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MEASURING THE CARBON INTENSITY OF THE SOUTH AFRICAN ECONOMY

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Abstract

We estimate the carbon intensity of industries, products and households in South Africa using data from a high resolution supply-use table. Direct and indirect carbon usage is measured using multiplier methods that capture inter-industry linkages and multi-product supply chains. Carbon intensity is found to be high for exports but low for major employing sectors. Middle-income households are the most carbon-intensive consumers. These results suggest that carbon pricing policies (without border tax adjustments) would adversely affect export earnings, but should not disproportionately hurt workers or poorer households. Seven percent of emissions arise through marketing margins, implying that carbon pricing should be accompanied by supporting public policies and investments.

JEL Classification: C67, Q43, Q56

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1. INTRODUCTION

South Africa is the world's most carbon-intensive non-oil-producing developing country.[1] Consequently, there is considerable interest and international pressure for the country to reduce greenhouse gas (GHG) emissions and contribute to global climate change mitigation. However, South Africa's economic development has long been founded on heavy industry and low-cost coal-fired electricity and, as a result, the economy is structured towards capital- and energy-intensive production technologies. Adopting a low-carbon growth trajectory, possibly by pricing carbon use, is likely to involve substantial structural change. Not surprisingly, various interest groups raise concerns. Businesses, particularly heavy industry, are concerned about eroded competitiveness, especially for exports. Organised labour is concerned about higher unemployment, particularly during the transition period. And while civil society often supports

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1 Measured in per capita CO_2 equivalent emissions in 2007 and excluding island states (World Bank, 2012).

environmental policy, there are concerns over how higher electricity and transport prices may affect poor households.

To provide an empirical basis for evaluating these concerns, we measure the carbon intensity of the South African economy at the detailed industry, product and household levels. We apply multiplier analysis techniques to a high-resolution database of production technologies to measure sectors' direct fuel and energy use, as well as the carbon embodied in other inputs. Ours is not the first carbon accounting study for South Africa. Blignaut *et al.* (2005) provide the most detailed study to date. The authors construct an inventory of GHGs and use an input–output approach to estimate carbon-intensities across industries. Based on similar data, various studies use computable general equilibrium (CGE) models to evaluate carbon and other environmental tax policies (see, van Heerden *et al.*, 2006; Pauw, 2007; Devarajan *et al.*, 2011). While less detailed than Blignaut *et al.* (2005), the CGE-based studies have the advantage of implicitly measuring carbon intensities across household groups.

We extend previous studies in three areas. Firstly, we make use of new high resolution data that allow us to estimate carbon intensities at the detailed scale required for designing tax policies. Secondly, our database and methodology distinguishes between industries and products, allowing us to capture inter-industry linkages and multi-product supply chains, and to decompose the carbon content of production and marketing processes. We also disaggregate household groups in order to evaluate the structure of carbon use across the income distribution. Finally, and perhaps most importantly, we account for variation in major energy prices across users. Our more detailed analysis can inform the design of carbon pricing policies and provides an initial assessment of the various interest groups' concerns.

In the next section, we describe our methodology and the reconciliation of economic and energy data. In Section 2, we present our carbon intensity estimates for sectors, products and households before discussing the relationship between carbon use, foreign trade and employment. In Section 3, we assess the potential economy-wide price effects of taxing carbon use in South Africa. We conclude by summarising our findings and identifying areas for further research.

2. METHODOLOGY AND DATA

2.1 Direct and Indirect Carbon Use

Carbon generally enters the economy as primary fuels (*i.e.* coal, crude oil and natural gas) and is used either as intermediate inputs or as final products. Most primary fuels are transformed into other forms of energy before being used (*e.g.* coal into electricity and crude oil into refined petroleum). This transformed energy is then used to produce downstream products (*e.g.* electricity used in factories or petroleum used in transport). An economy's carbon content can therefore be measured at two stages. We can either measure the CO_2 associated with the primary fuels as they enter the economy (*i.e.* as they are mined or imported), or we can measure the CO_2 implicitly embodied in final products.

At the global level, the two approaches produce the same estimate of overall carbon intensity because there are no leakages from the global system (*i.e.* total carbon supply must equal total use). At the country level, however, the two approaches may produce different estimates due to international trade. While it is relatively easy to track the carbon within traded fossil fuels (*e.g.* crude oil), it is more complicated to measure how much carbon enters and leaves a country inside processed products (*e.g.* refined petroleum, plastic products or transport services). For the latter, we need information on production technologies (*i.e.* the type and quantity of inputs used to produce goods and services).

Ignoring the carbon embodied in processed products may lead to an incorrect measure of South Africa's overall carbon intensity because we would not account for "virtual" carbon trade. For example, if more CO_2 is embodied in exports than in imports, then we would overstate how much carbon is actually used in the economy if we do not include the carbon trade surplus in our national measure.

We are also interested in comparing carbon intensities across sectors, products and households. Ignoring downstream industrial carbon use would incorrectly assign most of South Africa's CO_2 emissions to the energy transformation sectors, since they are the main direct users of fossil fuels. Ideally, we should track how carbon embodied in products is passed back and forth between sectors within intermediate inputs. Ignoring embodied carbon would also misattribute CO_2 to producers rather than final users. For example, we would assign CO_2 to garages or filling stations, rather than to households who use petroleum in their vehicles. A more accurate and policy-relevant measure of carbon intensity should therefore account for both direct and indirect carbon use in traded and final goods.

2.2 Multiplier Analysis of Carbon Intensity

Measuring direct and indirect embodiment of CO_2 naturally recommends input–output (IO) multiplier analysis. This is the standard approach to measuring carbon emissions. Leontief (1970) demonstrated how an IO analysis estimating the direct and indirect impact of a rise in final demand on sectoral gross outputs could be used in conjunction with sectoral environmental data to estimate changes in emissions. Variations on this method have since been widely used, particularly multi-regional IO methods to measure the CO_2 content of international trade (see, Proops, 1988; Lenzen *et al.*, 2004; McGregor *et al.*, 2008; Andrew *et al.*, 2009; Su and Ang, 2010). We first introduce this standard IO approach to measuring carbon intensities.

Assume there are n sectors (industries) in the economy, producing n homogenous products. Let $\mathbf{f}$ be a $n \times 1$ vector of sectoral final demands, $\mathbf{A}$ an $n \times n$ matrix of coefficients showing intermediate inputs per unit of gross output, and $\mathbf{x}$ an $n \times 1$ vector of sectoral gross outputs. The familiar Leontief solution is

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \qquad (1)$$

where $\mathbf{I}$ is an $n \times n$ identity matrix, and $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. The j^{th} column shows the gross outputs of each sector i required directly and indirectly to supply one unit of final demand of product j.

We can then define an $n \times 1$ vector $\mathbf{c}$ showing the total CO_2 emissions associated with each fossil fuel. This vector has entries for coal, crude oil and natural gas and zeros for all other products. Define $\hat{\mathbf{x}}$ as an $n \times n$ diagonal matrix with elements of $\mathbf{x}$ on the diagonal and zeroes elsewhere (*i.e.* $\hat{\mathbf{x}} = \mathbf{x} \cdot \mathbf{I}$). Then, we can define an $n \times 1$ vector $\mathbf{e}$ showing the CO_2 per unit of gross output

$$\mathbf{e} = \hat{\mathbf{x}}^{-1}\mathbf{c} \tag{2}$$

Total emissions in the economy **C** is

$$\mathbf{C} = \mathbf{e}'\mathbf{x} \tag{3}$$

where $\mathbf{e}'$ is the transpose of **e**. Substituting (1) into (3) gives

$$\mathbf{C} = \mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{4}$$

where $\mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}$ is a $1 \times n$ row vector. The i^{th} element shows the CO_2 directly and indirectly embodied in one unit of final output of the i^{th} sector. This is an IO-based carbon intensity measure (CIM).

IO tables conflate sectors and products (*i.e.* each sector produces only a single homogeneous product, and each product is produced by only one sector). This means that we can speak interchangeably about the CO_2 embodied in products and sectors. Supply-use tables (SUTs) relax this assumption (*i.e.* sectors can produce multiple products and products can be produced by multiple sectors). This allows us to distinguish between the CO_2 embodied in products and in the sectors that produce them. This distinction is important in structurally complex economies like South Africa, where individual firms often have multiple production plants producing different goods. Moreover, while international trade occurs at the product level, production and employment occur at the sector level. Measuring carbon intensity within a country thus requires an SUT approach. Table 1 presents a schematic SUT.

In our SUT multiplier analysis, we assume that intermediate inputs, domestic sales by industries, transaction margins, total industry supplies and gross output are endogenous. Final demands, factor inputs, taxes and imports are exogenous. We can represent this in matrix terms as

$$\begin{bmatrix} \mathbf{x_n} \\ \mathbf{x_m} \end{bmatrix} = \begin{bmatrix} 0 & \mathbf{D} \\ \mathbf{Z} & 0 \end{bmatrix} + \begin{bmatrix} 0 \\ \mathbf{f} \end{bmatrix} \tag{5}$$

where $\mathbf{x_n}$ is an $n \times 1$ vector representing the total outputs (*i.e.* total cost) of the industries, $\mathbf{x_m}$ is an $m \times 1$ vector representing the total uses (*i.e.* supplies) of products, **D** is an $n \times m$ matrix showing the deliveries of products by domestic industries, **Z** is an $m \times n$ matrix representing the flows of the m products as intermediate inputs to the n industries, and

Table 1. Schematic supply-use table

		Accounts making payments				
		Industry 1 . . . Industry n	**Product 1 . . . Product m**	**Margins**	**Demands**	**Total**
Account receiving payment	Industry 1 . . . Industry n		Sales by domestic industries (D_{nm})			Industry supply (x_n)
	Product 1 . . . Product m	Intermediate inputs (Z_{mn})		Margin products	Final demand (F_m)	Product demand (x_m)
	Margins		Transaction margins			
	Value-added	Factor inputs (Wn)				
	Taxes	Net taxes on production	Net taxes on products			
	Imports		Imports (Mm)			
	Total	Gross output	Product supply			

f is an $m \times 1$ vector representing the exogenous final demands for m products. There are no final demands for activities.

The algebra deriving the SUT multipliers is analogous to the IO multipliers. Let **B** be the coefficients matrix, now defined over industries and products:

$$\mathbf{B} \equiv \begin{bmatrix} 0 & \left\{ \frac{\mathrm{d}_{ij}}{\mathrm{x}_\mathrm{i}} \right\} \\ \left\{ \frac{\mathrm{z}_{ij}}{\mathrm{x}_\mathrm{j}} \right\} & 0 \end{bmatrix} \quad i = 1 \cdots m; \; j = 1 \cdots n \tag{6}$$

The system can then be rewritten as

$$\mathbf{x} = \mathbf{Bx} + \mathbf{f} \tag{7}$$

and the solution is

$$\mathbf{x} = (\mathbf{I} - \mathbf{B})^{-1}\mathbf{f} \tag{8},$$

and our SUT-based CIMs are now $\mathbf{e}'(\mathbf{I} - \mathbf{B})^{-1}$.

As with IO analysis, $(\mathbf{I} - \mathbf{B})^{-1}$ is the (extended) Leontief matrix. The first n rows of the product columns show the direct and indirect changes in sector output required to meet a one unit change in final demand for the associated product. The next m rows show the direct and indirect changes in the total supplies of products to meet that change in demand. The two differ because some products are supplied by imports, and because the industry outputs are measured at basic prices at the factory gate, while product supplies are measured at market prices (*i.e.* including net indirect product taxes) at the point of sale (*i.e.* including transaction margins).

It is tempting to interpret the n sector columns of the Leontief matrix in the same way as we do for the m products. However, while the mathematical interpretation is identical, to provide a similar economic interpretation is problematic, since there is no economic meaning of "final demand" for industries. An industry's "demand" is derived from its products' demand. In our analysis, we estimate how "demand" would need to change in order for a sector's output to expand by one unit. This requires scaling the activity columns in the Leontief matrix such that its diagonal elements are equal to one. This allows us to measure what is associated with expanding the activity by one unit, including the indirect requirements to produce that one unit. Multiplying these scaled coefficients by our unit CO_2 $\mathbf{e}'$ vector enables us to derive the CO_2 embodied in one unit of gross output for each sector.[2]

The above methods can be used (indeed, more commonly are used) *pari pasu* to measure employment multipliers. Algebraically, we simply interpret the **e** vector as showing the employment coefficients, that is the number of people employed in a sector per unit of gross output.

[2] As with standard multiplier analysis, our SUT approach assumes that a sector's "by-product" has the same average carbon content as the main product produced by that sector.

2.3 Data Sources

Our primary data source is the 2005 SUT (STATSSA, 2010), which contains demand/supply balances for 171 industries and 104 products.[3] Unfortunately, the structure of the energy sector in the SUT does not exactly match the 2005 Energy Balances (EB) (STATSSA, 2009). For example, electricity imports and exports appear in the EB but not in the SUT. To reconcile these data, we assume that aggregate energy demands/supplies in the EB are correct, but that the SUT more accurately reflects energy demand across final users. We adjust the SUT to match the aggregate quantity flows in the EB (*i.e.* physical units). These quantities are converted into values using average prices, which are calculated by dividing the domestic supply value from the SUT by the domestic supply quantity from the EB. We use the average import price for crude oil since there is no domestic production. We also introduce a natural gas sector into the SUT using quantity flows from the EB and technology coefficients from Pauw (2007).[4]

SUT adjustments are made for primary fossil fuels and transformed energy (*i.e.* electricity and petroleum). We target the EB's domestic production, imports, exports, stock changes and final demand. The remaining intermediate demand is distributed across industries using expenditure shares from the original SUT. An exception is fossil fuel use in the transformation sectors, which is drawn directly from the EB (*e.g.* the quantity of coal and crude oil used in electricity generation and petroleum refining). Using intermediate expenditure shares from SUT is appropriate since the EB is concerned with how energy is used rather than who uses it. For example, the EB reports total petroleum demand for transport use, whereas the SUT reports how much petroleum is used by individual industries and households. Only the latter is relevant for our economic analysis.

Multiplier analysis assumes that the same product price is paid by all users. A second adjustment to the SUT is therefore needed to reflect variation in electricity unit prices. For example, mining and metals producers pay lower (subsidised) electricity prices than other sectors. Using industry-level demand and price data for 2005 from the national electricity provider, we calculate the implicit subsidies (taxes) on users paying below-average (above-average) electricity prices. The SUT is adjusted so that all sectors pay the same average electricity price but now receive (pay) explicit subsidies (taxes).[5] In this way, electricity payments in the SUT now reflect actual quantities measured at the same unit price. It is not necessary to account for variation in petroleum prices, since users pay the same pump price, albeit with some composite variation caused by differences in petroleum and diesel usage and prices.

As a third adjustment to the SUT, we disaggregate household product demand using information from the 2005 Income and Expenditure Survey (IES) (STATSSA, 2006). Expenditure shares from IES were used to distribute consumption spending in the SUT (*i.e.* the product composition of total consumption spending remains unchanged in the

[3] A 2009 SUT was recently released, but this is less detailed than the 2005 table and is only a partial update (*i.e.* assumes the same production technologies as the 2005 SUT). A 2009 EB was not available at the time of writing.

[4] Natural gas is separated out from "other mining and quarrying" (I11) and "other minerals" (P7).

[5] Electricity subsidies/taxes are added to "other taxes less subsidies" in the SUT (V6) and the purchases of electricity (P8 and P88) are adjusted to reflect the average electricity price calculated using the SUT and EB.

Table 2. Emissions from combusting primary fuels, 2005

	Coal Tons	**Crude oil Tons**	**Natural gas Gigajoule**	**Primary fuels**
Total fuel supply (1000 tons or GJ)	246,845	16,150	169,888	–
Carbon factor (CO2 tons per mt or GJ)	1.93	2.33	0.056	–
Total CO2 emissions (mil. tons)	476.4	37.6	9.5	523.6
Total fuel demand (R mil.)	39,217	39,083	1,733	–
Unit price before carbon tax (R/mt or R/GJ)	159	2,420	10,201	–
Unit price after R200 carbon tax (R/mt or R/GJ)	545	2,886	10,212	–
Price change due to carbon tax (%)	243.0	19.3	0.1	–

Source: Authors' calculation using the Supply-Use Table (SUT) and Energy Balances (EB) (STATSSA, 2009, 2010).

SUT). We identify six household "income" groups based on their total per capita consumption levels, as reported in the survey (*i.e.* percentiles 0-20, 20-40, 40-60, 60-80, 80-96, 96-100). Employment data for the employment multipliers was obtained for the 45 sectors in the SASID database (SASID, 2010) and, where necessary, were distributed across the more detailed industries of the SUT using labour value-added weights (*i.e.* assuming the same wage rates within aggregate sectors).

The SUT provides the values of **B** and **f** in equation (8). To complete the model, we estimate the CO_2 emissions associated with each fossil fuel (*i.e.* **c** in equation (2)). Total quantities of primary fuels are reported in the EB and converted into CO_2 equivalents using standard carbon factors (IPCC, 2006).[6] As shown in Table 2, fossil fuel use in 2005 generated a total 523.6 million tons of CO_2 emissions. In the next section, we distribute these emissions across products and users and compare their resulting carbon intensities.

We could have further disaggregated transformed energy. For example, Pauw (2007) separates the electricity sector into coal -fired, hydropower, nuclear, wind and solar; and fuel processing into coal-to-liquid, gas-to-liquid and oil refining. We opted against a similar disaggregation for two reasons. Firstly, the non-energy sectors in Pauw (2007) are far less detailed than our own, and so using the author's technology vectors would have prevented us from providing a detailed empirical basis for carbon-based tax instruments. Secondly, consumers of energy *products* cannot usually distinguish between energy-producing *subsectors*. For example, consumers rarely know whether their electricity comes from coal-fired power plants or renewable energy sources. Accordingly, and like most studies, we do not distinguish between different energy products and sectors, and our estimated CIMs are contingent on the economic structure and energy mix prevailing in 2005.

3. ESTIMATED CARBON INTENSITY MEASURES

3.1 Products

Table 3 reports the estimated CIMs for aggregate product categories in 2005.[7] The average CIM of all products is 0.265 tons of CO_2 per thousand rand of final demand (*i.e.* 523.6 million tons of CO_2 divided by R1.97 trillion). The CIM of individual products

[6] 1.93 tons of CO_2 per ton of coal; 2.33 tons of CO_2 per ton of crude oil; and 56.1 tons of CO_2 per terajoule of natural gas.

[7] Tables A1 and A2 in the Appendix report detailed CIMs (*i.e.* 105 products and 172 sectors). Individual products and sectors were aggregated into major categories using final demand and gross output weights, respectively.

Table 3. Carbon intensity measures (CIM) and carbon price effects for aggregate products, 2005

	Carbon intensity (tons CO_2 per R1000 final demand)	Share of carbon content from marketing margins (%)	Export intensity (%)	Import intensity (%)	Price change from R200 carbon price (%)
All products	0.265	7.1	9.3	10.0	6.0
Agriculture	0.138	8.7	9.9	5.5	2.3
Coal	12.288	0.1	31.8	0.6	222.6
Natural gas	5.747	0.0	0.0	26.7	3.7
Crude oil	0.963	0.0	0.0	100.0	19.3
Other mining	0.278	1.5	60.5	3.0	3.9
Processed foods	0.154	16.0	4.9	5.0	2.4
Textiles & clothing	0.115	14.9	3.6	24.4	2.2
Wood & paper products	0.372	9.8	8.1	6.5	6.1
Petroleum	0.659	5.1	12.6	4.3	11.6
Chemicals	0.267	8.6	9.9	14.3	4.1
Non-metallic minerals	0.312	7.7	4.1	8.8	5.7
Metal products	0.396	6.4	32.8	6.6	6.0
Machinery	0.092	23.4	11.4	46.0	1.5
Vehicles	0.115	18.0	11.5	29.7	1.8
Other manufactures	0.145	16.6	25.4	15.8	2.4
Electricity & gas	3.290	0.0	5.5	4.4	55.4
Water distribution	0.772	0.0	0.0	0.0	13.5
Construction	0.188	0.0	0.2	0.2	3.0
Trade & catering	0.194	1.1	5.0	3.2	2.8
Transport & comm.	0.171	0.5	7.0	11.3	2.5
Financial services	0.031	1.3	3.4	2.0	0.5
Business services	0.142	0.2	1.0	2.8	2.7
Government	0.080	0.0	0.0	0.0	1.3
Other services	0.137	0.1	2.1	2.3	2.1

Notes: "Import intensity" is the share of imports on total supply; 'Export intensity' is the share of exports in total sales.
Source: Authors' calculations using STATSSA (2010) and multiplier analysis results.

varies considerably. Coal, for example, has the highest CIM (12.288). This exceeds the direct carbon content of coal itself (12.148) because we include in our measure the carbon embodied in the coal mining *process* (*i.e.* in the goods and services used to extract the coal from the ground and supply it to market). Although there is no final demand for crude oil or natural gas, since they are only used as intermediates in other sectors, their direct CIM is 0.963 and 5.500, respectively. The carbon contained within these primary fuels is reflected in the CIMs of other downstream products (*i.e.* those that either use gas or oil directly, or indirectly use transformed energy, such as electricity or refined petroleum).

As expected, many of the carbon intensive non-energy products are in heavy industry, such as non-metallic minerals (0.312), metal products (0.396) and other mining (0.278). These products are produced by sectors that typically use more primary fuels and transformed energy than other sectors (*e.g.* the coal used to produce clay bricks in the non-metallic minerals sector, or the electricity used in aluminium smelters). Heavy industrial products are also more carbon intensive because they often use each other in their production processes. For example, metal products are produced using mining inputs and therefore include the carbon embodied in these upstream products.

In contrast, services tend to be the least carbon intensive, with the lowest CIM reported for financial services. Unlike heavy industry, services rarely use primary fuels directly, and they also use intermediate inputs containing less embodied carbon. Moreover, the results from the multiplier analysis indicate that 7.1% of the carbon intensity of final demand in South Africa is incurred via transaction margins (*i.e.* in moving products from the factory to the market). These margins include the purchase of trade and transport services, which themselves embody carbon (*e.g.* the petroleum used by freight carriers). Since services typically have lower transaction margins than most agricultural and industrial products, their CIMs tend to be below the national average.

The CIMs provide insight into which products may be most affected by carbon pricing (this is examined in more detail later in the next section). Moreover, our approach to measuring carbon intensity can inform the assignment of border tax adjustments when designing carbon pricing policies. Firstly, it provides estimates of carbon contents that are needed to determine rebates on South African exports. Secondly, the estimation procedure can be applied to the SUTs of South Africa's trading partners to estimate carbon-based import tax adjustments. Finally, a policy implication that emerges from the analysis is that a significant share of carbon use occurs within transaction margins. Efforts to reduce the carbon intensity of trade and transport services, such as by shifting from road to rail or imposing fuel standards, could help reduce South Africa's overall carbon intensity.

3.2 Sectors

As discussed in section 2, an advantage of using SUTs for measuring carbon content is that they distinguish between products and sectors. Knowledge of how carbon intensity varies across sectors (as opposed to products) is also useful for designing policy, since it helps identify those sectors (and their workers) that may be most affected by carbon pricing. Table 4 reports our estimated CIMs for aggregate sector groupings (*i.e.* tons of CO_2 per thousand rand of gross output).

Table 4. Carbon intensity measures (CIM) for aggregate sectors, 2005

	Carbon intensity (tons CO_2 per R1000 gross output)			Share of national total (%)		Employment multiplier**
	Total	Direct*	Indirect	Gross output	Employment	
All products	0.264	0.088	0.176	100.0	100.0	7.2
Agriculture	0.149	0.062	0.087	2.6	9.4	16.6
Coal	0.143	0.071	0.072	1.1	0.4	4.1
Natural gas	0.339	0.253	0.087	0.0	0.0	5.3
Crude oil	–	–	–	0.0	0.0	0.0
Other mining	0.296	0.221	0.074	4.6	3.3	4.9
Processed foods	0.189	0.066	0.123	5.5	2.0	8.1
Textiles & clothing	0.250	0.107	0.143	1.3	1.8	11.1
Wood & paper products	0.451	0.270	0.181	2.6	1.4	7.4
Petroleum	1.378	0.039	1.339	2.5	0.1	1.8
Chemicals	0.355	0.184	0.171	5.2	1.0	5.0
Non-metallic minerals	0.490	0.324	0.165	1.0	0.8	7.0
Metal products	0.441	0.257	0.184	4.7	1.9	5.4
Machinery	0.186	0.027	0.159	2.6	1.4	5.6
Vehicles	0.179	0.023	0.156	4.6	1.2	5.5
Other manufactures	0.157	0.028	0.129	1.2	1.2	8.0
Electricity & gas	3.201	0.295	2.906	1.7	0.3	3.2
Water distribution	0.539	0.486	0.053	0.6	0.1	3.7
Construction	0.206	0.027	0.179	3.7	6.0	11.3
Trade & catering	0.135	0.040	0.096	9.8	21.7	11.3
Transport & comm.	0.170	0.108	0.062	9.1	4.1	5.1
Financial services	0.024	0.006	0.019	7.0	2.9	3.4
Business services	0.161	0.084	0.078	9.0	11.7	8.0
Government	0.078	0.022	0.057	10.2	12.8	7.1
Other services	0.107	0.027	0.080	9.4	14.5	8.7

Source: Authors' calculations using STATSSA (2010), Quantec (2011), and multiplier analysis results.

* Direct carbon content derives from direct use of primary fuels and transformed energy (*i.e.* petroleum and electricity). Indirect carbon includes the carbon embodied in intermediate inputs.

** The employment multiplier shows the number of jobs created following a million rand increase in final demand.

It should be noted that product and sector CIMs cannot be directly compared, since a given product can be supplied by more than one sector, and in such cases, the product's CIM reflects a weighted combination of production technologies. More importantly, the denominator of a sector multiplier (*i.e.* gross output) excludes the value of indirect taxes and imports, which are included within the denominator of product multipliers (*i.e.* final demand). Nevertheless, a rough comparison of *rankings* reveals some sharp differences between the CIMs of products and the main sectors that produce them. For example, as mentioned above, coal has the highest carbon intensity of all products since coal itself is particularly carbon rich. However, the coal mining sector's production process or technology is relatively low carbon intensive compared to other sectors (*i.e.* its CIM is 0.143 compared to an average for all sectors of 0.264). In this case, the sector CIM reflects the inputs used to mine the primary fuel rather than the carbon content of the fuel itself, which is supplied to downstream sectors, particularly to electricity generation.

Table 4 distinguishes between the direct and indirect components of our estimated CIMs. Many studies estimate carbon content based on sectors' direct use of primary fuels and transformed energy (*i.e.* electricity or petroleum). Under this approach, transport is fairly carbon intensive compared to many other sectors due to its direct demand for petroleum. However, it is crucial to account for indirect carbon use embodied in upstream products (*i.e.* intermediate inputs other than fuels and energy). Here, we find that while transport has a large direct CIM (0.108), its indirect CIM is quite small (0.062). In contrast, vehicle manufacturing's indirect CIM (0.156) is much larger than its direct CIM (0.023). Even though the vehicle sector is not a major direct user of fuels and energy, it does use many inputs whose production processes are very carbon intensive, such as steel and rubber. Vehicles' indirect carbon usage therefore makes it a more carbon-intensive sector than transport.

Finally, evaluating a sector or product's contribution to national carbon usage should not only depend on its carbon intensity but also recognise the relative size of sectors and products within total gross output or final demand. For example, while services have the lowest CIMs, these sectors together account for more than half of national gross output, and thus almost a quarter of national carbon usage. Accordingly, significantly reducing overall CO_2 emissions in South Africa, possibly via carbon pricing, would likely involve lowering absolute emissions within the service sectors, even though they are some of the country's cleaner economic sectors. Since the service sectors are typically less intensive *direct* carbon users, reducing their emissions requires reducing the carbon embodied in their intermediate inputs (*i.e.* in upstream non-service sectors).

3.3. Households

Table 5 presents the structure and carbon intensity of gross domestic product (GDP) and its components. Exports are far more carbon intensive than imports, even though this calculation assumes that foreign producers use the same production technologies and coal-based energy sources as South African producers. This is reflected in the CIM for exports of 0.674 compared to 0.258 for imports (see column 4).

It is worth noting that by assuming that foreign producers have similar product-level CIMs as domestic producers, we are likely to be overstating the carbon intensity of imports. To illustrate this, we compiled CO_2 emissions per unit of GDP for each of South Africa's trading partners and weighted these by each partner's share in the value of total imports (using data from World Bank, 2012 and SARS, 2012). This measure indicates

Table 5. Decomposing the carbon intensity of gross domestic product (GDP) and household consumption, 2005

	Share of total GDP (%)	Share of absorption (%)	Emissions (1,000 tons CO_2)	Carbon intensity (tons CO_2 per R1,000)	Share of emissions in absorption (%)	Per capita emissions (tons CO_2)	Price change from R200 carbon price (%)
GDP (market prices)	100.0		416.3				4.7
Total absorption	101.9	100.0	263.2	0.166	100.0		2.9
Household consumption	63.8	62.7	199.3	0.200	75.7	4.25	3.2
Percentile 0-20	0.9	0.9	3.0	0.208	1.1	0.32	3.3
Percentile 20-40	2.7	2.6	8.9	0.213	3.4	0.95	3.4
Percentile 40-60	5.0	4.9	17.3	0.224	6.6	1.85	3.6
Percentile 60-80	9.2	9.1	34.3	0.238	13.0	3.66	3.8
Percentile 80-96	18.6	18.2	63.7	0.220	24.2	8.50	3.6
Percentile 96-100	27.5	26.9	72.0	0.168	27.4	38.44	2.7
Government consumption	19.6	19.3	24.4	0.080	9.3		1.3
Gross fixed capital formation	16.9	16.6	35.4	0.134	13.4		2.1
Changes in inventories	1.5	1.5	4.2	0.179	1.6		3.0
Exports	24.8		260.3	0.674			11.5
Imports*	26.7		107.3	0.258			4.4

Source: Authors' calculations using STATSSA (2006, 2010) and multiplier analysis results.

* The carbon intensity of imports assumes that foreign producers use the same technology and energy sources as South Africa. Household percentiles are based on per capita consumption spending.

that the weighted carbon intensity of countries exporting to South Africa was one third of South Africa's own carbon intensity in 2005 (*i.e.* 0.825 kg CO_2 per dollar of GDP compared to South Africa's 2.545 kg).[8] This supports the possibility that our carbon content of imports is overestimated. However, South African imports are rapidly becoming more carbon intensive (*i.e.* the trade-weighted measure doubled from 0.521 kg CO_2 per dollar in 2000 to 1.039 kg in 2008). This is primarily driven by more carbon-intensive trading partners, particularly China, becoming more important exporters to South Africa. Moreover, during the same period, South Africa's own carbon intensity fell by 15% (*i.e.* from 2.774 kg CO_2 per dollar in 2000 to 2.354 kg in 2008). This suggests that the carbon gap between exports and imports is narrowing. Of course, a more rigorous assessment would replicate our product-level analysis for each of South Africa's major trading partners. Nonetheless, even with our overestimated carbon content of imports, South Africa is clearly a large net exporter of embodied carbon, and is likely to remain so for the foreseeable future.

Within domestic absorption, household consumption is more carbon intensive (0.200) than either government consumption (0.080) or gross fixed-capital formation (0.134). This is reflected in the fact that while household consumption comprises 62.7% of total absorption, it accounts for 75.7% of absorption's embodied carbon.

The carbon intensity of private consumption spending is unevenly distributed across the income distribution. Table 5 reports both the CIM and emission shares of households disaggregated according to per capita consumption groups or population percentiles (*i.e.* as a proxy for income). The most carbon intensive consumers are in the middle of the income distribution – the highest CIM is for the fourth expenditure quintile (*i.e.* 0.238 for individuals in the 60th to 80th percentiles). Higher income households have lower CIMs due to differences in their consumption patterns.[9] However, despite being less carbon-intensive consumers, households in the top expenditure group in the table account for 36.2% of all household carbon usage (or 27.4% of total absorption's carbon use). This is because, while these households' consumption is less carbon intensive per rand spent, the unequal distribution of income means that these households have much higher consumption levels, and thus higher absolute carbon use. Overall, households in the top 4% of the income distribution account for more than the total emissions embodied in the products consumed by the bottom 80% of the population.

Translating household emissions into per capita terms, each person in the top 4% of the population consumes 38.4 tons of CO_2 per year, compared to 0.3 tons for people in the bottom quintile. An international comparison suggests that the top 4% of the population in South Africa has levels of carbon use similar to the average for Kuwait (the

[8] Estimates are in 2,000 US dollars. Note that the World Bank data produces a slightly lower national CIM for 2005, *i.e.* 0.260 tons per R1000 of GDP at market prices vs. 0.301 when measured using official South African data.

[9] Although we calculate CIMs for 105 product categories, we do not capture differences between products within categories, such as between hybrid and fuel-based vehicles, whose carbon intensity is a weighted average in our calculations. Thus, while major compositional shifts in consumption are captured, our CIM estimates do not reflect how compositions *within* categories may change with income. However, we expect that a more refined product disaggregation would further lower the CIM of higher income households relative to other households, given the typically higher cost of more energy-efficient products and technologies.

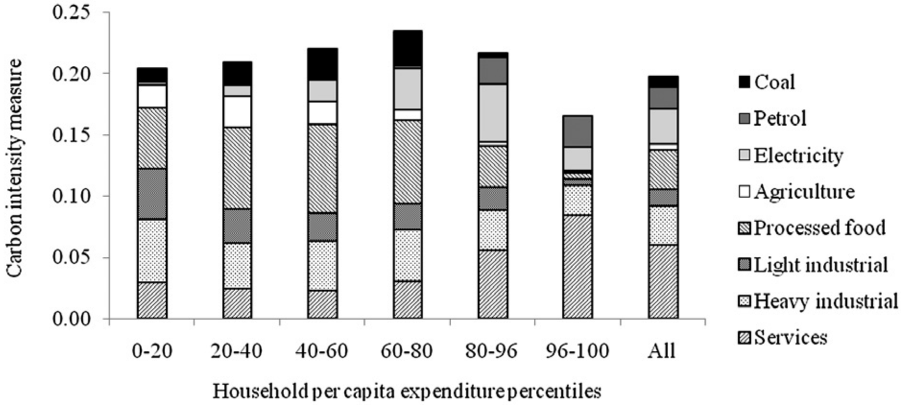

Figure 1. Decomposing the carbon intensity of household consumption, 2005
Source: Authors' calculations using STATSSA (2006, 2010) and multiplier analysis results.
Notes: 'Carbon intensity measure' is tons of CO_2 per R1000 of consumption demand.

world's second highest per capita CO_2 emitter), while the bottom quintile is similar to the average for Benin (one of the world's lowest emitters) (World Bank, 2012).

Fig. 1 decomposes households' CIM according to carbon embodied in the types of products they consume. All households purchase some primary fuel or transformed energy. Coal is consumed directly by lower income households, and, given this product's high carbon intensity, it accounts for a significant share of these households' total CIM. In contrast, the CIM of higher income households reflects their higher consumption of transformed energy, particularly electricity. While the direct consumption of energy products forms a significant share of households' overall carbon consumption, the majority of their carbon use is indirect, via the embodied carbon in non-energy products. For example, the carbon within agricultural, food and light manufactured products (*e.g.* textiles) accounts for most of the carbon consumed by households in the lowest three quintiles.

Services are a larger source of carbon use for households in the top percent of the income distribution. Two interesting observations emerge from the figure. First, much of the carbon intensity of high-income households' consumption comes from the carbon embodied in real estate services, which, according to the SUT and electricity data, is a large direct user of electricity. One explanation is that the sector includes renting and operating of flats, dwellings and non-residential buildings, which are often leased with the renter paying the electricity costs. Secondly, the carbon within transport services forms a much larger share of overall carbon use for higher income households. This is contrary to the perception that pricing carbon would more adversely affect low-income households due to the longer distances separating poorer households and their workplace.

3.4 Exports and Imports

As shown in Table 5, the carbon intensity of exports far exceeds that of other components of GDP. Introducing a carbon price therefore raises concerns about the competitiveness of the export sector. Fig. 2 compares the carbon and export intensities of aggregate product categories, and the size of the markers in the figure reflect the contribution of products to total export earnings. Broadly speaking, South Africa's main export products

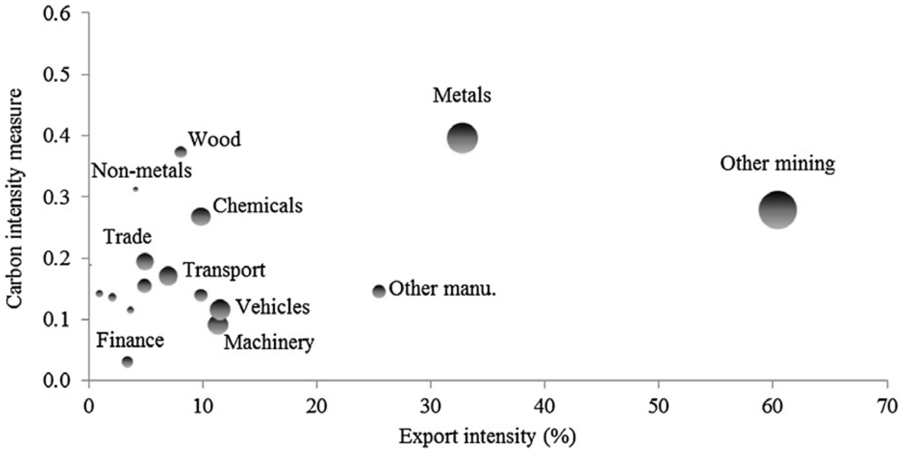

Figure 2. Carbon and export intensities for aggregate products, 2005
Source: Authors' calculations using STATSSA (2010) and multiplier analysis results.
Notes: Marker size indicates share of total export earnings; "Carbon intensity" is product-based and is the number tons of CO_2 equivalents per R1000 of final demand; "Export intensity" is the share of exports in total sales.

are also among the country's more carbon-intensive products (*e.g.* metals and other mining products).

Products with higher-than-average CIMs are more likely to be affected by a carbon price. This includes products with CIMs above 0.265, such as metals and wood products. Focusing solely on carbon intensity, we might conclude that these two sectors' competitiveness would be worst affected by a carbon price assuming that the carbon tax is not rebated on exports in a manner similar to value added taxes. However, the export intensity measure shows the importance of foreign markets in a product's overall sales. Even though wood products' export competitiveness would be eroded by a carbon price, exports only account for 8.1% of total sales of wood products (see, the third column of Table 3). In contrast, metal products have high carbon *and* export intensities, implying that these products not only stand to lose relative export competitiveness, but the loss of exports would have significant implications for total sales. Finally, the loss of competitiveness in non-metal products (*e.g.* glass and cement) has smaller implications for the economy as a whole, since these products account for only a small share of total export earnings. Taking products' size and carbon and export intensities into account, it is clear that metals and other mining products (*i.e.* excluding coal and natural gas) would not only be among the products most adversely affected by a carbon price, but this would also have important economy-wide implications.

As discussed in the previous subsection, a more accurate approach of measuring the carbon intensity of imported products would replicate our estimation procedure using SUTs and energy balances for South Africa's trading partners. However, if we assume that imported products are produced using the same technologies and energy sources as South African products, then we can compare carbon and import intensities, as shown in Fig. 3. Perhaps not surprisingly, imports are the mirror image of exports. The largest and most import-intensive products are generally the least carbon intensive (*e.g.* machinery and

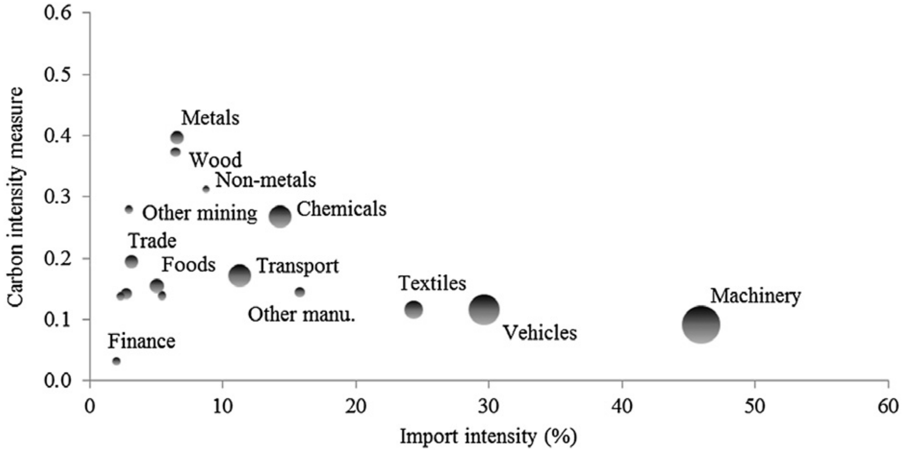

Figure 3. Carbon and import intensities for aggregate products, 2005
Source: Authors' calculations using STATSSA (2010) and multiplier analysis results.
Notes: Marker size indicates share of total import expenditure "Carbon intensity" is product-based and is the number tons of CO_2 equivalents per R1000 of final demand; "Import intensity" is the share of imports in total demand.

vehicles). Conversely, the most carbon-intensive products, such as non-metals and wood products, are also the least import intensive and account for only a small share of total import spending.

Our analysis of trade patterns is informative for designing carbon pricing policies. Firstly, if South Africa only prices the carbon in primary fuels (*i.e.* coal, oil and gas) it would exclude the carbon embodied in imported energy (*i.e.* refined petroleum and electricity) and processed products (*e.g.* plastics and other chemicals). In the absence of a global carbon price, domestic policy could tax the carbon embodied within imported products. Our estimation procedure, if applied to data from other countries, could inform the setting of these border tax adjustments. Secondly, it can be argued that the burden of carbon pricing should fall on final carbon users rather than producers who use carbon as intermediate inputs (*i.e.* to avoid carbon leakage between countries). This perspective suggests that importers of South African products are the final users, and so South African producers should not pay the carbon price. This more controversial border adjustment involves rebating producers according to the carbon content of their exports. Our CIMs can be used directly to determine these rebates.

3.5 Labour Employment

There are concerns that introducing a carbon price may result in structural transformation that reduces employment. Fig. 4 compares sectors' carbon intensities and employment multipliers. Our employment multipliers (also shown in Table 4) estimate the number of jobs created following a million rand increase in final demand for a sector's output. The multiplier reflects a sector's labour intensity, as well as its forward and backward linkages to the rest of the economy. For example, some of the 16.6 jobs created in agriculture following a demand expansion would be as farm workers and others would be in non-agricultural sectors, such as downstream food processing.

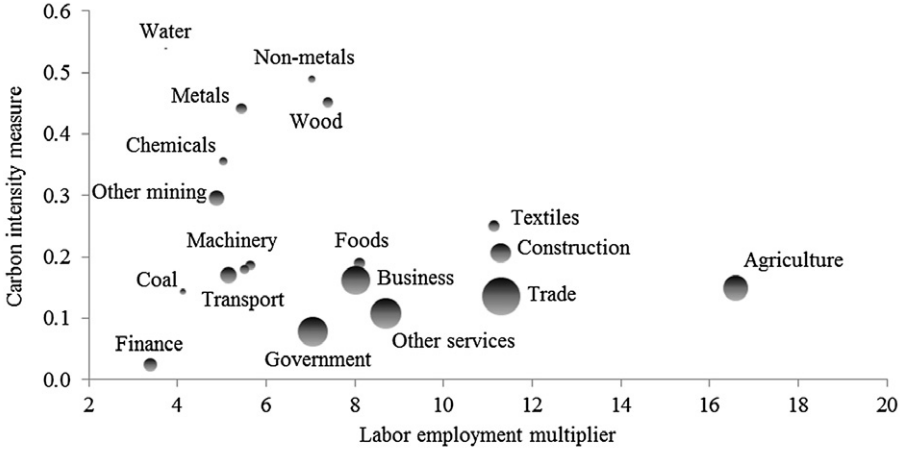

Figure 4. Carbon intensity and employment multipliers for aggregate sectors, 2005
Source: Authors' calculations using STATSSA (2010) and multiplier analysis results.
Notes: Marker size indicates share of total employment; "Carbon intensity" is sector-based and is the number tons of CO_2 equivalents per R1000 of final demand. The employment multiplier shows the number of jobs created following a million rand increase in final demand.

Wood and food products are both fairly labour intensive and have similar employment multipliers. However, wood products are more carbon intensive, and so workers in this sector are more likely to be affected by a carbon price than those in the food sector. Conversely, while food and agriculture have similar carbon intensities, the latter is much more important for overall employment, both because of its larger employment multiplier and because it accounts for a larger share of total employment (as shown by the larger size of its marker in the figure).

Two broad trends emerge from the figure. Firstly, sectors with the largest employment multipliers tend to be less carbon intensive than the overall economy (*e.g.* agriculture and services). This is reflected in the roughly inverse relationship between CIMs and employment multipliers in the figure (the unweighted correlation is −0.21). Secondly, the sectors contributing the most of total employment are also least carbon intensive. This is shown by the clustering of large sectors towards the bottom of the figure. Together, these trends suggest that carbon price is less likely to affect South Africa's more labour-intensive and major job-creating sectors.

In summary, our analysis provides a detailed assessment of how carbon intensity varies across products, sectors and households. We demonstrated the importance of measuring direct fuel and energy use, as well as the carbon indirectly embodied within inputs and industrial processes. By distinguishing between products and sectors, we accounted for inter-industry linkages and multi-product supply chains. We find that marketing margins account for a significant share of total emissions, suggesting a strong role for the transport sector in mitigation policy. Our CIMs suggest that South Africa's major exporters may be the most adversely affected sectors if carbon use was priced. However, while major unionised sectors, like metals and mining, may also be affected, the more carbon intensive sectors are generally less labour intensive and account for only a small share of overall employment. Finally, while middle-income households are the most carbon-intensive consumers, the high level of income equality in the country means that higher income households are by far the largest carbon users. In the next section, we directly estimate the effects of carbon pricing policy.

4. SIMULATING CARBON PRICING EFFECTS

Multiplier methods can be adapted to trace the price effects of pricing carbon use. This includes the direct production cost impacts on sectors using primary fuels and the indirect cost passed on via intermediate products. In this section, we simulate the introduction of a R200 carbon price per ton of CO_2. We first explain the multiplier price model before discussing our results.

4.1 Price Multipliers

As was shown in Section 2, the j^{th} column of the **A** matrix contains the shares of intermediate inputs in the gross output of the j^{th} industry. If we define a column vector **p** reflecting product prices, then we can write

$$\mathbf{p} = \mathbf{A}'\mathbf{p} + \mathbf{v} \tag{9}$$

where $\mathbf{A}'$ is the transpose of the **A** matrix, and **v** is a vector of the costs of primary inputs per unit of output. We can then solve equation (9) for **p**, as follows

$$\mathbf{p} = (\mathbf{I} - \mathbf{A}')^{-1}\,\mathbf{v} \tag{10}$$

The prices of products are the multiplier $(\mathbf{I} - \mathbf{A}')^{-1}$ times the unit costs of primary inputs, which are treated as exogenous. The multiplier is determined by the technical coefficients in the IO table. Given our linearity assumption, this relationship also applies to *changes* in exogenous prices:

$$\Delta\mathbf{p} = (\mathbf{I} - \mathbf{A}')^{-1}\,\Delta\mathbf{v} \tag{11}$$

This equation traces the effects of *exogenous* price changes. However, changing product prices, as we do with carbon pricing, is more complicated since products are *endogenous* in our multiplier model. We first determine the impact of a carbon price on the price of primary carbon products (*i.e.* coal, oil and gas). As shown in Table 2, our simulations impose an R200 carbon price per ton of CO_2. Coal has the initial price of R159 per ton.[10] Since burning a ton of coal generates 1.93 tons of CO_2, an R200 carbon price generates a post-tax price of R545 per ton (*i.e.* R159 + 1.93 × R200 = R545). This represents a 243% rise in the coal price. We then increase the share of coal inputs in each industry's cost structure by this percentage, and treat it as an element in the $\Delta\mathbf{v}$ vector. For instance, if coal is 2% of a sector's total costs, then a 243% higher coal price increases the sector's overall cost price by 4.9% (*i.e.* the $\Delta\mathbf{v}$ vector contains 0.049 in the sector's row). This is analogous to imposing a 4.9% indirect tax on the sector. This "tax equivalent" will vary

[10] The unit prices implied in our reconciled SUT and energy balance tables are similar to the prices reported by the Department of Energy. For example, our coal and crude oil prices are R159 and R2420 per ton, respectively, compared to R152 and R2554 reported in DOE (2010). Pre-tax gas prices are identical by construction.

depending on sectors' unique direct cost shares. Equation (11) allows us to derive the carbon price implications for all prices in the economy.

Once again, we transcribe this method from IO to SUT models. Equation (11) becomes

$$\Delta \mathbf{p} = (\mathbf{I} - \mathbf{B}')^{-1} \Delta \mathbf{v} \tag{12}$$

However, since we now distinguish between sectors and products, we must account for differences in market and producer prices. The supply matrix within the SUT (*i.e.* **D** in equation (5)) represents the supply of products by each sector. This is used to determine the "tax equivalent" price increase of pricing carbon. We apply this to the domestically supplied portion of a product's total supply. The difference between IO and SUT approaches is due to transaction margins and indirect taxes. We now apply price increases to products valued at basic prices (*i.e.* at the factory gate), and since transaction margins are endogenous in the model, they rise proportionately. Excluding imports means that any price change reduces the actual price increase, although the size of this reduction depends on a product's import intensity.

4.2 Simulation Results

As shown in Table 2, an R200 carbon price translates into a price increase of 243.0% for coal, 19.3 for crude oil, and 0.1% for natural gas. Taking account of direct and indirect carbon usages within the production of products, the final column of Table 3 shows the resulting change in product prices. Our multiplier price model assumes complete pass through to final users. We also assume that there is no behavioural adjustment caused by the price increase. In other words, consumers do not change the quantities they purchase in response to changing relative prices. As such, our price impacts can be interpreted as upper bounds change. Finally, we do not examine changes in wages caused by the carbon price. Incorporating these behavioural and factor market adjustments requires a general equilibrium framework in which prices are endogenously determined by market forces.

Our estimated price effect allows for variation in the price of electricity charged to different users, such that lower prices are paid by the metals sector and higher prices are charged to households. This differs from the estimated CIMs, which are based on quantities of electricity used (*i.e.* at a uniform average price). This means that the price effects may not be perfectly correlated with the CIMs. For example, sectors that currently pay low electricity prices may consume large amounts of electricity, and therefore have a higher CIM. However, the cost of this electricity may not form a large share of these sectors' overall production costs. Therefore, the effects of the carbon price may be more muted than if these sectors paid average electricity prices, even though they may be more carbon intensive.

As seen in Table 3, the R200 carbon price causes the average price of final demand to rise by 6%. Not surprisingly, the largest percentage price increase is on coal (222.6) and electricity (55.4). Note that the final price increase on coal is less than the simulated coal price increase (243.0). This is because the carbon price is imposed on the carbon within the coal before it is extracted from the ground. Therefore, the process of mining coal and transporting it to market requires the use of non-coal inputs. Since these inputs are only indirectly affected by the carbon price, the overall cost increase for coal products is less than the carbon price imposed on the raw product. This is partly reflected by the below-average CIM of the coal sector in Table 4 (*i.e.* 0.143 compared a national average of 0.264). Conversely, the natural gas sector is among the more carbon intensive sectors in the economy, and its price effect is higher (3.7) than the simulated price increase (0.1). Finally, since all crude oil is imported, the carbon price is effectively charged on the final good delivered to the South African market. As such, its price effect is the same as the simulated price increase (19.3).

The final column of Table 5 reports price effects for the different components of GDP. Overall, an R200 carbon price increases the GDP deflator by 4.7%. Note that this substantial increase is a once-off level effect, and does not imply an increase in the inflation rate. Given the importance of carbon intensive products in South Africa's export basket, the largest price increases are observed on total exports (11.5%). This means that the price increases for domestic absorption (an aggregate welfare measure), and its components are below the rise in the GDP deflator. For example, the government consumption spending deflator rises by only 1.3%. The impact on household consumer prices is fairly uniform by comparison, with differences following households' pattern of carbon intensities (see Fig. 1). Individuals in the middle of the income distribution experience the largest price increase (3. 8%), while the highest and lowest income households experience smaller price increases. The "regressiveness" of an R200 carbon price therefore remains ambiguous

5. CONCLUSIONS

Despite the debate surrounding carbon pricing policy in South Africa, the country lacks a sound empirical basis on which to evaluate the concerns of different stakeholders. In this paper, we have provided a detailed measurement of carbon intensity for different sectors, products and household income groups. Our multiplier approach expanded on previous studies by using a high resolution SUT that distinguishes between products and sectors. This allowed us to better capture inter-industry linkages and multi-product supply chains. We also corrected for variation in energy prices across users. As a result, our analysis is currently the most accurate representation of carbon intensity for South Africa. We also developed a price multiplier model and used this to evaluate carbon pricing policy, admittedly assuming full pass through of costs and no behavioural responses.

Our results confirm the importance of accounting for both direct and indirect carbon usage. For example, while transport is a large direct user of petroleum, the vehicle sector is actually more carbon intensive overall given its indirect use of carbon-intensive intermediates, such as metals and rubber. This suggests that any compensating measures granted to sectors after introducing a carbon tax should be based on *total* carbon use. Secondly, our results emphasise the distinction between products and sectors. While coal is a very carbon-intensive product, the coal mining process itself is less carbon intensive than most other sectors. Thirdly, we find that about 7% of South Africa's total carbon emissions occur due to transaction margins, part of which incurs when moving goods from ports/factories to markets. This indicates a key role for transport policy in helping reduce overall emissions. More generally, carbon pricing policies should be accompanied by "green" investments (*e.g.* replacing road freight with cleaner bulk transport options, such as rail).

In terms of the debate on carbon pricing, we find that South Africa is a major net exporter of carbon-based products, and that the country's main metals and mining exports are among the most carbon intensive of all products. As a group, exporters are therefore more likely to be adversely affected by carbon pricing than other sectors (in the absence of export rebates). Secondly, we find that South Africa's main employers are actually among the least carbon-intensive sectors in the economy. There is little evidence then to suggest that carbon pricing would affect employment or wages more than capital returns. Finally, based on the consumption patterns, our results suggest that middle-income households are the most carbon-intensive consumers, although the unequal income distribution means that the highest 4% of earners account for more than a third of total household emissions. Our price simulations produce ambiguous results as to whether carbon pricing is regressive (*i.e.* whether it disproportionately hurts the poor).

While this paper is an advance over previous studies for South Africa and provides insights into carbon pricing policy, there are areas where further research is needed. Firstly, in terms of data, greater scrutiny is needed on the differences between official supply-use tables and energy balances. Secondly, an accurate measurement of the carbon intensity of imported goods would involve applying our methodology to SUT for South Africa's major trading partners. This would provide a more accurate estimate of the country's net carbon trading position. Finally, our multiplier analysis did not capture behavioural and factor market responses when introducing a carbon price. Nor did it take into account the impact of possibly recycling carbon taxes, such as through increased investment or reduced taxes elsewhere in the economy. Addressing both of these aspects of carbon pricing policy would require a general equilibrium framework.

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APPENDIX: DETAILED PRODUCT AND SECTOR RESULTS

Table A1. Ranked carbon intensity measures (CIMs) for detailed products, 2005

P5	Coal & Lignite	12.288	P13	Fruit & nuts	0.188
P7gas	Natural gas	5.747	P16	Grain mill products	0.184
P88	Electricity distribution	3.290	P12	Vegetables	0.179
P7oil	Crude oil	0.963	P15	Dairy products	0.179
P9	Natural water	0.784	P55	Jewelry	0.175
P89	Water distribution	0.772	P84	Passenger transport	0.174
P38	Petroleum products	0.659	P19	Bakery products	0.174
P36	Paper products	0.541	P18	Animal feeding	0.172
P50	Structural non-refractory clay	0.469	P94	Leasing & rental services	0.169
P58	Iron & steel products	0.453	P98	Telecommunication	0.169
P51	Plaster & cement	0.410	P87	Postal & courier services	0.167
P53	Other non-metallic mineral products	0.391	P100	Other manufacturing services	0.165
P39	Basic chemicals	0.389	P22	Pasta products	0.163
P59	Non-ferrous metals	0.380	P71	Electrical machinery	0.159
P49	Non-structural ceramics	0.355	P23	Other foods	0.157
P17	Starch products	0.355	P54	Furniture	0.153
P99	Support services	0.343	P75	Ship & boats	0.153
P43	Soap, cleaning products & perfume	0.330	P2	Live animal	0.147
P40	Fertilizers & pesticides	0.324	P14	Oils & fats	0.147
P41	Paint & related products	0.307	P102	Education services	0.145
P6	Metal ores	0.285	P80	Construction services	0.141
P27	Textile fabrics	0.284	P93	Real estate services	0.140
P52	Articles of concrete	0.274	P1	Agriculture	0.139
P97	Other business services	0.259	P103	Health & social services	0.137
P60	Structural metal products	0.244	P25	Soft drinks	0.136
P44	Other chemical products	0.239	P29	Carpets	0.134
P7	Other minerals	0.239	P104	All other services	0.133
P62	Other fabricated metal	0.235	P85	Freight transport	0.131
P57	Waste & scraps	0.234	P10	Meat	0.130
P61	Tanks & reservoirs	0.232	P81	Trade services	0.130
P79	Construction	0.224	P95	Research & development	0.130
P46	Other rubber products	0.223	P83	Catering services	0.127
P76	Railway & trams	0.221	P3	Forestry	0.126
P48	Glass products	0.215	P74	Motor vehicles & parts	0.121
P37	Printing	0.213	P66	Lifting equipment	0.119
P31	Knitting fabrics	0.210	P33	Leather products	0.119
P47	Plastic products	0.207	P21	Confectionary products	0.116
P20	Sugar	0.204	P42	Pharmaceutical products	0.116
P45	Rubber tyres	0.201	P68	Special machinery	0.112
P11	Fish	0.194	P24	Alcohol & beverages	0.106
P30	Other textiles	0.191	P86	Supporting transport services	0.105
P28	Made-up textiles & related articles	0.191	P69	Domestic appliances	0.104
P35	Wood products	0.190	P67	General machinery	0.103
P64	Pumps & compressors	0.101	P96	Legal & accounting services	0.063
P32	Wearing apparel	0.100	P72	Radio & television	0.058
P63	Engines & turbines	0.099	P90	Financial services	0.049
P82	Accommodation	0.097	P73	Medical appliances	0.047
P78	Other transport equipment	0.091	P56	Other manufactured products	0.045
P65	Bearing & gears	0.090	P77	Aircrafts	0.027
P4	Fishing	0.080	P91	Insurance & pensions	0.024
P101	Public administration	0.080	P70	Office machinery	0.023
P26	Tobacco products	0.080	P92	Other financial services	0.006
P34	Footwear	0.075			

Notes: 'Carbon intensity' is tons of CO2 per R1000 of final demand. Product codes correspond to STATSSA (2010).
Source: Authors' calculations based on results from the multiplier analysis.

Table A2. Ranked carbon intensity measures (CIMs) for detailed sectors, 2005

I123	Electricity & gas	3.201	I78	Tanks, reservoirs & metal containers	0.262
I73	Other non-metallic minerals	1.389	I77	Structural metal products	0.260
I54	Petroleum products	1.378	I52	Services relating to printing	0.259
I45	Pulp, paper & paperboard	1.231	I36	Article of fur	0.258
I47	Other articles of paper	0.791	I90	Machine tools	0.252
I69	Structural non-refractory products	0.744	I120	Jewellery & related articles	0.250
I68	Refractory ceramics	0.697	I62	Other chemicals	0.249
I70	Cement, lime & plaster	0.654	I16	Fruit & vegetables	0.248
I57	Plastics in primary form	0.633	I65	Plastic	0.247
I67	Non-structural non-refractory ceramics	0.582	I71	Articles of concrete & cement plaster	0.247
I124	Water	0.539	I51	Printing	0.247
I74	Basic iron & steel	0.532	I8	Copper mining	0.246
I75	Basic precious & non-ferrous metals	0.511	I93	Machinery for food & beverages	0.244
I29	Finishing of textiles	0.497	I161	Other business activities	0.243
I80	Forging & stamping of metal	0.462	I31	Carpets, rugs & mats	0.242
I20	Starch products	0.449	I7	Chrome mining	0.242
I61	Soap & detergents	0.434	I66	Glass and glass products	0.241
I55	Basic chemicals	0.422	I92	Machinery for mining & construction	0.239
I10	Platinum mining	0.403	I34	Knitting & crocheted fabrics	0.237
I76	Casting of metals	0.395	I23	Sugar	0.236
I46	Corrugated paper & containers	0.393	I58	Pesticides & agro-chemicals	0.235
I56	Fertilizers	0.386	I96	Other household appliances	0.235
I28	Spinning & weaving of textiles	0.365	I42	Builders' carpentry & joinery	0.234
I33	Other textiles	0.349	I113	Bodies of motor vehicles & trailers	0.233
I12gas	Natural gas	0.339	I9	Manganese mining	0.231
I12	Other mining	0.338	I30	Made-up textiles	0.229
I118	Other transport	0.336	I114	Parts & accessories for motor vehicles	0.228
I41	Veneer sheets & plywood	0.331	I59	Paints, varnishes & printing ink	0.225
I116	Railway & tramway locomotives	0.327	I82	Cutlery & general hardware	0.225
I79	Steam generators	0.321	I101	Accumulators, cells and batteries	0.224
I91	Machinery for metallurgy	0.320	I87	Lifting & handling equipment	0.222
I147	Water transport	0.302	I126	Building of complete construction	0.222
I6	Iron ores	0.295	I13	Mining services	0.221
I15	Fish	0.293	I72	Cutting, shaping, finishing of stones	0.213
I83	Other fabricated metal products	0.293	I156	Computer & related activities	0.213
I100	Insulated wire and cables	0.289	I22	Bakery	0.213
I89	Agriculture & forestry machinery	0.287	I32	Cordage, rope, twine & netting	0.211
I50	Other publishing	0.286	I110	Optical & photographic equipment	0.208
I63	Rubber tyres	0.286	I26	Other foods	0.204
I64	Other rubber tyres	0.284	I17	Oils & fats	0.203
I148	Air transport	0.277	I48	Books & other publications	0.203
I11	Other metal ore mining	0.265	I35	Wearing apparel	0.199
I81	Treatment & coating of metal	0.264	I137	Retail trade in food & beverages	0.199
I169	Recreation, cultural & sport activities	0.197	I4	Mining of coal & lignite	0.143
I170	Other services	0.194	I132	Wholesale of household goods	0.142
I37	Tanning & dressing of leather	0.194	I39	Footwear	0.142
I115	Building & repairing of boats & ships	0.193	I166	Health activities	0.142
I145	Restaurants	0.193	I167	Sewerage, refuse & sanitation	0.141
I128	Building completion	0.192	I117	Aircrafts	0.141
I19	Grain mill	0.190	I144	Accommodation	0.141
I88	Other special purpose machinery	0.189	I112	Motor vehicles	0.141
I133	Wholesale of non-agriculture products	0.189	I105	Television & radio transmitters	0.140
I98	Electric motors & generators	0.189	I139	Repair of personal & household goods	0.139
I125	Site preparations	0.184	I38	Luggage & handbags	0.137
I160	Advertising	0.183	I131	Wholesale of agriculture raw material	0.137
I119	Furniture	0.183	I155	Renting of machinery & equipment	0.132
I103	Other electrical equipment	0.183	I2	Forestry & related services	0.130
I99	Electricity distribution apparatus	0.175	I138	Other retail	0.129
I146	Land transport	0.173	I107	Medical & surgical equipment	0.127
I49	Newspapers & periodicals	0.171	I27	Beverage & tobacco	0.126
I122	Recycling	0.171	I60	Pharmaceuticals	0.125
I21	Animal feeds	0.171	I109	Industrial process control equipment	0.120
I53	Reproduction of recorded media	0.171	I111	Watches & clocks	0.115
I150	Post & telecommunication	0.170	I159	Architectural & other consultant fees	0.108
I14	Meat	0.170	I149	Supporting & auxiliary transport	0.108
I40	Sawmilling & wood planing	0.169	I130	Wholesale trade on fee	0.106
I85	Pumps, compressors & valves	0.168	I86	Bearings, gears & driving elements	0.099
I168	Membership activities	0.165	I162	Central government	0.096
I127	Building installation	0.165	I158	Legal & accounting activities	0.095
I43	Wooden containers	0.165	I134	Wholesale trade in machinery	0.091

Table A2. Continued

I18	Dairy products	0.164	I164	Local government	0.091
I24	Cocoa & chocolate	0.164	I141	Maintenance & repair of vehicles	0.091
I95	Other special purpose machinery	0.163	I143	Sale, maintenance, repair & fuel	0.090
I94	Machinery for textile, apparel & leather	0.163	I121	Other manufacturing	0.086
I84	Engines & turbines	0.159	I140	Sale of motor vehicles	0.082
I165	Education & other training services	0.153	I171	Unobserved & informal households	0.079
I1	Agriculture & related services	0.153	I108	Instruments for measuring & testing	0.078
I157	Research & development	0.151	I97	Office & computing machinery	0.077
I44	Other products of wood	0.150	I104	Electronic valves & tubes	0.077
I136	Non-specialised retail trade in stores	0.150	I3	Fishing & related activities	0.069
I129	Renting of construction equipment	0.149	I106	Television & radio receivers	0.068
I135	Other wholesale trade	0.149	I142	Sale of motor vehicle parts	0.063
I25	Pastas	0.146	I163	Provincial government	0.055
I102	Electric lamps, lighting equipment	0.146	I151	Financial, insurance & pension funding	0.037
I5	Mining of gold & uranium	0.145	I152	Insurance & pension funding	0.025
I154	Real estate activities	0.144	I153	Other financial intermediation activities	0.003

Notes: 'Carbon intensity' is tons of CO2 per R1000 of gross output. Industry codes correspond to STATSSA (2010).
Source: Authors' calculations based on results from the multiplier analysis.