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Tax Policy to Reduce Carbon Emissions in a Distorted Economy: Illustrations from a South Africa CGE Model*

Shantayanan Devarajan, Delfin S. Go, Sherman Robinson, and Karen Thierfelder

Abstract

Noting that developing countries may not have the administrative capacity to levy a "pure" carbon tax, we compare the impact of alternative energy taxes with that of a carbon tax in an economy with multiple distortions. We use a disaggregated computable general equilibrium (CGE) model of the South African economy and simulate a range of tax policies that reduce CO_2 emissions by 15 percent. Consistent with a "first-best" economy, a carbon tax will have the lowest marginal cost of abatement. But the relationship between a tax on energy commodities and one on pollution-intensive commodities depends critically on other distortions in the system and on structural rigidities in the economy. We demonstrate that if South Africa were able to remove distortions in the labor market, the cost of carbon taxation would be negligible. We conclude that the welfare costs of taxing carbon emissions in developing countries depend more on other distortions than on the country's own carbon emissions.

KEYWORDS: carbon tax, carbon emission, marginal cost of abatement, tax policy

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From Pigou (1920), we know that a direct tax on carbon emissions is the most efficient tax instrument for CO_2 abatement. In developing countries, however, targeting environmental taxes accurately can be a problem because it is difficult to monitor emissions and enforce such policies. Furthermore, these countries lack institutions that could effectively administer a tax on carbon emissions or other market-based instruments such as tradable permits (Aldy *et al*., 2008, Summers, 1991, and Schmutzler and Goulder (1997)).

Noting that indirect instruments do not require knowledge of actual emissions, Eskeland and Devarajan (1996) suggest that taxes on pollution-intensive goods, especially if they already exist, may be easier to implement than a pollution tax. In the case of CO_2, countries can tax energy commodities or sales of pollution-intensive commodities to reduce carbon emissions.[1] Fullerton *et al.* (2001) criticize these tax policies as "missing the target." Using an analytical general equilibrium model, they compare the welfare effect of taxing output rather than emissions and find that the welfare gain from an output tax is less than half the gain from an emission tax. However, their stylized framework does not include policies and other distortions important to the analysis of emission policies in developing countries.

In this paper, we use a detailed computable general equilibrium (CGE) model of South Africa to explore the implications of using tax policy to mitigate CO_2 emissions in a second-best environment characterized in particular by labor market distortions. We focus on labor market distortions because they are arguably the most important in developing countries in general, and in South Africa in particular. We capture three features of the labor market. The first is the high degree of unemployment among low- and medium-skilled workers. Efforts to redress the inequities of apartheid have resulted in labor regulations and union agreements that have generated rigidities in the labor market and high unemployment.[2] Banerjee *et al.* (2007) and others have characterized South Africa's high equilibrium unemployment rate among the low and medium-skilled workers as structural. Second, high demand for skilled labor brought about by the recent economic transformation of South Africa has not spilled over to the lower skilled: the skill gap is too wide, and the two groups are not substitutable. Third, the combination of reduced labor mobility and increased friction in exits from employment that arose from labor regulations and union agreements have given

[1] Pollution in this paper refers only to CO_2 emissions.

[2] Unlike in developed countries, labor market distortions do not stem from labor taxes that affect labor-leisure choice. We do not model labor-leisure choice and the effects of factor taxes as in Parry *et al.* (1999), and Bovenberg and Goulder (1997). Instead, we focus on distortions more relevant to South Africa and other developing countries, such as rigid wages and differential wages across sectors for workers with the same skills. Moreover, labor taxes are not a significant source of tax revenue.

rise to the marginal product of labor differing in equilibrium across sectors, even for the same type of worker.[3]

To capture these structural features, which are very pronounced in South Africa, our model differentiates 43 production activities, several taxes, and three types of labor – low-skilled, medium-skilled, and high-skilled. In our model, wages can adjust collectively to generate the level of employment feasible under the structural constraints. However, fixed sectoral "wedges" in wages prevent the complete reallocation of labor across industries to equalize the marginal product of labor (see Go *et al.* (2010) for a detailed description of South Africa's labor market and how it is modeled). We also test an alternative interpretation, namely that high unemployment is not completely structural – it is caused by high and rigid real wages for low and medium skilled labor because of strong union bargaining and representation in government. In this alternative, unemployment can vary and wages for lower skilled labor are fixed but can still differ across sectors.

Our contribution to the literature on tax policy and CO_2 abatement is therefore an empirical analysis that extends the analytical models towards a second-best environment more characteristic of developing countries. With this model specification, we compare the effects of different tax instruments that achieve the same amount of carbon reduction: (1) a tax on pollution directly using a 'pure' carbon tax; (2) a proxy tax on energy commodities (coal, petroleum, and electricity); and (3) a proxy tax on pollution-intensive commodities.[4]

Like many papers in the public finance literature, the welfare analysis is derived from Sandmo's (1975) extensions of Diamond and Mirrlees (1971), which show how the cost of taxing an externality-creating commodity depends on the other taxes in the system and the marginal social damage. By targeting a given level of carbon reduction (15 percent in this case), we avoid having to measure the social damage of CO_2 in the atmosphere; the different tax options are comparable because they achieve the same reduction in emissions. The welfare results therefore look only at the cost side, considering what society in a developing country might have to pay in order to reduce emissions at the margin with different tax instruments. Our paper extends the empirical estimation of the marginal cost of public funds for revenue purposes, as in Devarajan *et al*. (2002), to include the marginal cost of carbon taxation in a distorted economy.

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[3] Such labor market fragmentation - reduced mobility, structural unemployment, sector-specific factor productivity differences as well as limited substitutability among labor types that enhances the structural features – exists in varying degrees in developing countries and has been incorporated in CGE modeling of developing countries (see Robinson (1989) and Devarajan *et al.* (2002)).

[4] Whalley and Wigle (1991) also explore the effects of using different tax instruments to reduce CO_2 emissions.

Fullerton and Heutel (2007) show that the general-equilibrium incidence of environmental taxes depends on factor intensities of labor, capital, energy, and carbon emissions in economic activities, as well as the varying elasticities of substitution among factors, energy inputs, and outputs. Extending that conceptual work, the empirical application in this paper uses the detailed economic structure and levels of substitution possibilities found in Devarajan *et al.* (2009) for South Africa. Elasticities of substitution in developing countries are generally low, but we also examine a "rigid" case where the relevant substitution parameters among the factors above are even lower, a case likely in South Africa. Consistent with Fullerton and Heutel, our tax results are quite sensitive to production elasticities. For example, the carbon tax needed for a 15 percent reduction in emission declines to one-fifth of the tax rate needed when the elasticity of substitution between energy and capital increases from zero to 0.2 and the elasticity of substitution among energy inputs increases from zero to 0.1.

We also look at the potential for a double dividend when the additional tax revenue from CO_2 abatement is recycled to reduce pre-existing tax distortions in the economy. This is a prominent issue in the environmental tax literature.[5] Noting that factor taxes are generally less important than indirect taxes as revenue sources in developing countries – South Africa does not impose any factor taxes – we look at the implications of revenue recycling by reducing all indirect taxes (production taxes, sales taxes, and import tariffs) that are not part of the policy experiment, while maintaining revenue neutrality. [6] The experiment is similar to Goulder (1998) but applied to distortionary taxes more relevant to developing countries.

In South Africa, institutional distortions rather than tax distortions in the labor market will affect the welfare impact of a tax on carbon emissions. Welfare changes depend on the indirect general equilibrium effects of a tax policy change on factor prices and how the latter affect incomes of households. Given sector-specific factor productivity differences, a policy shock that moves labor to different sectors will have an additional impact on factor income – for example, labor that moves to a low productivity sector will receive a lower income following the policy shock. We consider a hypothetical case in which the marginal product of labor is equal across sectors. This permits us to decompose welfare changes into the tax policy effects and factor-market-distortion effects.

[5] See Bovenberg and Goulder (2002), Goulder (1998), Jorgenson and Wilcoxen (1993), McDonald, Robinson, and Thierfelder (2008), and Fullerton and Metcalf (2001).

[6] Liang *et al*. (2007) explore the possibility of using revenue from a carbon tax to support production in energy and trade-intensive sectors in China. Xie and Saltzman (2000) discuss issues of CGE modeling of environmental policies in developing countries and analyze pollution emission taxes and pollution abatement subsidies.

Finally, we consider the sensitivity of our welfare results to our assumption about unemployment.

Three key results add to previous findings in the literature. Like others, we find that a direct tax on carbon emissions imposes the lowest distortion, where household welfare declines roughly by 0.3 percent in order to reduce emissions by 15 percent. An indirect tax on pollution-intensive commodities imposes a higher cost – by as much as 10 times that of a carbon tax, an amount that is much higher than suggested in the conceptual approach. This is because the possibilities of substitution among labor types are quite low in developing countries and particularly in South Africa.

Second, the welfare cost is very sensitive to factor market distortions. In the extreme case of limited flexibility in production and sector-specific factor productivity differences, a sales tax on energy inputs is better in terms of welfare than even a direct tax on carbon. Furthermore, the welfare cost of reducing emissions across a range of tax instruments is significantly lower when labor flexibility in production is improved, indicating that the problem with carbon taxation is its interactions with existing factor market distortions, not 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.

Finally, the effects on equity differ from the ranking of tax policies by aggregate welfare effects. We find that a carbon tax is regressive because low-income households spend a larger share of their income on goods whose prices increase with a tax on carbon – electricity and water. A sales tax on energy inputs is less regressive, particularly if it is difficult to substitute among factors in production. When it is difficult to substitute between capital and energy inputs, the return to capital declines more, reducing income of the richer households who own the capital stock.

Section I of the paper is a brief overview of the economic framework. Section II discusses the simulation results, and section III draws general conclusions.

I. Modeling Energy and CO_2 Emissions in South Africa

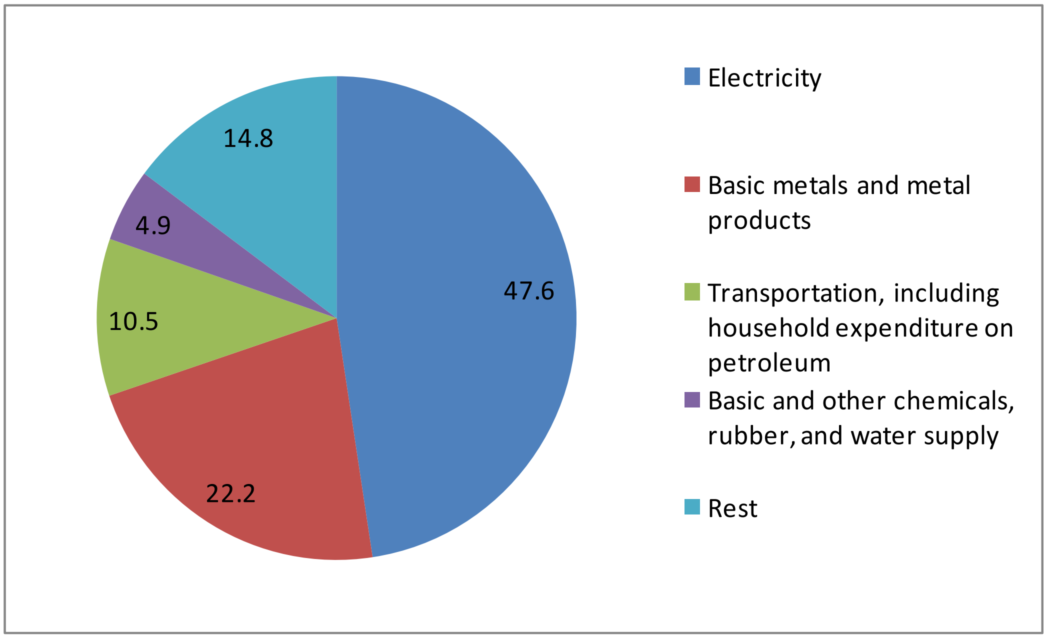
South Africa's energy-related CO_2 emissions are relatively high among developing countries, estimated to be 8.5 metric tons per capita in 2006, placing it ahead of China (4.7), Mexico (4.3), Mauritius (3.0), Botswana (2.5), Brazil (1.9), India (1.4), and Nigeria (0.7), but behind South Korea (9.8).[7] It has surpassed the European Union (8.2) or advanced countries such as Spain (7.9), France (6.2), and

[7] World Bank's *World Development Indicators* database.

Portugal (5.6), but not United Kingdom (9.1), Germany (9.7), and the United States (19.3). Because of the size of its economy, its aggregate emissions of 443.6 million metric tons ranks 11th globally, placing it among developing countries behind China (6018), India (1293), and Iran (477), and just ahead of Mexico (436) and Brazil (377). Within Sub-Saharan Africa, Nigeria (101) is a distant second to South Africa in aggregate emissions.

South Africa's energy supply mix is heavily skewed towards coal - 82 percent of the energy-related CO_2 emissions are attributed to coal; only about 17 percent is due to oil and a very small amount (1 percent) is due to natural gas.[8]

Figure 1: Sectors emitting the most CO_2 in South Africa



Source: CGE model data base in Devarajan *et al.* (2009).

Taxes on the purchase of energy commodities are relatively low in South Africa, suggesting some potential for using tax policy to regulate carbon emissions. Among energy inputs, a 15.4 percent sales tax is applied to purchases of refined petroleum, but basically none is applied to coal, electricity and gas.[9]

The CGE model of South Africa contains detailed treatment of the country's energy use, energy taxes, and CO_2 emissions as well as its labor market problems – see Devarajan *et al.* (2009). "Energy" refers to energy inputs (such as coal, petroleum, and electricity) utilized in production by each sector. "Carbon

[8] IEA (2006).
[9] Sales taxes are *ad valorem* equivalent.

emissions" refer to fossil fuel emissions and not emissions from land-use change and forestry.[10] We use a nested CES production structure common in the CGE literature on energy analysis: coal, petroleum, and electricity form an aggregate energy input which is combined with capital. The capital-energy input is then combined with aggregate labor, which is an aggregate of different skill-types. With this specification, producers substitute among energy inputs as their prices change.

Like other developing countries, South Africa is already replete with taxes and labor market distortions. The welfare impact calculated by the CGE model therefore captures whether the introduction of a new tax exacerbates or dampens these existing distortions through the economy-wide effects on relative prices and factor incomes received by households. We assume a standard public finance closure, holding government's real spending, real investment, and aggregate foreign savings constant.[11] 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, government revenue is fixed, 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.

One feature that characterizes the labor market in South Africa is the high rate of unemployment among low-skilled and semi-skilled workers. We first take the approach that the high unemployment is structural – that is, the nonparticipation of the less-skilled who are jobless is caused by structural problems and the protection of labor in South Africa, and not a voluntary choice. We assume that these structural factors, and hence the level of unemployment, will not be affected by a tax on carbon emissions. Accordingly, we model all the labor market categories with aggregate employment or relevant labor supply fixed exogenously, its elasticity being zero, and wages varying to clear the labor market at that employment level. We also consider the case in which unemployment is caused by high and rigid real wages. We fix real wages for lower skilled labor and allow unemployment to vary with the implication that their labor supply is

[10] Land-use effects in agriculture and deforestation are outside the scope of the paper. Moreover, unlike other African countries, agriculture accounts for a very small share of the economy at only 4 percent of GDP. Land devoted to agriculture has not changed very much from 80.2 percent of land area in 1990-92 to 82 percent in 2003-05. Unlike many countries, deforestation is also negligible. Forest area in South Africa has remained constant at 92 thousand sq. km from 1990 to 2005. Data are from World Bank *World Development Indicators, 2009.*

[11] Since we have a static model, savings and investment are accounting items.

therefore perfectly elastic. Given these specifications of the labor markets and the fact that the model is static, we do not model labor-leisure choice directly.[12]

Given the focus of the paper, we do not model dynamics or the incentives for producers to adopt carbon-saving technology for production directly. The welfare costs will therefore be an overstatement. The analysis also does not consider practical design issues and the administrative costs of a carbon tax.[13]

II. Scenarios and Results

Given a target reduction of CO_2 emissions, the economic cost or impact of various tax instruments depends on three 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.[14]

We examine three alternative taxes to reduce CO_2 emissions in South Africa by 15%: i) a carbon tax; ii) a sales tax on energy commodities (coal, petroleum, and electricity); and iii) a sales tax on pollution-intensive commodities (basic iron and steel, transportation, basic non-ferrous metals, and metal products excluding machinery)[15]. Except for the specific tax on carbon, all other simulated taxes are *ad valorem* taxes. The level of the tax (the absolute increase in the tax rate over its base year rate) is adjusted to meet the emissions target. Energy and pollution-intensive outputs are purchased both by producers as intermediate inputs and by households as final goods. The initial expenditure shares for producers and households are based on data in the Social Accounting Matrix (SAM) for South Africa.

The simulated 15% cut in emissions is a significant reduction when held against the actual performance of Kyoto signatories. But it is still far from what is required if climate is to be stabilized this century, when the average per capita emissions for the globe may have to reach between 1 and 2 tons per capita. We consider the sensitivity of the effects of a tax on carbon to the emission target.[16]

When no other tax rate is changed (i.e. there is no "revenue recycling"), the additional tax revenue is returned to households through lump-sum transfers,

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[12] This approach is standard in the development literature, especially in the presence of unemployment, low income, or a borrowing constraint.

[13] See brief discussion and references cited in Devarajan *et al.* (2009).

[14] The importance of elasticities of substitution is noted in Devarajan *et al*. (2002) and Fullerton and Heutel (2007).

[15] The pollution-intensive commodities have the highest CO_2 coefficients per unit of output. Calculations were done using data on CO_2 coefficients for energy inputs and intermediate use of energy inputs from the Social Accounting Matrix (SAM) for South Africa. See Devarajan *et al*. (2009) for a more detailed discussion of the ranking and data used.

[16] More simulations are available in Devarajan *et al.* (2009).

thus maintaining revenue neutrality. Since the model has several household groups, we make this as neutral as possible by effectively adjusting the saving rates so that the aggregate household expenditure for each group is affected uniformly.[17]

In the reference case, as is common in the literature on CGE models of developing countries, the elasticity of substitution is low: 0.2 among energy inputs and 0.4 between energy and capital. For the rigid case, the value of the elasticity parameter is halved to 0.1 for energy inputs and 0.2 for capital and energy, thus bordering on the Leontief case of no substitution. The latter case in effect provides a proxy for various factors 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 the reference and the rigid cases, the elasticity values are still generally low.[18] We relax this assumption in one set of simulations below.[19]

Table 1 shows the welfare impact associated with the policy change (measured as standard equivalent variation in monetary equivalent of the change in utility). These welfare measures are comparable because they all reach the same CO_2 emission target. They thus look only at the cost side of the cost-benefit calculation by construction. The welfare results are expressed as percent change from the base expenditures for easy comparison. Equity implications are derived for household groups by income deciles. The total welfare change is a simple aggregation of the welfare results for all households groups; no additional weighting scheme is attempted. Reflecting the high 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).

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[17] Other changes in household income that are revenue-neutral are possible. For example we could give an equiproportionate change in household savings rates rather than an equal absolute change in the household savings rate. This approach would transfer more revenue to the households with the highest savings rates.

[18] Other elasticities of substitution in production are also low. The elasticity of substitution among labor types (skilled, semi-skilled, and unskilled) is 0.5; the elasticity of substitution between the labor aggregate and the capital-energy aggregate is 0.75. See Devarajan *et al*. (2009) for a diagram showing the nesting structure used for production.

[19] One can also interpret the rigid case as representing the short run, in which it is difficult to change the composition of capital and energy inputs. Over time, as producers adjust to price signals, it will become easier to substitute among inputs (reference case). In the long run, producers may find alternative production technology, for example shifting away from coal and into hydro for electricity production. We do not explore changes in production technology in this paper. It is an important area for future research.

Table 1: Welfare impacts of a 15% reduction in CO_2 emission using tax policy

Equivalent variation as a percent of baseline household expenditure

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

Source: CGE model simulations.

Notes: Energy commodities = coal, electricity and gas, and petroleum; pollution-intensive commodities = 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.

The welfare impact has an interesting pattern and confirms the principle that it is best to tax a distortion at its source. 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 the lowest. It benefits from behaving like a factor tax, affecting directly the carbon content in each sector, without the cascading effects of input taxes. It is followed by the sales tax on energy commodities where the welfare impact is twice that of the carbon tax. Although the welfare results look only at the cost side of the taxes for a similar reduction of carbon emissions, the difference in magnitude is very similar to Fullerton, Hong, and Metcalf (2001) despite a more complicated economic and tax structure. The sales tax on pollution-intensive outputs is the worst, with its cost reaching almost 10 times that of a direct carbon tax. Its indirect and negative impact affects many economic activities since these commodities are important intermediate goods. Unlike energy inputs, producers cannot substitute other inputs for the more expensive pollution-intensive commodities used in production.[20]

The story becomes more complicated when the economy is not flexible– in the rigid case, the sales tax on energy inputs is the most economically efficient among the taxes. In this case, lower economic flexibility prevents significant substitution and wider dispersion of the higher energy cost throughout the economy. It is difficult for producers to substitute capital for energy so pollution-intensive commodities contract more than when the production structure is more flexible. Likewise, non-pollution-intensive commodities expand further. When the economy is less flexible, the welfare effects are as expected for a carbon tax and a tax on pollution-intensive goods – in each case welfare declines more when the economy is rigid. Interestingly, a sales tax on energy commodities does better in the rigid case than in the flexible case. It also has the best welfare results among the tax instruments in the rigid case. Some of the welfare change can be attributed to second best effects of tax changes in a distorted economy, particularly the presence of sector-specific factor productivity differences in the context of different energy contents of sectors. In particular, output of low energy commodities with high factor productivity expand the most following a sales tax on energy, offsetting some of the negative welfare effects. Examples of sectors with relatively low energy intensity and high factor productivity in South Africa are its sophisticated financial services and agriculture.[21] As noted later in Table 2, when sector-specific factor productivity differences are removed and the simulations re-run, a sales tax on energy commodities is not the best tax in terms

[20] Trade implications are not the focus of the paper, but energy taxes will affect South Africa's trade patterns. A tax on energy inputs will lead to a decline in petroleum output and imports of crude oil. Given the high share of crude oil in total imports, the net effect is an appreciation; other imports must increase to maintain a constant nominal current account balance (a model closure assumption). A tax on carbon has the opposite effect on the exchange rate, it reduces demand for coal, the dirtiest input. Coal has a very small import share. Instead, the domestic costs of production increase, imports appear more attractive, and the exchange rate must depreciate to maintain the current account balance. In the case of revenue recycling, border taxes do adjust and the exchange rate effect will be enhanced. The direction of exchange rate changes in response to different tax instruments, is the same for both the reference and the rigid case.

[21] See Devarajan *et al*. (2009) for more description of output changes following the policy shocks.

of welfare costs. Reducing the substitution elasticities has a minimal impact on the welfare loss associated with a carbon tax. It remains low, with a decline of 0.35 rather than 0.33 percent in the flexible case. The worst case continues to be a sales tax on pollution-intensive commodities.

The equity impact of each tax is different from the efficiency impact. The sales tax on energy commodities has the best results as it imposes no burden on the lower income groups. In this scenario, there is a dramatic increase in the price of petroleum for which poor households have lower expenditure shares compared to rich households. The sales tax on pollution-intensive commodities places no burden on the lowest income groups, but unlike the sales tax on energy commodities, it hurts some of the lower income groups. The carbon tax is generally regressive, imposing the highest relative burden on the lower income groups. The poorest households spend more of their income on electricity and water, commodities whose prices increase with a tax on carbon. 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. 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. The equity impact depends, in large part, on the consumer price index faced by different households.[22]

Revenue recycling can improve the welfare effects of energy taxes by using the revenue generated to reduce other taxes, typically factor use taxes.[23] However, South Africa, like other developing countries, does not have factor use taxes. Hence, we simulate revenue recycling by reducing other indirect taxes (production taxes, sales taxes, and import tariffs), that are not part of the policy experiments.[24] Also, no revenue is recycled back to reduce base taxes on energy inputs or pollution-intensive commodities (instead those rates are held at base values, unless they are increased in the policy experiment). While this approach retains some distortions in taxes that do not target CO_2 emissions, it avoids contradictory or conflicting effects on incentives to emit CO_2.

We find a similar pattern of results for total welfare changes in the case with revenue recycling. When the instrument is either a tax on carbon or a tax on

[22] We compute the consumer price index by household income group (not shown but available). The pattern of price changes followed and supported the equity impact described in the paragraph.

[23] A reduction in the tax on capital use has particularly strong benefits in a dynamic model – see Jorgensen and Wilcoxen (1993).

[24] This is accomplished through an equi-proportionate change in the tax rates for all indirect taxes (production taxes, sales taxes, and import tariffs). If the revenue generated by taxes to reduce CO_2 emission exceeds the revenue that would be collected from other indirect taxes, the remaining revenue is redistributed to households in a lump-sum.

energy commodities, the welfare costs are slightly less with revenue recycling.[25] Interestingly, when the instrument is a tax on pollution-intensive goods, revenue recycling generates a slightly bigger welfare loss. In this case, the tax instruments used to reduce CO_2 emissions increase more than the case of no revenue recycling (because of greater economic activity in the sectors whose taxes are now lowered), so the distortion created to target the CO_2 reduction is bigger than in the other simulations.

Sensitivity of the welfare impact to factor market distortions

First, we examine the welfare effects of sectoral differences in productivity for each factor. We model this distortion by specifying fixed ratios of the marginal product of a factor in a sector to the average return of that factor, which act as fixed wage differentials across sectors for labor of the same type. In a simulation, the average wage adjusts to allow employment to reach the level permissible under the structural constraints in the labor markets. This type of factor-market distortion, specified as wage differentials by which wage rates are flexible but unequal between sectors for identical factors, has a long history in trade theory (see, for example, Bhagwati and Srinivasan (1971), Jones (1971), and Neary (1978)). It has also been widely adopted to introduce factor market distortions and labor segmentation in CGE models applied to developing countries (see, for example, Dervis *et al.* (1982)). In this paper, we describe the effects of sector-specific wage differentials on the analysis of a carbon tax and public finance issues in developing countries. This modeling has the effect of a tax at a different rate on different uses of labor, but without a public revenue effect. Instead factor incomes reflect the sector-specific wage differentials. We examine the impact of factor productivity differences by sector on the marginal cost of a new tax policy by specifying a "distortion free" base where there are no differences.[26] Revenue is returned to households by lump-sum transfer. 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.

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 (experiment I in Table 2). The worst case remains the sales tax on pollution-intensive commodities. These results indicate that the relatively low welfare losses in the reference case were due in part to the factor

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[25] Like Timilsina and Shrestha (2002), who analyze welfare changes following a carbon tax in Thailand, we find a weak double dividend for a tax on carbon and for a tax on energy commodities.

[26] Since we eliminate the distortion, we show the extreme values for welfare impacts –with and without current factor market distortions.

market distortions—labor moved to higher productivity sectors, such as finance and agriculture, when the carbon tax was imposed. The pattern when the economy is more rigid is what one would expect – all tax instruments reduce welfare further. For either type of flexibility in the economy, the most direct tax instrument has the least welfare loss and the least direct tax instrument causes the greatest welfare loss. Recall that this pattern was not evident in the rigid-case results from Table 1, when the factor market distortions were in place.

Table 2: Welfare impacts of labor market distortions or specifications

Equivalent Variation as a percent of baseline household expenditure

	tax on carbon emission by activities	sales tax on energy commodities	sales tax on pollution-intensive commodities
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. Distortion free base (no sectoral differences in factor productivity and no indirect taxes)			
Reference case	-0.48	-1.08	-3.81
Rigid case	-0.70	-1.46	-4.37
III. Higher substitution elasticity among all labor and capital-energy			
Reference case	0.04	0.91	-1.84
Rigid case	0.26	2.42	-2.17
IV. Unemployment in the low and medium skilled workers			
Reference case	-0.90	-2.94	-9.01
Rigid Case	-1.01	-3.27	-11.14

Source: CGE model simulations.

We also consider the welfare effects of energy taxes against a distortion-free base in which we eliminate all indirect taxes and sector differences in factor productivity (experiment II in Table 2). Relative to experiment I above, we find little welfare difference for a tax on carbon and a slight improvement with a sales tax on energy commodities. Interestingly, the least direct tax, a sales tax on pollution-intensive commodities, is slightly worse in the distortion free base (compared to the base with no factor productivity differences, experiment I in Table 2). This is because without taxes on energy inputs (i.e. the 15.4% sales tax on petroleum) in the base model, the sales taxes on pollution-intensive commodities, the least direct tax instrument to reduce CO_2 emissions considered in this analysis, must increase further to meet the emission targets. For example, in the reference case the taxes increase to 43.5% with no labor market distortions but increase to 51.5% in the distortion free base.

Labor market segmentation and rigidity in South Africa are further reflected by a low elasticity of substitution among factors of production, particularly between unskilled and skilled labor. This is why there is at the same time unemployment among unskilled workers and scarcity of skilled workers. To test the implications of this feature of the South African economy, we raise the elasticity of substitution between labor and the capital-energy aggregate and between labor types all to 2.0 (experiment III in Table 2), other production elasticities do not change. The carbon tax and the sales tax on energy now result in welfare *gains* due to second-best effects, which essentially channel resources away from sectors with high carbon or energy intensity to sectors with relatively high productivity and low carbon/energy content, such as other products, financial services, agriculture, wood products, basic chemicals, and leather. In effect, we find a strong double dividend – the carbon tax improves welfare even ignoring environmental benefits. Here there are gains because high-productivity sectors are expanding, there is no revenue recycling by which other taxes are reduced. The tax policy change leads to a change in production and the welfare changes occur due to pre-existing factor productivity differences by sector.

The welfare effects from resource reallocation are much stronger in the rigid case, with the biggest gains following a sales tax on energy commodities. 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 associated with removing sectoral wage differences for each labor type (experiment I of Table 2) or introducing unemployment (as defined in experiment IV of Table 2) .

The final labor market distortion examined is the unemployment problem in South Africa (experiment IV in Table 2). As an alternative to the base case in the first set of simulations, we allow for unemployment among low-skilled and medium-skilled formal workers, with sticky real wages, while the other labor markets clear in equilibrium, similar to the formulations in Go *et al.* (2010).[27] In this specification, the unemployed are not strictly speaking represented in the utility function, so the specification is not ideal. However, the presence of significant within-household income transfers in South Africa mean that the consumption of the unemployed is partially represented in the various household units. The results show that welfare losses for various tax options increase

[27] We do not specify employment by households. Instead the changes in income to low-skilled and semi-skilled labor is distributed to households based on the share of income by labor type to the household calculated from the base data.

significantly when compared to the base case in Table 1. With its lower welfare cost, the carbon tax is still better than other taxes.

Unemployment in South Africa is concentrated among low- and medium-skilled workers, where real wages are fixed and protected by post-apartheid labor policy. A carbon tax, because it will induce a change in production, will generate a 1 percent reduction in employment of either low-skilled and slightly more for medium-skilled labor, in either the reference or rigid case (Table 3). Employment losses are more dramatic with a tax on either energy or pollution-intensive commodities. With a tax on pollution-intensive commodities, employment can decline over 16 percent in the rigid case.[28]

Table 3: Percent change in employment of low-skilled and medium-skilled labor with fixed real wages

	tax on carbon emission	sales tax on energy commod-ities	sales tax on pollution-intensive commod-ities	tax on carbon emission	sales tax on energy commodit ies	sales tax on pollution-intensive commod-ities
	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

Source: CGE model simulations.

The sensitivity analysis suggests that labor market distortions in South Africa matter very much. In particular, unemployment likely raises the cost of carbon taxation significantly, while greater labor market flexibility lowers it. If labor market reforms are difficult to implement, the results suggest that a tax directly on carbon is the best option. If monitoring of carbon emissions is a problem, then a tax on energy inputs is a distant second option, particularly with revenue recycling to reduce the pre-existing indirect tax distortions.

Sensitivity of the carbon tax rate to the elasticity of substitution among energy inputs in production and to the level of emissions reduction

The carbon tax per metric ton of CO_2 emission is about \$12.72 in the reference case. We further investigate the effect of elasticity values for energy inputs on the

[28] Note, the simulations represent the long run, in which the economy adjusts to a new output levels and all factors have relocated across sectors.

carbon tax required to reduce emissions by 15 percent (Table 4). 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 increases to about $127 per metric ton of CO_2 emission. 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 is lower. This result suggests another use of the potential revenue of the carbon tax – to finance investment in new and alternative-energy technologies. Such analysis require a different and more dynamic analysis, however, including estimation of the possible cost structure of new and cleaner energy technology, which is beyond the scope of the present paper.

Table 4: Sensitivity of the carbon tax to elasticities of substitution among energy and other inputs

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

Source: CGE model simulations.

We also test the sensitivity of the effects of a tax on carbon to the target level of emission reductions, and we find that the tax on carbon increases non-linearly. As targets increase, the tax needed to achieve them increases at an increasing rate (Table 5). Likewise, the welfare loss is non-linear, ranging from a decline of 0.04 percent to 1.15 percent, but the direction of change is the same. Nevertheless, even for a 25 percent reduction in emissions, the welfare costs are low – a decline of 1.15 percent. (See Devarajan *et al*. (2009) for details and other results.)

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 of CO_2 emission, 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.[29]

Table 5: 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 of CO_2 emission (USD)	0.00	2.95	7.05	12.72	20.65	31.91
Carbon tax per metric ton of CO_2 emission (Rand)	0.00	22.29	53.32	96.25	156.21	241.38

Source: CGE model simulations.

III. Conclusions

As their contribution to global greenhouse gas emissions rises, developing countries' role in mitigating CO_2 emissions is an increasingly contentious issue. Without taking a stand on how much mitigation is desirable, we look at the welfare effects of tax policies to reach a given carbon emissions target in South Africa, the largest economy in Africa. To capture the administrative and technical constraints facing many developing countries, we compare alternative taxes, such as those on energy commodities, or on pollution-intensive commodities, to a pure carbon tax. To incorporate some of the distortions prevalent in many developing countries, we use a detailed, general-equilibrium model of the South African economy that captures tax and factor-market distortions.

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 lower the cost. 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 used in this analysis. If the revenue generated can be used to reduce pre-existing tax distortions, the net welfare cost becomes negligible. However, we do find that a carbon tax is

[29] However, the "use the market" scenario in Pauw (2007) 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.

regressive: low-income households have high expenditure shares on commodities whose prices increase with a tax on carbon and therefore are hurt by a carbon tax. If a carbon tax is not feasible, a sales tax on energy inputs may be the next-best instrument: it has a higher overall welfare cost than a carbon tax, but a less regressive impact, given the existing distortions in the economy.

The results confirm the conventional argument that the relevant deadweight loss will generally be small for energy related taxes. Furthermore, they show that the bulk of the losses come from the interaction with other distortions in the economy. Indeed, when we create a distortion-free base model and consider tax policy options for CO_2 mitigation, we replicate insights from the analytical models. In our sensitivity analysis, we also show that partial reforms of labor market distortions can lead to a strong double dividend from a tax on carbon or a sales tax on energy inputs – welfare improves even ignoring environmental benefits. We observe a strong double dividend when there is high substitutability among inputs and there are sector-specific wage differentials – expansions in output of high-productivity, low-carbon sectors are large enough to generate a welfare gain.

Our contribution to the literature is that we show how distortions found in an empirical model can affect the efficiency of tax instruments. Specifically, labor market distortions such as labor market segmentation, or unemployment due to fixed real wages and entry barriers will likely dominate the welfare and equity implications of a carbon tax for South Africa. Put another way, if South Africa were able to remove some of the distortions in the labor market, the cost of carbon taxation would be negligible.

Several points are worth emphasizing. The simulations do not account for the social gains of emissions reduction nor for dynamic or productivity gains including benefits from clean technologies. Our approach can be interpreted as setting a lower bound on the welfare gains from carbon reduction.

Given that it is the least costly, a carbon tax may be worth considering, especially if it can be implemented simply in developing countries and in the absence of abatement technologies. Tax rates can be fuel- specific and tuned to the actual carbon content, which as a rule is fixed stoichiometrically per unit of fuel.

With the supply mix of energy in South Africa 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 of this paper, adaptation measures will also be important for South Africa. In addition, South Africa interacts with other countries in southern Africa and potentially can share power resources in the region. Finally, carbon leakages may become a problem as South

Africa imports goods from neighboring countries with lower taxes applied to energy goods. All these are areas for further research.

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