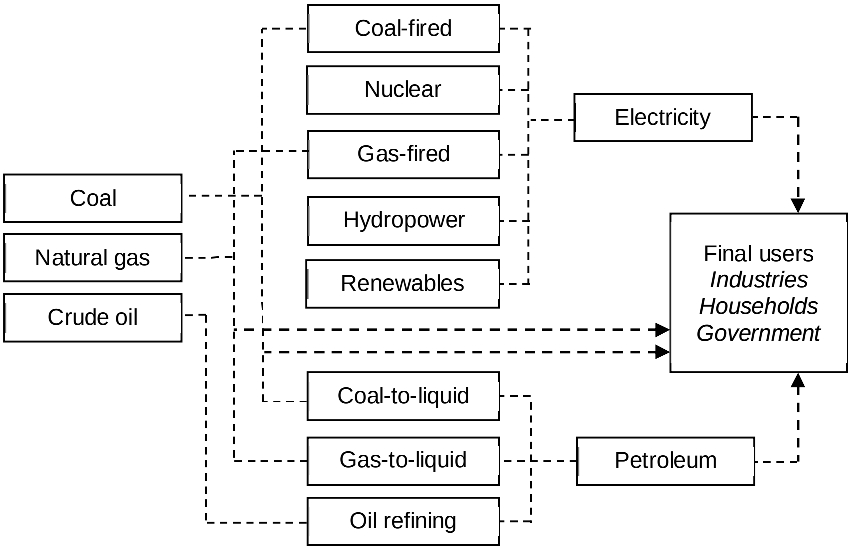
3.7 Energy subsectors

Our model includes a detailed treatment of the energy sector. As described earlier, the three primary fossil fuels, i.e., coal, crude oil and natural gas, are either transformed into electricity and petroleum or are used directly by final users, i.e., industries and households. Our model disaggregates electricity and petroleum into subsectors, as shown in Figure 2.

Coal and natural gas are used to produce electricity. Other sources include nuclear, hydropower (domestic and imported) and renewables (i.e., solar and wind). Each electricity subsector supplies its output to the national grid, where it is combined into a single electricity commodity. Each subsector has its own production technology, i.e., intermediate coefficients io. These technologies are based on Pauw (2007) and StatsSA (2009). The coal-fired electricity subsector gradually switches to cleaner coal technology based on projections from DOE (2011). Finally, coal and natural gas are used to produce petroleum via 'coal-to-liquid' (CTL) and 'gas-to-liquid' (GTL) transformation processes. However, more than 80 per cent of petroleum is still produced by refining imported crude oil.

In summary, our model captures the complex production and consumption linkages between industries and households, which allow us to measure both the direct and indirect effects of carbon taxes. The model allows us to evaluate domestic and foreign BTAs, as well as various revenue recycling options, including direct and indirect taxes and social transfers. In the next section we present the results of our carbon tax simulations.

Figure 2:
Structure of the energy sector in the CGE model



Source: Authors'illusration.

4 Simulation results

4.1 Baseline scenario

We first construct a baseline scenario that excludes carbon taxes (i.e., *cd* and *ci* are zero). Economic growth in the CGE model is determined by labour and capital supplies and technical change. An exception is the electricity subsectors, whose production paths follow the 'revised baseline' projections in Figure 1 (using load factors to translate capacity into output). Technical change is captured by exogenous TFP growth of one per cent per year in all sectors (α in Equation 2).

Given South Africa's skills constraints, we assume that secondary and tertiary-educated labour supplies are exogenous and grow at 2.0 and 1.5 per cent per year, respectively (i.e., ε in Equation 17 is zero and *ls* increases exogenously). To reflect high unemployment amongst low-skilled workers, we assume that the supply of primary-educated and uneducated workers is determined endogenously by an upward-sloping supply curve with modest real wage-supply elasticities (i.e., ε equals 0.1).[4] We conduct sensitivity analysis on labour market rigidities by imposing lower (0.05) and upper (0.3) bound elasticities. Elasticities close to zero suggest that unemployment is primarily 'structural' and that labour market adjustments occur through (negotiated) movements in real wages (see Devarajan et al. 2011). Higher elasticities suggest that employment levels, rather than wages, are more likely to respond to changing labour demands.

Investment and capital accumulation rates are determined by the level of savings. Since marginal savings rates are fixed (*s* in Equation 16), private saving is determined

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[4] Heintz and Posel (2008) provide empirical evidence of labour market segmentation in South Africa. This supports our assumption of less-than-perfectly-elastic labour supply and persistent open unemployment.

endogenously by private incomes (*Y*). We assume that foreign savings (*F*) and public savings (*B*) grow at roughly the same rate as national economic growth and thus remain a fixed share of total GDP in the baseline. Since government savings are endogenous, this implies public consumption growth of three per cent per year (*G* in Equation 15).

The above assumptions lead to average annual GDP growth of 3.9 per cent during 2010-2025, which is consistent with the growth rate used to forecast electricity demand (DOE 2011). Total labour employment grows at 2.6 per cent per year, implying an employment-growth elasticity of 0.67 and a gradual decline in the national unemployment rate (given annual population growth of 1.5 per cent).[5] GDP growth is fairly even across sectors as a result of uniform productivity growth and mobile labour. Overall, the baseline scenario provides a reasonable economic trajectory for South Africa.

4.2 Carbon tax scenarios

We now introduce carbon taxes and the resulting counterfactual simulations are compared to the baseline scenario. We simulate three carbon tax scenarios. The first simulation imposes a domestic carbon tax on the net supply of primary fossil fuels (i.e., *tc* in Equation 8 is now nonzero).[6] A carbon tax of US$3 (R21) per ton of CO_2 is introduced in 2012 and this rises gradually until it reaches US$30 per ton in 2022. We call this the 'production' scenario because the tax is imposed on all domestically produced goods. All carbon tax revenues are recycled through a uniform percentage point reduction in indirect sales tax rates for all products (i.e., *ts* in Equation 8 adjusts to maintain the baseline fiscal balance *B*).

The second simulation not only imposes a phased-in US$30 per ton carbon tax on fossil fuel supplies, but it also introduces a US$30 per ton phased-in BTA that taxes imports and rebates exports based on embodied carbon (i.e., *tb* in Equations 11 and 12 is nonzero and equal to *tc*). This compensates domestic producers by maintaining their import and export competitiveness even though trading partners do not introduce their own carbon taxes. The BTA means that South Africa only pays carbon taxes on consumed products, regardless of whether they are produced domestically or imported. We therefore call this the 'consumption' scenario and again assume that all carbon tax revenues are recycled through reduced indirect taxes.

The third simulation assumes that South Africa's trading partners introduce a carbon tax and BTA, but South Africa does not. This means that import prices remain unchanged, but export prices fall (i.e., *tr* in Equation 12 is nonzero). We set the foreign BTA at US$15 per ton, because it is unlikely that all trading partners introduce the same BTA and so exports can be redirected towards countries with lower or no taxes. The BTA is phased-in from US$1.50 in 2012 to US$15 in 2022. This is the 'foreign carbon tax' scenario.

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[5] The growth elasticity of employment is higher than in other emerging markets but is consistent with South Africa's experience during 2003-08.

[6] We tax fossil fuels at their point of entry into the economy, i.e., imported fuels (crude oil) are taxed at the border, and domestic fuels (coal and natural gas) are taxed at the mine-head. Even though an emissions-based tax is more efficient (see Devarajan et al. 2011), we conclude that its administrative complexity makes it an implausible option for South Africa over the near term.

Table 2
GHG emissions results, 2010-25

	Business-as-usual, 2010	Deviation from ‘business-as-usual’ scenario, 2025 (%)			
		Revised baseline	Production carbon tax	Consumption carbon tax	Foreign carbon tax
Total CO_2 emissions (mil.mt) using the reference approach	447.5	-8.6	-36.6	-36.2	-19.6
Electricity generation	237.0	-19.0	-19.0	-19.0	-19.0
Other sectors/households	210.5	0.0	-51.3	-50.5	-20.1
Total CO_2 emissions (mil.mt) using the sectoral approach	397.4	-8.6	-40.4	-41.4	-21.0

Notes: Includes CO_2 emissions from burning primary fuels but excludes other GHGs. ‘Sectoral approach’ includes the carbon embodied within imports and excludes carbon within exports. We assume that exported fossil fuels are exempt in the production carbon tax scenario but imported fossil fuels are not.

Source: CGE model results.

Table 2 shows the changes in CO_2 emissions in the three simulations. The table uses two metrics to measure carbon emissions. The ‘reference’ approach is based on fossil fuel supply, whereas the ‘sectoral’ approach accounts for the carbon embodied within imports and exports. For example, the latter approach includes the carbon within imported refined petroleum, which only indirectly uses crude oil. The former approach is consistent with a production-based tax (i.e., no BTAs), while the latter approach is consistent with a consumption based tax. In the Production scenario and using the reference approach, the phased-in US$30 per ton carbon tax reduces total emissions by 36.6 per cent relative to the ‘business-as-usual’ scenario. As discussed in Section 2, the revised baseline scenario in DOE (2011) projects a 19 per cent reduction in electricity sector emissions by 2025, which is equal to an 8.6 per cent reduction in total emissions. The production-based carbon tax, therefore, generates an additional 28 percentage point reduction in emissions, all of which comes from reduced carbon use in the non-electricity sectors. In the consumption scenario and using the sectoral approach, total emissions decline by 41.4 per cent by 2025, which is close to the national target. Both approaches result in similar total emissions reductions. Hence, the choice between a production- and consumption-based carbon tax depends principally upon economic impacts and political feasibility.

Table 3 presents macroeconomic results. A production-based carbon tax reduces total absorption in 2025 by 1.2 per cent below the baseline GDP level in 2025.[7] This implies a modest 0.08 percentage point reduction in the average annual absorption growth rate during 2010-25. This deceleration is mainly due to the effect of falling national incomes and savings on investment demand. Private consumption growth also decelerates, although this is offset by recycling carbon taxes through lower sales taxes. Exports also decline with a production-based tax because producers’ competitiveness is eroded in foreign markets. This prompts a slight depreciation of the real exchange to support exports and discourage imports.

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[7] Absorption is an aggregate welfare measure equal to the sum of private and public consumption and investment.

Table 3
Macroeconomic results, 2010-25

	Initial value, 2010	Baseline growth rate (%)	Deviation from baseline value, 2025 (%)		
			Production carbon tax	Consumption carbon tax	Foreign carbon tax
GDP at market prices (%)	100.0	3.91	-1.23	-1.07	-1.00
Absorption	100.1	3.93	-1.20	-1.04	-1.74
Household consumption	63.0	4.15	-0.63	-0.56	-2.06
Percentile 0-50	11.3	2.56	-0.78	-0.79	-1.74
Percentile 50-90	25.1	2.67	-0.67	-0.62	-2.07
Percentile 90-10	26.6	2.59	-0.52	-0.40	-2.17
Government consumption	19.2	3.00	0.00	0.00	0.00
Investment demand	17.9	4.38	-4.06	-3.48	-2.15
Exports	24.6	4.11	-0.88	0.24	-0.42
Imports	-26.6	4.19	-0.81	0.22	-3.19
Employment (1000s)	12,244	2.63	-0.56	-0.50	-0.83
High-educated workers	5,148	1.83	0.00	0.00	0.00
Low-educated workers	7,096	3.16	-0.90	-0.80	-1.32
Average wages (R per year)	74,303	2.72	-1.37	-1.20	-1.90
High-educated workers	116,709	4.11	-1.97	-1.73	-3.11
Low-educated workers	43,538	0.89	-0.92	-0.80	-0.39

Notes: High-educated labour includes workers with completed secondary or tertiary educations.
Source: CGE model results.

In the production-based approach, the carbon tax puts pressure on producers of traded goods because embodied carbon on imports is not taxed and embodied carbon in exports is not rebated. In contrast, a consumption-based carbon tax rebates exports and taxes imports making the implications for traded sectors unclear *a priori*. In the event, the consumption-based tax heightens incentives to produce for foreign markets resulting in a small increase in exports. Given a fixed trade balance, imports increase as well. The consumption-based tax maintains a higher level of employment and does not push resources out of (often more productive) traded sectors. As a result, the deceleration in absorption growth is smaller under the consumption scenario. A BTA therefore reduces the economic losses of a carbon tax and addresses concerns raised about a loss of export and import competiveness.

Labour demand declines with the introduction of a carbon tax due to slower national economic growth. This is reflected in slower employment growth for less educated workers and slower wage growth for more educated workers. Overall employment in the production scenario is 0.6 per cent below the baseline in 2025. This implies a modest 0.04 percentage point reduction in annual employment growth. As shown in Table 4, slower job creation occurs in the more export- and carbon-intensive mining and heavy industrial sectors, such as chemicals and machinery. This is offset by new production and job opportunities in less carbon-intensive sectors, such as food, textiles and financial services. Fewer job losses occur in the consumption scenario because exporters and import-competing producers are shielded by a BTA. The only exceptions are machinery and transport, which rely on imported carbon-intensive inputs that are now subject to the carbon tax, such as refined petroleum. Overall, the slowdown in job creation is relatively small, although more unionized industrial sectors are most affected.

Table 4
Sectoral employment results, 2010-25

	Employment share, 2010 (%)	Carbon-intensity measure, 2005	Deviation from baseline value, 2025 (%)		
			Production carbon tax	Consumption carbon tax	Foreign carbon tax
All sectors	100.0	0.265	-0.56	-0.50	-0.83
Agriculture	3.7	0.138	1.54	0.21	0.47
Mining	7.4	1.661	-5.43	-3.74	-2.03
Manufacturing	15.4	0.201	0.05	-0.13	-0.42
Food	2.7	0.154	1.05	0.41	-0.89
Textiles	1.0	0.115	1.84	0.19	0.42
Wood products	2.2	0.372	-0.83	-0.63	-0.79
Chemicals	2.0	0.422	-0.61	0.05	-0.83
Non-metals	0.8	0.312	-1.09	-1.02	-1.13
Metals	2.3	0.396	-0.22	0.95	-0.25
Machinery	1.8	0.092	-1.34	-1.84	-0.51
Vehicles	1.6	0.115	1.38	-0.08	0.74
Other	0.9	0.145	1.79	0.65	0.65
Other industry	4.9	0.513	-2.43	-2.08	-1.51
Services	68.6	0.162	-0.12	-0.13	-0.80
Trade	17.4	0.194	-0.30	-0.21	-1.04
Transport	6.5	0.171	-0.60	-0.89	-0.48
Finance	6.1	0.031	0.19	0.10	-0.63
Business	5.0	0.142	0.10	0.07	-1.06
Government	20.6	0.080	0.19	0.17	-0.43
Other	12.9	0.137	-0.31	-0.30	-1.19

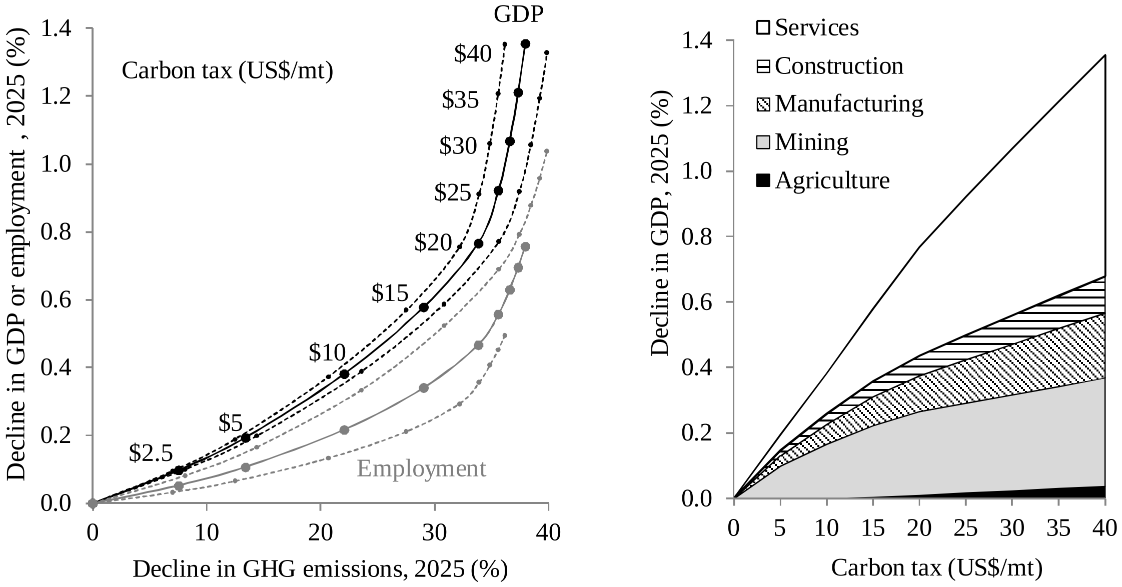
Notes: ‘Carbon intensity’ is tons CO_2 per R1000 (US$160) final demand in 2005 prices.

Source: CGE model results; carbon-intensity measures from Arndt et al. (2012).

We conduct sensitivity analysis on the size of the carbon tax and on labour market rigidities. The left-hand side of Figure 3 shows the final GDP losses in 2025 at different carbon tax rates (i.e., an economy-wide abatement cost curve), while the right-hand side shows the sectoral sources of GDP losses. The abatement cost curve is strongly non-linear and rises rapidly for carbon tax rates above US$20 per ton. This is because the economy initially reduces emissions in the more carbon-intensive sectors, such as mining. However, as carbon taxes rise, the economy’s ability to further reduce emissions becomes more constrained, and eventually even less carbon-intensive sectors are affected, such as services. More importantly, the electricity sector accounts for half of total emissions and its future emissions path is fixed. This implies that any further emissions reductions have to take place in non-electricity sectors, even if economy-wide abatement costs are higher.

Employment losses are also more pronounced at carbon taxes above US$20 per ton. The dashed lines in Figure 3 show results using lower and higher labour supply elasticities

Figure 3
Economy-wide abatement costs and their sectoral sources, 2010-25



Notes: Emissions reductions are in addition to the 8.9 per cent in the revised baseline scenario. The carbon tax is in 2005 prices and includes a BTA. Black dashed lines are GDP results using lower (top) and upper (bottom) bound labour supply elasticities. Grey dashed lines are employment results for upper (top) and lower (bottom) bound elasticities

Source: CGE model results.

(see Section 3). Not surprisingly, the estimated number of job losses is sensitive to the value of these elasticities. For example, the decline in employment by 2025 for a US$30 per ton carbon tax ranges from 0.71 to 0.32 per cent under more or less elastic supply, respectively. Estimates of GDP losses are far more robust—ranging from 1.04 to 1.07 per cent for a US$30 per ton carbon tax.

Changes in employment and wages also influence the distributional effects of carbon taxes. As shown in Table 3, the impact of domestic carbon taxes falls disproportionately on lower-income households due to their greater reliance on incomes from low educated workers. Real household consumption is also affected by changes in consumer prices. Arndt et al. (2012) measure the carbon intensity of household consumption patterns and show that they are lowest for households in the highest income deciles. These households are therefore less likely to be affected by carbon taxes and higher energy prices. Moreover, a BTA further reduces impacts on higher-income households, because they are more likely to receive the capital earnings from export-oriented sectors, such as mining and heavy industry. In the next section, we consider alternative revenue recycling options in order to alter distributional outcomes.

The above discussion has focused on the impacts of *domestic* carbon taxes. Should other countries unilaterally impose a carbon tax on South African exports, in the absence of a domestic carbon tax, it also causes South African emissions to decline (see Table 2). This is primarily due to a contraction of carbon-intensive exports and slower economic growth (see Table 3). Foreign BTAs reduce export prices for many of South Africa’s larger export sectors, causing the terms-of-trade to deteriorate significantly. Although the resulting real exchange rate depreciation encourages less carbon-intensive exports, it also raises the cost of import-intensive investment, which slows absorption growth. More importantly, South Africa does not collect revenues from foreign taxes. This means that falling private consumption is not offset by recycled revenues. As a result, employment losses are larger because private consumption is an important source of demand for labour-intensive products. Ultimately, total absorption (welfare) losses from a foreign carbon tax outweigh those of a domestic carbon tax. This supports pre-emptive action by South Africa to reduce its GHG emissions.

4.3 Revenue recycling scenarios

We evaluate how alternative revenue recycling options influence the growth and distributional impacts of domestic carbon taxes. The simulations above assumed that revenues are recycled through a uniform reduction in indirect sales tax rates (i.e., *ts* in Equation 8). This is compared to two other options. First, we reduce the corporate taxes imposed on the capital earnings of domestic enterprises. Second, we scale up existing social transfer programmes (i.e., *st* in Equation 14). In each scenario we impose the same carbon tax (gradually increasing to US$30 per ton) with a BTA. Table 5 summarizes the results for the recycling scenarios. Note that the sales tax scenario replicates the earlier consumption scenario.

Table 5
Alternative revenue recycling results, 2010-25

	Deviation from baseline, 2025 (%)		
	Sales taxes	Corporate taxes	Social transfers
Total CO_2 emissions	-41.40	-41.52	-41.57
Total GDP	-1.15	-0.68	-1.72
Absorption	-1.04	-0.58	-1.61
Total employment	-0.50	-0.82	-1.27
Average wages	-1.20	-1.97	-3.48
Per capita consumption	-0.56	-0.62	-0.87
Percentile 0-50	-0.79	-1.61	3.06
Percentile 50-100	-0.51	-0.41	-1.71

Note: CO_2 emissions are relative to 'business-as-usual' and measured using the sectoral approach.

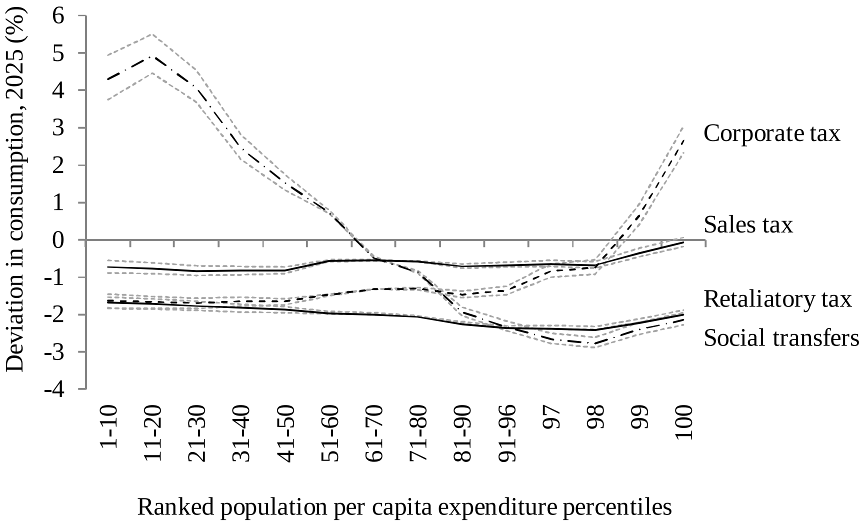
Source: CGE model results.

Each scenario generates emissions reductions that are broadly consistent with the national target of a 42 per cent reduction from 'business-as-usual'. Reducing corporate taxes leads to the smallest reduction in total GDP and absorption. This is because enterprises are a major source of domestic savings in South Africa and so reducing corporate taxes offsets the decline in investment. As discussed in Section 3, the rate of capital accumulation determines how quickly producers can shift towards less carbon-intensive sectors or energy-saving technologies. Higher investment therefore accelerates the adjustment process and reduces absorption losses relative to the sales tax scenario.

Figure 4 reports changes in per capita consumption for different household income groups. Lowering sales taxes is almost distributional neutral, as reflected by the horizontal consumption growth incidence curve. In contrast, households in the highest income percentiles are the main beneficiaries of corporate tax reductions, because a larger share of their income comes from capital earnings. This also generates larger employment losses than in the SALES Tax scenario, because high-income households consume more import- and capital-intensive products. All household groups outside the top five percentiles are worse off. Therefore, using all carbon tax revenues to reduce corporate taxes dampens the decline in investment and economic growth, but it results in a more regressive welfare outcome.

Using carbon tax revenues to expand social transfers (based on current allocations) leads to strongly progressive welfare outcomes. This is shown in Figure 4, where households in the bottom five deciles benefit from the carbon tax, whereas consumption falls for higher-income households. However, household savings rates in South Africa are low, especially amongst low-income households. Directing revenues towards these households consequently leads to lower levels of savings and investment (see Table 5). In contrast to the corporate tax scenario, a lower investment slows the adjustment process and worsens the deceleration of GDP and absorption growth. Therefore, while carbon tax revenues can be used to benefit low-income households, this comes at the cost of lower national absorption (welfare) and employment.

Figure 4
Per capita consumption changes under retaliatory taxes and revenue recycling schemes



Notes: Relative to a ‘no carbon tax’ baseline. Revenues scenarios include a BTA.
Faint dashed lines are results using lower or upper bound labour supply elasticities.

Source: CGE model results.

5 Conclusions

South Africa is considering using carbon taxes to reduce its high levels of greenhouse gas emissions. There are concerns that this will impose substantial adjustment costs on the economy. We have extended previous impact assessments for South Africa by constructing a dynamic economy-wide model that is linked to projections from an energy sector model. Unlike previous studies, ours incorporates South Africa's long-term electricity investment plan; captures rigidities in both capital and labour markets; and allows industries to invest in energy-saving technology.

A carbon tax of about US$3 per ton in 2012 rising linearly to US$30 per ton by 2022 reduces emissions to targeted levels. In considering the welfare impacts of the tax, one challenge is to identify an appropriate baseline scenario (counterfactual) that captures what would occur if South Africa decided against the introduction of carbon taxes. If the baseline scenario is characterized by free disposal of emissions, constant world prices, and no behaviour change on the part of South Africa's trading partners, then simulation results indicate that domestic carbon taxes reduce national income and employment, although losses are smaller than previous estimates. However, these assumptions about the baseline may be inappropriate. Most obviously, this welfare analysis considers in detail the economic costs of a carbon tax but ignores all benefits from reduced emissions. Less obviously, we find that if South Africa's trading partners were to unilaterally impose carbon taxes with BTAs, then South African export prices decline without raising additional tax revenues. Under this plausible baseline, a domestic carbon tax may actually increase national welfare.

Across all scenarios, economic costs are small at low levels of carbon taxes but increase with the level of the tax. Economic costs become particularly pronounced at tax levels greater than about the US$20 per ton level. The phased introduction of the tax over a ten year period thus provides a window to implement, evaluate and adjust. Notably, we find that BTAs that rebate exports and tax imports based on carbon content reduce economic costs while delivering essentially the same emissions reductions. Growth and distributional impacts are also found to depend on how carbon tax revenues are recycled. In our principal scenario, revenues from carbon taxes are used to reduce indirect sales taxes. This scenario is distribution neutral. We compare reductions in indirect taxes with two additional options and discovered trade-offs. Reducing corporate taxes favours economic growth and higher-income households, but the welfare of most of the population deteriorates. Expanding social transfers improves the welfare of low-income households but leads to larger declines in national income. In addition, we test the robustness of our findings to assumptions about labour market rigidities and technology substitution possibilities. This sensitivity analysis shows that estimated employment losses depend on labour market assumptions, but estimated national income and welfare losses are more robust.

The agenda for future research is large. We consider only six areas. First, the appropriate baseline or counterfactual is important and merits further scrutiny. For example, in the absence of global climate policy, future fossil fuel prices are expected to be higher and more volatile. The baseline could incorporate the risks from continued dependence on fossil fuels. Second, we used South Africa's supply-use tables to estimate BTA rates. These estimates should be refined based on the country-specific energy and industrial technologies of trading partners. Third, more detailed analysis is needed to identify the optimal combination of recycling options, including a political economy assessment. Furthermore, other recycling options were not considered, such as accelerated depreciation allowances, public-funded research into cleaner energy-saving technologies, and targeted energy subsidies for low-income households. Fifth, although we allowed industries to adopt energy-saving technologies, the analysis would benefit from firm- and sector-level estimates of marginal abatement costs.

Finally, and perhaps most importantly, the emissions reductions in South Africa's electricity investment plan may be inconsistent with national emissions targets. Our analysis showed that preferential treatment for the electricity sector places considerable pressure on the non-electricity sectors to reduce their emissions. The current investment plan is based on estimated abatement costs within the electricity sector. However, further work is needed to determine whether the investment plan would change if *economy-wide* abatement costs are considered. Moreover, taking greater advantage of regional energy options, such as hydropower, might reduce South Africa's abatement costs. It might also reduce the need for large carbon taxes and assist South Africa in transitioning to a low carbon development path.

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