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Working Paper No. 2011/45

Measuring the Carbon Intensity of the South African Economy

Channing Arndt[1], Rob Davies[2], Konstantin Makrelov[3], and James Thurlow[4]

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Abstract

We estimate the carbon intensity of industries, products, and households in South Africa. 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. 7per cent of emissions arise though marketing margins, implying that carbon pricing should be accompanied by supporting public policies and investments.

Keywords: greenhouse gas emissions, carbon use, input-output analysis, South Africa

JEL classification: D57, 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. Organized labor is concerned about higher unemployment, particularly during the transition period. And while civil society often supports environmental policy, there are concerns over how higher electricity and transport prices may affect poor households.

South Africa lacks an empirical basis on which to evaluate the consequences of shifting to low-carbon development. To address this gap, we measure the carbon intensity of the 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. While ours is not the first study to measure a country's carbon intensity (see, for example, Rueda-Cantuche and Amores 2010), it is, to our knowledge, the first detailed application to South Africa. We also extend previous studies by employing a database and method that distinguishes between industries and products, thus allowing us to capture inter-industry linkages and multi-product supply chains, and to decompose the carbon content of production and marketing processes. Importantly, we account for variation in some energy prices across users. Our analysis informs the design of carbon pricing policies, and provides an initial assessment of the 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 summarizing 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

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1 Measured in per capita CO_2 equivalent emissions in 2007, and excluding island states (World Bank 2010).

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, and hence the net carbon leakages implied by the country's trade deficit. 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 deficit 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

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

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 $\mathbf{C}$ is

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

where $\mathbf{e'}$ is the transpose of $\mathbf{e}$. 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, $\mathbf{D}$ is an $n \times m$ matrix showing the deliveries of products by domestic industries, $\mathbf{Z}$ is a $m \times n$ matrix representing the flows of the m products as intermediate inputs to the n industries, and $\mathbf{f}$ is a $m \times 1$ 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:

$$\mathbf{B} \equiv \begin{bmatrix} 0 & \left\{\frac{\mathrm{d_{ji}}}{\mathrm{x_i}}\right\} \\ \left\{\frac{\mathrm{z_{ij}}}{\mathrm{x_j}}\right\} & 0 \end{bmatrix} i = 1 \cdots m;\ j = 1 \cdots n \tag{6}$$

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**e**' vector enables us to derive the CO_2 embodied in one unit of gross output for each sector.

The above methods can be used (indeed, more commonly are used) *pari passu* 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.

2.3 Data sources

Our primary data source is the 2005 SUT (StatsSA 2010), which contains demand/supply balances for 171 industries and 104 products.[2] 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).[3]

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 (subsidized) electricity prices than other sectors. Using industrylevel 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).[4] 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.

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2 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 is not unavailable at the time of writing.

3 Natural gas is separated out from 'other mining and quarrying' (I11) and 'other minerals' (P7).

4 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.

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 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 (Quantec 2010) and, where necessary, were distributed across the more detailed industries of the SUT using labor 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.[5] As shown in Table 2, fossil fuel use in 2005 generated a total 517.3 billion tons of CO_2 emissions. In the next section we distribute these emissions across products and users and compare their resulting carbon intensities.

3 Estimated carbon intensity measures

3.1 Products

Table 3 reports the estimated CIMs for aggregate product categories in 2005.[6] The average CIM of all products is 0.262 tons of CO_2 per thousand rand of final demand (i.e. 517.3 million tons of CO_2 divided by R1.97 billion). The CIM of individual products varies considerably. Coal, for example, has the highest CIM (12.285). 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 2.109, 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 (0.304), metal products (0.386), and other mining (0.275). 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

[5] 246.8 million tons of coal supplied at 1.93 tons of CO_2 per ton of coal, 2.33 tons of CO_2 per ton of crude oil, and 0.019 tons of CO_2 per terajoule of natural gas.

[6] 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.

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 per cent 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. First, it provides estimates of carbon contents that are needed to determine rebates on South African exports. Second, 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).

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 0.140 compared to an average for all sectors of 0.260). 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' directuse 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 (0.060). In contrast, vehicle manufacturing's indirect CIM (0.152) is much larger than its direct CIM (0.023). Even though the vehicles 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 recognize 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.

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.[7] This is reflected in the CIM for exports of 0.669 compared to 0.251 for imports (see column 4). South Africa is therefore a large net exporter of embodied carbon. Within domestic absorption, household consumption is more carbon-intensive (0.197) than either government consumption (0.079) or gross fixed capital formation (0.131). This is reflected in the fact that while household consumption comprises 62.7 per cent of total absorption, it accounts for 75.8 per cent 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 emissions 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. 0.235 for individuals in the 60th to 80th percentiles). Higher-income households have lower CIMs due to differences in their consumption patterns.[8] However, despite being less carbon-intensive consumers, households in

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[7] This assumption probably overstates the carbon content of imports, since South Africa is dirtier than most of its trading partners (with the possible exception of China and the oil-exporting countries).

[8] 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

the top expenditure group in the table account for 36.1 per cent of all household carbon usage (or 27.4 per cent 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 4per cent of the income distribution account for more than the total emissions embodied in the products consumed by the bottom 80 per cent of the population.

Translating household emissions into per capita terms, each person in the top 4per cent of the population consumes 37.8 tons of CO_2 per year, compared to 0.3 tons for people in the bottom quintile. An international comparison suggests that the top 4per cent of the population in South Africa has levels of carbon use similar to the average for Kuwait (the 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 2010).

Figure 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 of 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 per cent of the income distribution. Much of this comes from the carbon embodied in real estate (i.e. in the imputed use value of owner-occupied dwellings, which implicitly includes building materials, and whose asset value is low for lower-income households). Moreover, the carbon within transport services forms a 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. Figure 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 are also amongst the country's more carbon-intensive products (e.g. metals and other mining products).

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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.

Products with higher-than-average CIMs are more likely to be affected by a carbon price. This includes products with CIMs above 0.262, 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 per cent 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 amongst the products most adversely affected by a carbon price, but this would also have important economy-wide implications.

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 Figure 3.[9] 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 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. First, 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. Second, 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.

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[9] Overall, we expect that imported products are less carbon-intensive than equivalent South African products. However, this would vary by trading partner. For example, Chinese textiles might be more carbon-intensive than local textiles, while German machinery is likely to be less carbon-intensive.

3.5 Labor employment

There are concerns that introducing a carbon price may result in structural transformation that reduces employment. Figure 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 gross output for a sector. The multiplier reflects a sectors' labor 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.

Wood and food products are both fairly labor-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. First, 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). Second, 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 labor-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 unionized sectors, like metals and mining, may also be affected, the more carbon-intensive sectors are generally less labor-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 a R200 carbon price per ton of CO_2. Coal has the initial price of R159 per ton. Since burning a ton of coal generates 1.93 tons of CO_2, a R200 carbon price generates a post-tax price of R545 per ton (i.e. R159 + 1.93×R200 = R545). This represents a 243 per cent 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 per cent of a sector's total costs, then a 243 per cent higher coal price increases the sector's overall cost price by 4.9 per cent (i.e. the $\Delta\mathbf{v}$ vector contains 0.049 in the sector's row). This is analogous to imposing a 4.9 per cent indirect tax on the sector. This 'tax equivalent' will vary 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, a R200 carbon price translates into a price increase of 243.0 per cent for coal, 19.3 for crude oil, and 37.3 per cent 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 behavioral 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 changes. Finally, we do not examine changes in wages caused by the carbon price. Incorporating these behavioral 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 6per cent. Not surprisingly, the largest percentage price increase is on coal (222.6) and electricity (56.0). 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. 0.140 compared a national average of 0.260). Conversely, the natural gas sector is amongst the more carbon-intensive sectors in the economy and its price effect is higher (40.9) than the simulated price increase (37.3). 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, a R200 carbon price increases the GDP deflator by 4.7 per cent. Note that this substantial increase is a once-off level effect, and does not imply a percentage point 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 per cent). 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 per cent. The impact on household consumer prices is fairly uniform by comparison, with differences following households' pattern of carbon intensities (see Figure 1). Individuals in the middle of the income distribution experience the largest price increase (3.9 per cent) while the highest and lowest income households experience smaller price increases. The 'regressiveness' of a 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 supply-use table 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 behavioral 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 vehicles 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. Second, our results emphasize 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. Third, we find that about 7per cent 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 amongst 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). Second, we find that South Africa's main employers are actually amongst 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 4per cent of earners account for more than 80 percent of total absolute 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. First, in terms of data, greater scrutiny is needed on the differences between official supply-use tables and energy balances. Second, an accurate measurement of the carbon intensity of imported goods would involve applying our methodology to supply-use tables 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 behavioral 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.

References

Andrew, R., G.P. Peters, and J. Lennox. (2009). 'Approximation and Regional Aggregation in Multi-Regional Input–Output Analysis for National Carbon Footprint Accounting', *Economic Systems Research*, 21(3):311-35.

Lenzen, M., L.-L. Pade, and J. Munksgaard. (2004). 'CO_2 Multipliers in Multi-region Input-Output Models', *Economic Systems Research*, 16(4): 391-412.

Leontief, W.W.(1970).'Environmental Repercussions and the Economic Structure: An Input–Output Approach', *The Review of Economics and Statistics*, 52(3): 262-71.

McGregor, P.G., J.K. Swales, and K. Turner. (2008). 'The CO_2'Trade Balance' Between Scotland and the Rest of UK: Performing A Multi-Region Environmental Input–Output Analysis with Limited Data',*Ecological Economics*, 66(40): 662-73.

Pauw, K. (2007). 'Economy-wide Modeling: An Input into the Long Term Mitigation Scenarios Process,' Long-Term Mitigation Scenarios Input Report 4. Energy Research Centre, University of Cape Town, South Africa.

Proops, J. (1988).'Energy Intensities, Input-Output Analysis and Economic Development'.In M. Chiaschini (ed.),*Input-Output Analysis: Current Developments.* London: Chapman and Hall

Rueda-Cantuche, J.M., and A.F. Amores. (2010).'Consistent and Unbiased Carbon Dioxide Emission Multipliers: Performance of Danish Emission Reductions Via External Trade', *Ecological Economics*, 69: 988-99.

Quantec(2011). 'South African Standard Industrial Database'. Pretoria: Quantec Research.

StatsSA(2006).'2005 Income and Expenditure Survey'. Pretoria: Statistics South Africa.

________ (2009). 'Environmental Economic Accounts: Energy Accounts for South Africa, 2002-2006'. Pretoria: Statistics South Africa.

________(2010). 'Final Supply-Use Tables for South Africa: 2005'. Pretoria: Statistics South Africa.

Su, B., and B.W. Ang.(2010).'Input–Output Analysis of CO_2 Emissions Embodied in Trade: The Effects of Spatial Aggregation', *Ecological Economics*, 70: 10-18.

World Bank(2010). *World Development Indicators Online Database*. Washington, DC: World Bank.

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 ($\mathbf{D}_{nm}$)			Industry supply ($\mathbf{x}_n$)
	Product 1 … Product m	Intermediate Inputs ($\mathbf{Z}_{mn}$)		Margin products	Final demand ($\mathbf{F}_m$)	Product demand ($\mathbf{x}_m$)
	Margins		Transaction margins			
	Valueadde d	Factor inputs ($\mathbf{W}_n$)				
	Taxes	Net taxes on production	Net taxes on products			
	Imports		Imports ($\mathbf{M}_m$)			
	Total	Gross output	Product supply			

Table 2: Emissions from combusting primary fuels (2005)

	Coal	Crude oil	Natural gas	Primaryfu els
	Tons	Tons	Gigajoule	
Total fuel supply (mil. tons or GJ)	246.8	16.2	169.9	-
Carbon factor (CO_2 tons per unit)	1.930	2.330	0.019	-
Total CO_2 emissions (mil. tons)	476.4	37.6	3.2	517.3
Total fuel demand (R mil.)	39,217	39,083	1,733	80,033
Unit price before carbon tax (R)	158.9	2,420.0	10.2	-
Unit price after R200 carbon tax (R)	544.9	2,886.0	14.0	-
Price change due to carbon tax (%)	243.0	19.3	37.3	-

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

Table 3: Carbon intensity measures 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	0.262	7.1	9.3	10.0	6.0
Agriculture	0.136	8.7	9.9	5.5	2.3
Coal	12.285	0.1	31.8	0.6	222.6
Natural gas	2.109	0.0	0.0	26.7	40.9
Crude oil	0.963	0.0	0.0	100.0	19.3
Other mining	0.275	1.5	60.5	3.0	3.9
Processed foods	0.152	16.0	4.9	5.0	2.4
Textiles & clothing	0.114	14.9	3.6	24.4	2.2
Wood & paper products	0.369	9.8	8.1	6.5	6.1
Petroleum	0.648	5.1	12.6	4.3	11.7
Chemicals	0.263	8.6	9.9	14.3	4.1
Non-metallic minerals	0.304	7.8	4.1	8.8	5.8
Metal products	0.386	6.5	32.8	6.6	6.0
Machinery	0.089	23.5	11.4	46.0	1.5
Vehicles	0.113	18.1	11.5	29.7	1.8
Other manufactures	0.138	17.1	25.4	15.8	2.4
Electricity & gas	3.231	0.0	5.5	4.4	56.0
Water distribution	0.770	0.0	0.0	0.0	13.5
Construction	0.184	0.0	0.2	0.2	3.0
Trade & catering	0.191	1.1	5.0	3.2	2.8
Transport & comm.	0.168	0.5	7.0	11.3	2.5
Financial services	0.030	1.3	3.4	2.0	0.5
Business services	0.139	0.2	1.0	2.8	2.7
Government	0.079	0.0	0.0	0.0	1.3
Other services	0.134	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.

Table 4: Carbon intensity measures 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	0.260	0.088	0.172	100.0	100.0	7.2
Agriculture	0.146	0.062	0.084	2.6	9.4	16.6
Coal	0.140	0.071	0.069	1.1	0.4	4.1
Natural gas	0.335	0.253	0.083	0.0	0.0	5.3
Crude oil	-	-	-	0.0	0.0	0.0
Other mining	0.292	0.221	0.071	4.6	3.3	4.9
Processed foods	0.186	0.066	0.120	5.5	2.0	8.1
Textiles & clothing	0.247	0.107	0.140	1.3	1.8	11.1
Wood & paper products	0.447	0.270	0.177	2.6	1.4	7.4
Petroleum	1.356	0.039	1.318	2.5	0.1	1.8
Chemicals	0.350	0.184	0.165	5.2	1.0	5.0
Non-metallic minerals	0.477	0.324	0.153	1.0	0.8	7.0
Metal products	0.430	0.257	0.173	4.7	1.9	5.4
Machinery	0.181	0.027	0.154	2.6	1.4	5.6
Vehicles	0.175	0.023	0.152	4.6	1.2	5.5
Other manufactures	0.150	0.028	0.122	1.2	1.2	8.0
Electricity & gas	3.143	0.295	2.848	1.7	0.3	3.2
Water distribution	0.537	0.486	0.052	0.6	0.1	3.7
Construction	0.202	0.027	0.175	3.7	6.0	11.3
Trade & catering	0.133	0.040	0.094	9.8	21.7	11.3
Transport & comm.	0.167	0.108	0.060	9.1	4.1	5.1
Financial services	0.024	0.006	0.018	7.0	2.9	3.4
Business services	0.159	0.084	0.075	9.0	11.7	8.0
Government	0.077	0.022	0.055	10.2	12.8	7.1
Other services	0.105	0.027	0.078	9.4	14.5	8.7

Notes: * Direct carbon content for ‘all sectors’ includes transformed carbon, but excludes the primary fuels entering the transformation sectors.

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

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

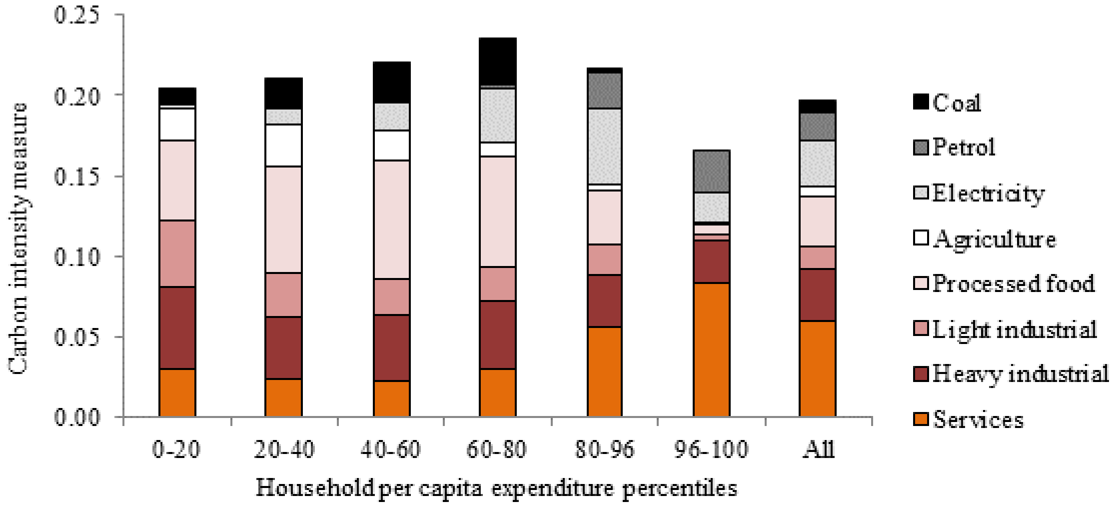
Table 5: Decomposing the carbon intensity of gross domestic product and household consumption (2005)

	Share of total GDP (%)	Share of absorption (%)	Emissions (1000 tons CO_2)	Carbon intensity (tons CO_2 per R1000)	Share of emissions in absorption (%)	Per capita emissions (tons CO_2)	Price change from R200 carbon price (%)
GDP (market prices)	100.0		412.8				4.7
Total absorption	101.9	100.0	258.9	0.163	100.0		3.0
Household consumption	63.8	62.7	196.2	0.197	75.8	4.19	3.2
Percentile 0-20	0.9	0.9	2.9	0.205	1.1	0.31	3.3
Percentile 20-40	2.7	2.6	8.8	0.210	3.4	0.94	3.4
Percentile 40-60	5.0	4.9	17.1	0.221	6.6	1.82	3.6
Percentile 60-80	9.2	9.1	33.9	0.235	13.1	3.61	3.9
Percentile 80-96	18.6	18.2	62.7	0.217	24.2	8.36	3.6
Percentile 96-100	27.5	26.9	70.8	0.166	27.4	37.79	2.7
Government consumption	19.6	19.3	24.0	0.079	9.3		1.3
Gross fixed capital formation	16.9	16.6	34.6	0.131	13.4		2.2
Changes in inventories	1.5	1.5	4.1	0.176	1.6		3.0
Exports	24.8		258.3	0.669			11.5
Imports*	26.7		104.4	0.251			4.4

Notes: * 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.

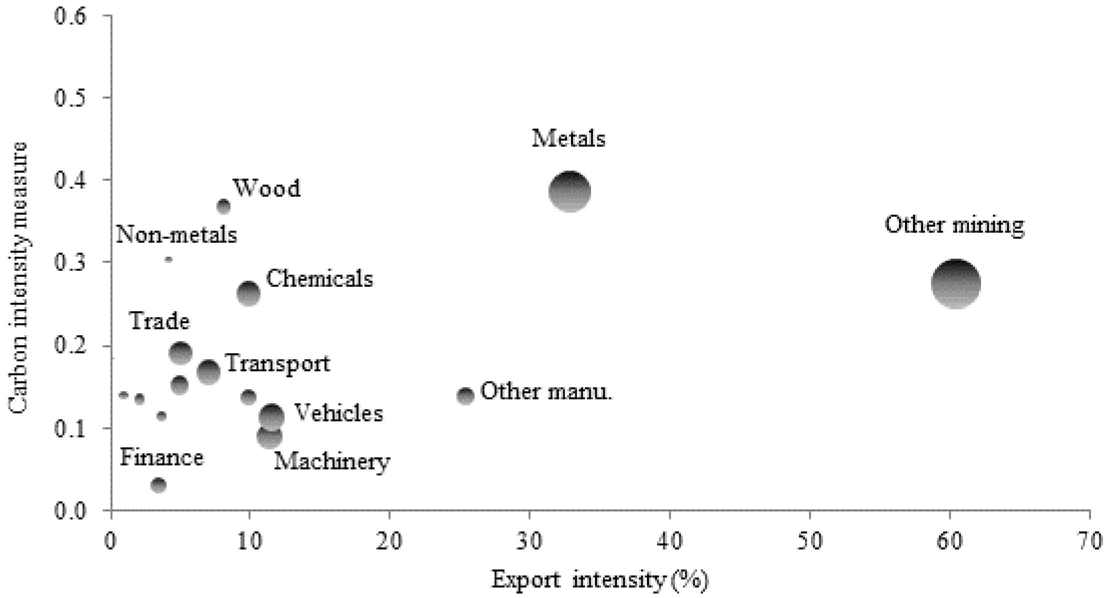
Source: Authors' calculations using StatsSA (2006; 2010) and multiplier analysis results.

Figure 1: Decomposing the carbon intensity of household consumption (2005)



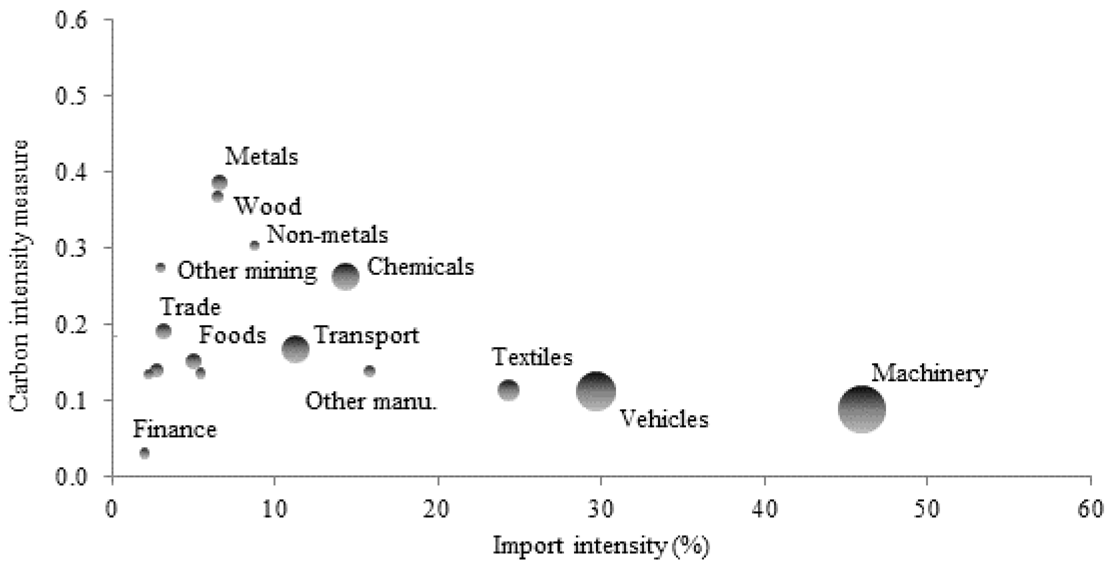
Notes: 'Carbon intensity measure' is tons of CO_2 per R1000 of consumption demand.
Source: Authors' calculations using StatsSA (2006; 2010) and multiplier analysis results.

Figure 2: Carbon and export intensities for aggregate products (2005)



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.
Source: Authors' calculations using StatsSA (2010) and multiplier analysis results.

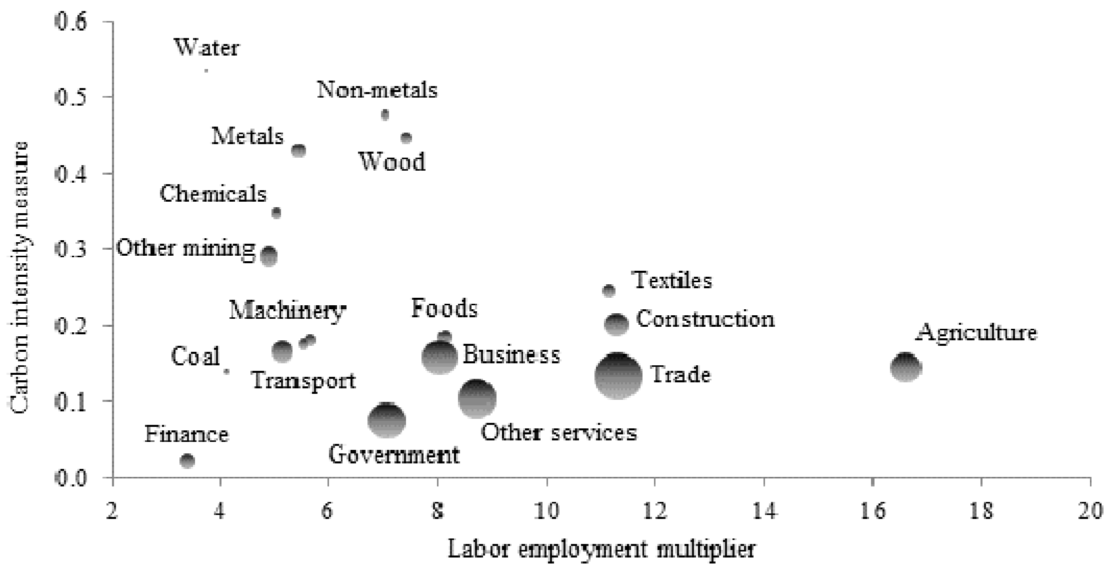
Figure 3: Carbon and import intensities for aggregate products (2005)



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.

Source: Authors' calculations using StatsSA (2010) and multiplier analysis results.

Figure 4: Carbon intensity and employment multipliers for aggregate sectors (2005)



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.

Source: Authors' calculations using StatsSA (2010) and multiplier analysis results.

Appendix: Detailed product and sector results

Table A1: Ranked carbon intensity measures for detailed products (2005)

P5	Coal &lignite	12.285	P13	Fruit & nuts	0.186
P88	Electricity distribution	3.231	P16	Grain mill products	0.181
P7gas	Natural gas	2.109	P12	Vegetables	0.176
P7oil	Crude oil	0.963	P15	Dairy products	0.176
P9	Natural water	0.782	P84	Passenger transport	0.172
P89	Water distribution	0.770	P19	Bakery products	0.171
P38	Petroleum products	0.648	P18	Animal feeding	0.170
P36	Paper products	0.537	P94	Leasing & rental services	0.167
P50	Structural non-refractory clay	0.458	P98	Telecommunication	0.166
P58	Iron & steel products	0.440	P87	Postal & courier services	0.164
P51	Plaster & cement	0.402	P100	Other manufacturing services	0.163
P39	Basic chemicals	0.382	P22	Pasta products	0.160
P53	Other non-metallic mineral products	0.382	P71	Electrical machinery	0.156
P59	Non-ferrous metals	0.374	P55	Jewellery	0.154
P17	Starch products	0.349	P23	Other foods	0.154
P49	Non-structural ceramics	0.349	P54	Furniture	0.151
P99	Support services	0.337	P75	Ship & boats	0.150
P43	Soap, cleaning products & perfume	0.325	P14	Oils & fats	0.145
P40	Fertilizers & pesticides	0.319	P2	Live animal	0.145
P41	Paint & related products	0.302	P102	Education services	0.142
P6	Metal ores	0.282	P80	Construction services	0.138
P27	Textile fabrics	0.281	P93	Real estate services	0.138
P52	Articles of concrete	0.265	P1	Agriculture	0.137
P97	Other business services	0.255	P103	Health & social services	0.134
P60	Structural metal products	0.238	P25	Soft drinks	0.134
P44	Other chemical products	0.235	P29	Carpets	0.131
P7	Other minerals	0.235	P104	All other services	0.131
P62	Other fabricated metal	0.230	P85	Freight transport	0.129
P57	Waste & scraps	0.230	P81	Trade services	0.128
P61	Tanks & reservoirs	0.228	P95	Research & development	0.128
P46	Other rubber products	0.220	P10	Meat	0.127
P79	Construction	0.219	P83	Catering services	0.125
P76	Railway & trams	0.216	P3	Forestry	0.124
P37	Printing	0.209	P74	Motor vehicles & parts	0.119
P48	Glass products	0.208	P33	Leather products	0.117
P31	Knitting fabrics	0.208	P66	Lifting equipment	0.117
P47	Plastic products	0.204	P21	Confectionary products	0.115
P20	Sugar	0.202	P42	Pharmaceutical products	0.114

P45	Rubber tyres	0.198	P68	Special machinery	0.109
P11	Fish	0.192	P24	Alcohol & beverages	0.105
P30	Other textiles	0.189	P86	Supporting transport services	0.104
P35	Wood products	0.188	P69	Domestic appliances	0.101
P28	Made-up textiles & related articles	0.187	P67	General machinery	0.100
P32	Wearing apparel	0.099	P96	Legal & accounting services	0.062
P64	Pumps & compressors	0.098	P72	Radio & television	0.057
P63	Engines & turbines	0.097	P90	Financial services	0.049
P82	Accommodation	0.096	P73	Medical appliances	0.047
P78	Other transport equipment	0.089	P56	Other manufactured products	0.044
P65	Bearing & gears	0.088	P77	Aircrafts	0.026
P101	Public administration	0.079	P91	Insurance & pensions	0.024
P4	Fishing	0.079	P70	Office machinery	0.023
P26	Tobacco products	0.078	P92	Other financial services	0.006
P34	Footwear	0.074			

Notes: 'Carbon intensity' is tons of CO_2 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 for detailed sectors (2005)

I123	Electricity & gas	3.143	I78	Tanks, reservoirs & metal containers	0.256
I73	Other non-metallic minerals	1.371	I52	Services relating to printing	0.255
I54	Petroleum products	1.356	I36	Article of fur	0.255
I45	Pulp, paper & paperboard	1.225	I77	Structural metal products	0.254
I47	Other articles of paper	0.788	I90	Machine tools	0.246
I69	Structural non-refractory products	0.730	I16	Fruit & vegetables	0.246
I68	Refractory ceramics	0.676	I62	Other chemicals	0.245
I70	Cement, lime & plaster	0.646	I8	Copper mining	0.243
I57	Plastics in primary form	0.622	I65	Plastic	0.243
I67	Non-structural non-refractory ceramics	0.574	I7	Chrome mining	0.240
I124	Water	0.537	I31	Carpets, rugs & mats	0.239
I74	Basic iron & steel	0.517	I161	Other business activities	0.238
I75	Basic precious & non-ferrous metals	0.502	I93	Machinery for food & beverages	0.238
I29	Finishing of textiles	0.490	I51	Printing	0.237
I80	Forging & stamping of metal	0.451	I34	Knitting & crocheted fabrics	0.234
I20	Starch products	0.441	I71	Articles of concrete & cement plaster	0.234
I61	Soap & detergents	0.427	I23	Sugar	0.234
I55	Basic chemicals	0.417	I66	Glass and glass products	0.232
I10	Platinum mining	0.399	I58	Pesticides & agro-chemicals	0.232
I46	Corrugated paper & containers	0.390	I42	Builders' carpentry & joinery	0.232
I76	Casting of metals	0.388	I92	Machinery for mining & construction	0.231
I56	Fertilizers	0.381	I96	Other household appliances	0.230
I28	Spinning & weaving of textiles	0.361	I113	Bodies of motor vehicles & trailers	0.227
I33	Other textiles	0.345	I9	Manganese mining	0.227
I12gas	Natural gas	0.335	I30	Made-up textiles	0.225
I12	Other mining	0.334	I114	Parts & accessories for motor vehicles	0.224
I118	Other transport	0.329	I59	Paints, varnishes & printing ink	0.222
I41	Veneer sheets & plywood	0.327	I82	Cutlery & general hardware	0.219
I116	Railway & tramway locomotives	0.319	I101	Accumulators, cells and batteries	0.219
I79	Steam generators	0.313	I13	Mining services	0.219

I91	Machinery for metallurgy	0.312	I126	Building of complete construction	0.217
I147	Water transport	0.297	I87	Lifting & handling equipment	0.217
I15	Fish	0.291	I120	Jewellery & related articles	0.214
I6	Iron ores	0.291	I22	Bakery	0.210
I83	Other fabricated metal products	0.287	I156	Computer & related activities	0.209
I50	Other publishing	0.284	I32	Cordage, rope, twine & netting	0.208
I100	Insulated wire and cables	0.284	I110	Optical & photographic equipment	0.204
I63	Rubber tyres	0.282	I17	Oils & fats	0.201
I89	Agriculture & forestry machinery	0.281	I26	Other foods	0.201
I64	Other rubber tyres	0.279	I48	Books & other publications	0.201
I148	Air transport	0.273	I35	Wearing apparel	0.197
I11	Other metal ore mining	0.263	I137	Retail trade in food & beverages	0.196
I81	Treatment & coating of metal	0.258	I169	Recreation, cultural & sport activities	0.194
I72	Cutting, shaping, finishing of stones	0.192	I132	Wholesale of household goods	0.140
I37	Tanning & dressing of leather	0.191	I4	Mining of coal & lignite	0.140
I170	Other services	0.191	I39	Footwear	0.140
I145	Restaurants	0.190	I166	Health activities	0.139
I115	Building & repairing of boats & ships	0.189	I167	Sewerage, refuse & sanitation	0.139
I128	Building completion	0.188	I144	Accommodation	0.139
I19	Grain mill	0.187	I117	Aircrafts	0.139
I133	Wholesale of non-agriculture products	0.186	I112	Motor vehicles	0.138
I98	Electric motors & generators	0.185	I105	Television & radio transmitters	0.138
I125	Site preparations	0.181	I139	Repair of personal & household goods	0.137
I160	Advertising	0.180	I38	Luggage & handbags	0.135
I119	Furniture	0.180	I131	Wholesale of agriculture raw material	0.135
I103	Other electrical equipment	0.179	I155	Renting of machinery & equipment	0.130
I88	Other special purpose machinery	0.178	I2	Forestry & related services	0.128
I99	Electricity distribution apparatus	0.171	I138	Other retail	0.127
I146	Land transport	0.170	I107	Medical & surgical equipment	0.125

I49	Newspapers & periodicals	0.169	I27	Beverage & tobacco	0.125
I21	Animal feeds	0.168	I60	Pharmaceuticals	0.123
I122	Recycling	0.168	I109	Industrial process control equipment	0.117
I53	Reproduction of recorded media	0.168	I111	Watches & clocks	0.113
I150	Post & telecommunication	0.168	I159	Architectural & other consultant fees	0.107
I40	Sawmilling & wood planing	0.166	I149	Supporting & auxiliary transport	0.106
I14	Meat	0.166	I130	Wholesale trade on fee	0.105
I85	Pumps, compressors & valves	0.163	I86	Bearings, gears & driving elements	0.097
I43	Wooden containers	0.162	I162	Central government	0.094
I168	Membership activities	0.162	I158	Legal & accounting activities	0.094
I127	Building installation	0.162	I134	Wholesale trade in machinery	0.090
I18	Dairy products	0.161	I164	Local government	0.090
I24	Cocoa & chocolate	0.161	I141	Maintenance & repair of vehicles	0.089
I95	Other special purpose machinery	0.160	I143	Sale, maintenance, repair & fuel	0.089
I94	Machinery for textile, apparel & leather	0.159	I121	Other manufacturing	0.083
I84	Engines & turbines	0.155	I140	Sale of motor vehicles	0.081
I1	Agriculture & related services	0.151	I171	Unobserved & informal households	0.078
I165	Education & other training services	0.151	I108	Instruments for measuring & testing	0.077
I157	Research & development	0.148	I97	Office & computing machinery	0.076
I44	Other products of wood	0.148	I104	Electronic valves & tubes	0.075
I136	Non-specialised retail trade in stores	0.147	I3	Fishing & related activities	0.068
I129	Renting of construction equipment	0.146	I106	Television & radio receivers	0.067
I135	Other wholesale trade	0.146	I142	Sale of motor vehicle parts	0.062
I25	Pastas	0.143	I163	Provincial government	0.054
I102	Electric lamps, lighting equipment	0.143	I151	Financial, insurance & pension funding	0.036
I5	Mining of gold & uranium	0.142	I152	Insurance & pension funding	0.025
I154	Real estate activities	0.142	I153	Other financial intermediation activities	0.003

Notes: 'Carbon intensity' is tons of CO_2 per R1000 of gross output. Industry codes correspond to StatsSA (2010).

Source: Authors' calculations based onresults from the multiplier analysis.