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Book

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Carbon tax and its impact on South African households

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Abstract

This paper focuses on evaluating the economy-wide impact of a carbon tax as a policy mechanism designed to reduce GHG emissions in South Africa, with a particular focus on households. Impacts of the carbon tax are evaluated across different households, including low-income households, who are often said to be the least responsible for climate change. A dynamic CGE model of the South African economy that includes detailed tax information allowing for accurate measurement of the effects of imposing a carbon tax is used to conduct the modelling simulations. Results show that the effects of the carbon tax on economic growth are minimised when the revenue collected is recycled back into the economy. Additionally, low-income households are shown to be more affected by the carbon tax implementation compared to high-income households. The results from this study confirm that policymakers need to be careful in introducing new taxes on goods that form a large part of the consumption bundle of vulnerable households, such as energy, and have mitigation policies ready to support such households.

Keywords: CGE Modelling, Carbon Tax, Households, South Africa

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1. Introduction

Over the last few decades, much of policy-related research in the energy space, both locally and internationally, has focused on mitigating greenhouse gas (GHG) emissions. Finding new, renewable, cleaner energy sources that will enable future economic development without further damaging our planet has been vital in these mitigation efforts. The world's current fossil fuel use has contributed to observed global warming and rapidly rising demand for crude oil, threatening the world's economy (IPCC, 2014). In the case of developing countries such as South Africa, the goal of reducing GHG emissions and mitigating climate change needs to be achieved whilst working to ensure economic growth and development by taking into consideration its effects on different households – significantly poorer households that, compared to industries and the electricity generation sector, are least responsible for GHG emissions and therefore climate change.

Currently, the world is experiencing an environmental failure – more broadly known in economics as a market failure – whereby pollution costs are not reflected in the final prices of goods and services. In other words, the current price of production largely excludes environmental or externality costs. To correct this failure and include these external costs in the prices of goods and services, governments need to intervene by creating regulations and policies that influence the decision-making process and behaviour of producers and consumers (National Treasury, 2013a). This is already happening to some extent in some markets (e.g. emissions tax on motor vehicles provides an incentive for the development of cleaner technologies) around the world and in South Africa with the "*Post-2015 National Energy Efficiency Strategy",* which aims to reduce energy efficiency as a barrier to future progress to encourage permanent growth and the introduction of the carbon tax in early 2019 (DoE, 2016; National Treasury, 2015; 2019).

To achieve GHG emission reductions, South Africa is considering adopting a mix of policies and measurements (PAMs). One of these PAMs – and its main instrument– is a carbon tax policy outlined in May 2013 by the South African National Treasury and implemented in June 2019 (National Treasury, 2013b; Republic of South Africa, 2019). South Africa's National Treasury recognises that a carbon tax as a proposed carbon pricing mechanism is insufficient; hence, they have highlighted that carbon pricing and low carbon energy policies must be implemented simultaneously to adequately incentivise a least-cost decarbonisation path in South Africa (National Treasury, 2013c). Therefore, sectoral emission targets, company-level carbon budgets, and energy efficiency gains in different sectors – including the residential sector – are some of the PAMs being considered.

Given the high inequality levels in South Africa, its climate change policies need to be formulated in a way that low-income households are less affected. The South African GHG mitigation plan allows for a smooth transition to a low-carbon economy. It has been designed to incentivise producers and consumers, especially those in carbon-intensive industries, to move towards cleaner technologies and reduce emissions whilst minimising the potential adverse impacts on low-income households (National Treasury, 2013b, Republic of South Africa, 2019).

Despite PAMs being designed to promote economic growth, whilst considering the persistent income inequalities in the country, research needs to be done to analyse the impact of these PAMs, including the carbon tax, on households at different income levels. This study's main objective is to evaluate the impact of the carbon tax as one of the main policies to reduce GHG emissions in the South African economy, focusing on different households, especially low-income households.

The carbon tax has been devised to avoid hindering industry competitiveness by reducing the risk of South Africa's exports being subject to border carbon adjustment (BCA) tariffs (National Treasury, 2013b; Republic of South Africa, 2019). The Carbon Tax Bill of 2019 details that the main objective of the carbon tax is to reduce GHG emissions in a sustainable, cost-effective and affordable manner (Republic of South Africa, 2019). The carbon tax has been designed under the 'Polluter Pay Principle' whereby *"…those responsible for harming the environment must pay the costs of remedying pollution and environmental degradation and supporting any consequent adaptive response that may be required"* (National Treasury, 2018:3). This already implies that households should not bear the total weight of the carbon tax.

To evaluate how households at different income levels are affected by policies imposed by a national group aimed at reducing GHG emissions, an improved and updated CGE model of the South African economy is implemented. The CGE model used in this study is a dynamic CGE model similar to other CoPS-style models used in papers such as Bohlmann et al. (2015), Van Heerden et al. (2016) and Roos et al. (2020)[‡]. Since the basic details of the carbon tax have remained the same as that on which the Van Heerden et al. (2016) paper was based, we expect to find similar impacts of the carbon tax on key macroeconomic and environmental variables, e.g., the impact on GDP or expected reduction in emissions. However, evaluating the effects of the carbon tax on its own provides the base to evaluate the impact of the carbon tax on different households. Bohlmann and Inglesi-Lotz (2021) split the South African households per income level and estimated their income, electricity, and food elasticities. This estimation informed our analysis in this study regarding the behaviour of South African households. The model's business-as-usual baseline path is updated to include the latest macroeconomic projections (IMF, 2020). Lastly, following the strategy in Roos et al. (2020), the impact of the projected revenue generated from the carbon tax, as noted in the 2020 Budget Review, is modelled. Similar modelling assumptions to Roos et al. (2020) as far as the model closure is concerned will be used.

This paper is structured as follows: Section 2 presents the literature review that deals with households' electricity and energy behaviour profiles, and secondly, studies that evaluate the impact of carbon tax implementation. Next, the methodology section discusses the Computable General Equilibrium (CGE) modelling, scenario design and dataset. Finally, the empirical results are presented, and the policy insights are discussed.

2. Literature review

2.1. Electricity and energy profile of South African consumers

The international literature on energy and electricity consumption in the residential sector is vast. It includes research on factors influencing residential energy consumption, factors influencing energy efficiency in the residential sector, and further analysis, including various econometric techniques that study the evolution of energy consumption in developed and developing countries (Donatos and Mergos, 1991; Al-Faris, 2002; Dergiades and Tsoulfidis, 2008; Achao and Schaeffer, 2009; Dai et al., 2012; Lopez-Rodriguez, 2013; Cuddington & Dagher, 2015). Most studies in the South African literature focus on the determinants of electricity demand – primarily on the economy in its entirety or mainly on energy-intensive sectors; much less focus has been given to the residential industry – with the exception of Ziramba (2008). A significant gap in the literature is the analysis of changes over time in household energy-use characteristics.

In South Africa, policies regarding access to essential services, including access to electricity in rural areas, were not a priority during the Apartheid era (1948 – 1991), when only a third of the population had access to electricity (Ziramba, 2008; Amusa et al. 2009; Odhiambo, 2009; Inglesi, 2010; Inglesi-Lotz & Blignaut, 2011). Electricity access became a national policy priority for the South African government only post-Apartheid, starting in the early 1990s and especially in 1994. Against this background, the South African literature regarding residential energy consumption post-1994 focussed on the effects of access to electricity on rural households' energy consumption and not on the trends and patterns of households' energy demand (Davis, 1998; Thom, 2000).

Davis (1998) studied energy consumption patterns in rural areas in South Africa, focusing mainly on identifying the effects of access to electricity on fuel choices used for everyday tasks such as cooking, heating and lighting. Davis (1998) found evidence of the literature's 'energy ladder: as income rises, households in rural areas trend away from low-quality fuels like biomass and wood towards more convenient and modern fuels such as electricity and gas to fulfil their energy needs basic everyday tasks. However, access to electricity was also found to influence the energy transition process. As income rises, electrified households tend to be more dependent on electricity. Additionally, the fuel choice patterns of low-income electrified households were similar to that of non-electrified households;

[‡] The details of Van Heerden et al. (2016) and Roos et al. (2020) has been provided in the literature review session.

electricity is seen as an additional energy source—Davis (1998) detailed energy consumption patterns in rural areas. However, there was a lack of comparison regarding how energy consumption in rural areas compares to the rest of the country and the critical electrification policies implemented in South Africa up to1998.

Thom (2000) also studied aspects of electricity and energy consumption in South Africa. The study attempts to explain how access to electricity influences electrical appliance ownership in rural households. Additionally, the study described how electrified rural households tend to use electricity and other energy sources for lighting, cooking and electrical appliances such as radios. This study was based on a project by the Energy and Development Research Centre on '*The Role of Electricity in the Integrated Provision of Energy to Rural Areas*' that secured the availability of reliable and detailed data for the period 1995 - 1998. By 1999, the electrification of rural households had increased to around 46 per cent, compared to 12 per cent in 1994.

The main findings suggest that even though many households have become owners of electric appliances such as radios, televisions, kettles, irons and refrigerators, still the level of adoption of these technologies is low and dependent on income levels. Thom (2000) suggests that to meet their basic energy needs, most households in rural areas use a combination of fuels, including paraffin and candles. Apparently, access to electricity adds electricity to the mix of fuels used by rural households; however, it does not fully substitute the use of other fuels. Even though grid electricity is most commonly used for lighting, it was observed that rural households also use electricity for cooking. Yet, low-income households do not use electricity as a single fuel for cooking; they still rely on firewood and paraffin. The relatively low cost of paraffin has led to its continued use for cooking and water heating, even after electrification.

Thom (2000) highlighted how the South African electrification program has been implemented as a 'blanket' program and has failed to recognise that some rural households are still unable to afford to pay for electricity beyond the free-electricity allocation. That leads to rural households still relying on other energy sources to satisfy their basic needs.

Madubansi and Shackleton (2006) confirmed one of the key findings by Thom (2000), concluding that, regardless of widespread access to electricity in the country, households still rely on a mix of electricity and other fuels such as paraffin and firewood for lighting, cooking and thermal use. This confirms, as highlighted in the literature and Thom (2000), that households view electricity as a complement to other fuel sources instead of a substitute. Thus, Mabudansi and Shackleton (2006) concluded that as electrification increases in rural areas, energy consumption and the total number of household fuels increases. However, despite the rise in expenditure on all energy sources, the study reported that in 2003, rural households spent around 60 per cent of their total energy expenditure on electricity. This is explained by the relatively high monetary value of grid-based electricity relative to alternative energy sources such as wood or kerosene.

Anderson (2004) used a Heckman sample selection model to analyse the determinants of electricity demand on prepaid electricity users. The author used expenditure data and found that the income and price elasticity of demand are estimated to be 0.32 and -1.35, respectively, indicating that the price of electricity is expected to significantly impact the electricity consumption of prepaid users (Anderson, 2004). Ziramba (2008) estimated the residential demand for electricity in South Africa from 1978-2005. The author used real GDP per capita and the price of electricity as the main explanatory variables following the bound testing approach to cointegration by Pesaran (2001) used in Narayan and Smyth (2005). The long-run income elasticity is 0.31, and the short-run income elasticity is 0.30, indicating that income electricity consumption is a normal good – income increases lead to electricity increases. The long-run price elasticity is -0.04, and the short-run value is 0,02; however, price elasticities are statically insignificant in both the long and short-run. The results suggested that income is the primary determinant of electricity demand, while electricity price was insignificant.

Ye et al. (2018) estimated the determinants of residential energy demand in South Africa by combining data from the South African Income and Expenditure Survey and the National Energy Regulator of South Africa (NERSA). The authors concluded that household income and electricity prices are key determinants of energy demand in the South African residential sector. As expected, the authors found that household demand is higher for appliance-rich urban households; this is also influenced by the number of people and the size of the household dwelling.

Bohlmann and Inglesi-Lotz (2018) concentrated on analysing the energy characteristics of the South African residential sector while considering their energy-use profile and comprehending other factors like their geographic distribution and demographics. The results showed that South African households, particularly low-income ones, still utilise diverse energy sources, including wood and paraffin, to meet their basic energy requirements, despite the 50 kW/h of free electricity per month of FBE. Around 75% of non-electrified families in rural areas, where solid fuels are primarily used for cooking, heating, and lighting, rely on solid fuels. Low-income South African families utilise between 5 and 10 per cent of their total energy for lighting; the remaining 85 to 90 per cent is used for space heating and cooking.
Bohlmann and Inglesi-Lotz (2021) applied an Auto Regressive Distributed Lag (ARDL) econometric model; a bounds testing approach to testing cointegration methodology as used by Narayan and Smyth (2005) and Ziramba (2008) to estimate the determinants of electricity demand at both the aggregate and at disaggregated income levels. Residential power demand was calculated as a function of gross national disposable income, energy costs, food costs, and a dummy variable that accounted for any possible structural breaks brought on by load shedding and electricity pricing restructuring. This study adds to the body of literature on South Africa by analysing the years 1975 to 2016, which is a more extended period than has previously been covered in the country's literature and takes into account the country's electricity price restructuring (increases in electricity prices) starting in 2007.
According to the research, there is a long-term correlation between household electricity use, gross national disposable income, power prices, and food prices. All income groups' disposable income elasticities have a positive sign, showing that South African families use more power as income rises. As a result, electricity might be regarded as a typical good. This is the first South African study to find negative and significant home price elasticities, indicating that electricity prices affect power consumption for South African households after 2008. Price elasticities are expected to be negative and significant. This study concluded that, at both the aggregate and disaggregate income levels, food and power are replacement items for all South African households, regardless of whether they are complementary or interchangeable.
All in all, the literature on South African households has confirmed that energy pricing directly affects the households' decision to consume energy due to price and income elasticities. Also, the literature shows that energy costs create budgetary constraints for households and indirectly impact their purchasing ability.

2.2. CGE – a tool to evaluate the impact of carbon tax

Over the years, the South African government has closely worked with the private sector and academia to develop broad policy frameworks that identify climate change as a key challenge (Davis Tax Committee, 2015). Therefore, several studies have been modelling the broad impact of a carbon tax on South Africa (van Heerden et al., 2006; Pauw, 2007; Devarajan et al., 2009; Alton et al., 2014; van Heerden et al., 2016). These modelling exercises have focussed on the decision-making process regarding the best mitigation policy to follow by informing policy design and analysing the implications on different economic areas, including macroeconomic indicators, industries and other stakeholders.
Details have been given and studied regarding how the carbon tax and policies designed to combat climate change will balance South Africa's commitment to reduce GHG emissions with the need to reduce poverty, promote economic growth and maintain trade competitiveness. South Africa's Intended Nationally Determined Contribution (INDC), submitted as part of the ratification of the Paris Agreement, specify the route that the country will follow to achieve the transition path towards a low-carbon economy, along with the suite of policies intended to achieve this goal. However, not enough detail is given regarding the apparent effects these policies will potentially have on different households. In the South African literature, regarding the effects of climate change policies on specific households, only van Heerden et al. (2006) show in detail how different environmental taxes and recycling schemes will impact the welfare of other households. Using a CGE model that includes more detail with regards to electricity generation types, households' price elasticities of electricity consumption and updated macroeconomics values; this study contributes by providing an updated analysis of the effects that carbon tax aimed at reducing GHG emissions in South Africa will have on different households as well as in the economy as a whole.

CGE models have been widely used in analysing the effects of policies designed to mitigate GHG emissions on the overall economy. Babatunde et al. (2017) did a systematic literature review of all the available peer-reviewed papers evaluating the climate change mitigation measures and policy interventions using CGE modelling. The authors concluded that CGE modelling is one of the preferred tools to address climate change mitigation topics at a global, regional and national level. The main research themes focused on the carbon tax, energy efficiency, emissions reduction target and renewable energy. Regarding the type of CGE model used, the authors found that static CGE models are employed more often than dynamic ones (Babatunde et al., 2017).

Van Heerden et al. (2006) employed a static, multi-sector CGE model to evaluate the economy-wide impacts as well as the prospective for a double or triple dividend of different environmental taxes, including a tax on GHG; a fuel tax; a tax on electricity use; and an energy tax – and other recycling options in South Africa. The authors could quantify the effects of different policies on different household groups. A triple dividend (i.e., reducing emissions, reducing poverty, and increasing GDP) was found when any of the environmental taxes were fully recycled to subsidise food prices. Additionally, the authors concluded that the carbon tax has a higher environmental effect than the other environmental taxes (van Heerden et al., 2006).

Devarajan et al. (2011) used and static CGE model of South Africa to examine the impact of different environmental taxes, including a carbon tax, a sales tax on energy commodities, and a sales tax on pollution-intensive commodities, in lowering GHG emissions on the South African economy by 15 per cent. Devarajan et al. (2011) found that the carbon tax would yield modest effects on South African welfare and employment levels, followed by the sale tax on energy commodities and the sale tax on pollution-intensive commodities. Additionally, Devarajan et al. (2011) concluded that the welfare of medium-skilled labour would be more impacted than the low-skilled labour group. This study did not evaluate the impact of the different policies on households at a disaggregated level.

Alton et al. (2012) used a dynamic multi-sector CGE model with detailed electricity generation sectors to examine the impact of a carbon tax in South Africa. The authors found that the effects of a carbon tax over different scenarios are relatively small. Relative to the baseline, by 2025, real GDP is expected to decline between 1 and 1.23 per cent (Alton et al., 2012). It was concluded that the impact of the carbon tax would be relatively small on the industrial sector, given the different tax-free allowance assumptions.

Van Heerden et al. (2016) thoroughly evaluated the impacts of the carbon tax with different recycling schemes on the South African economy. The authors used a dynamic 53-sector CGE model. Results showed that for 2016-2035, the carbon tax would effectively reduce GHG emissions. However, the carbon tax is shown to have a negative effect on GDP growth relative to the baseline. The effectiveness of the carbon tax depends on the tax exemption level.

Interestingly, the authors showed that different recycling schemes reduce the effectiveness of the carbon tax because various recycling schemes are designed to promote economic growth (van Heerden et al., 2016). It was concluded that the better recycling scheme that yielded the lowest negative impact on GDP growth was recycling the tax revenue to all industries as a production subsidy (van Heerden et al., 2016). This study follows the assumptions and recycling schemes followed in van Heerden et al. (2016); however, this thesis contributes to the literature focusing on the effects of the carbon tax on South African households.

Nong (2020) developed a global CGE model that included an emissions database incorporating CO_2 and non-CO_2 emissions. According to the author, the inclusion of non-CO_2 emissions allows for a better evaluation of the impacts of energy policies. The paper's main objective was to evaluate the impacts of the carbon tax in South Africa. Results suggested that the ideal and most cost-effective carbon tax rate is \$9.15 (equivalent to the effective taxation of R120 per ton of CO_2eq). At this rate, South Africa will reduce emissions by between 12.3 and 15.6 per cent – this considering CO_2 and non-CO_2 emissions – with a GDP decline of between 1.17-1.59 per cent. Despite the contraction in the economy, results show that renewable energy sectors will expand their production, and the economy will move towards a low-carbon and sustainable path (Nong, 2020).

This study closely follows the study by van Heerden et al. (2006). However, in terms of the methodology used, the way the scenarios are designed, and the policy shocks applied to the economy, the methods used by Roos et al. (2020) are adopted. Roos et al. (2020) implemented a dynamic multi-regional CGE model of the South African economy, with substantial Government Financial Statistics (GFS) detail – including tax and spending – to evaluate the economy-wide and regional impacts of raising VAT and increasing expenditure on education and health. The study was based on the South African government's announcement to cover its tax revenue shortfall by introducing an additional R36 billion in the fiscal period 2018/19 (Roos et al., 2020). The extra tax revenue will come from a 1 per cent increase in VAT – taking the effective VAT rate to 15 per cent – from April 2018.

The authors acknowledge that increasing the VAT rate increases the cost of living for all South Africans. Therefore, the policy simulation was designed in a manner in which the funds raised from the increase in VAT were recycled back into the provincial governments to finance expenditure programmes, including education and health (Roos et al., 2020). In this study, a similar approach is followed by recycling the revenue collected from the carbon tax into expenditure such as health and education that benefits low-income households the most.

Roos et al. (2020) concluded that increasing VAT has different effects in different regions; overall, the effects on GDP are adverse in all areas. Regarding employment, the results suggest that the tax causes the real cost of labour to increase, decreasing employment in the short run. In the long run, real wages adjust and employment returns to baseline.

3. Methodology and Database

As discussed in the previous section, CGE modelling is well suited and designed to analyse new policies' economy-wide effects. The ability of CGE models, such as UPGEM, to recognise the many real inter-linkages in the economy, and account for price-induced behaviour and resource constraints in determining the economy-wide effects of a shock on the economy over time, has made it one of the preferred methodologies for practical policy analysis around the world (Adams & Parmenter, 2013). The policy component of this study was conducted using the UPGEM suite of models broadly described in Van Heerden et al. (2016) and Roos et al. (2020).

3.1. Model theory and database

This study draws on the work done by Van Heerden et al. (2016) and Roos et al. (2020), with a couple of notable additions. Both papers used the CGE modelling methodology. Van Heerden et al. (2016) examine the macroeconomic and environmental impacts of introducing the carbon tax in South Africa. Roos et al. (2020) look at the macroeconomic and regional impacts of collecting additional VAT revenue through an increase in the VAT rate in South Africa. This section provides details regarding the CGE model in this study. It presents more detail regarding the similarities with Roos et al.'s (2020) approach to modelling increases in taxes in a CGE model with sufficient tax details.

UPGEM is a dynamic CGE model of the South African economy with various energy and environmental extensions[§]. To perform a more accurate policy analysis, information in the model's business-as-usual (BAU) baseline path was updated to include the latest available macroeconomic projections (IMF, 2020). Additionally, the latest elasticities estimated in Bohlmann and Inglesi-Lotz (2021) concerning households' response to changes in electricity prices are incorporated in the model. Also, the model is linked to an emissions database and includes detailed tax information that allows us to measure the effects of the carbon tax accurately.

Following the strategy in Roos et al. (2020) – where the authors modelled the impact of an increase in VAT by designing the policy shock in a way that it represented the expected revenue to be raised from increasing the VAT rate – the impact of the projected revenue to be generated from the carbon tax – as noted in the National Treasury 2020 Budget Review – is modelled. Similar modelling assumptions to Roos et al. (2020) as far as the model closure is concerned are used.

[§] This section borrows heavily from the description of UPGEM in Bohlmann, H.R. et al. (2015) and Bohlmann, J.B. et al. (2016) where the same model and database were used.

The model's theory and data structure have been well documented; therefore, only an overview of the model is provided. The model's theoretical structure is based on the renowned MONASH model developed by the Centre of Policy Studies (CoPS) and documented in Dixon & Rimmer (2002) and Dixon et al. (2013). The UPGEM database used in this study is based on the 2011 supply-use (SU) tables published by Statistics South Africa. Following the mapping used in Van Heerden et al. (2016), the modified version of UPGEM used in this study distinguishes 48 sectors. As required for CoPS-style models, the initial levels solution of the model is provided by the base year data. One of the benefits of dynamic CGE models is their ability for the base data to be updated to reflect the latest available statistics and national accounts data without the need to build a new database. The baseline has been updated to include available historical data on the key macroeconomic indicators for up to 2019.

The database, in combination with the model's theoretical specification, numerically describes the main interlinkages in the economy. The theory of the model is, essentially, a set of equations that describe how the values in the model's database move through time and in response to any given shock (see Figure 1 for a stylised representation of the database). As per van Heerden et al. (2016), the model includes a detailed electricity generation model which incorporates four types of electricity generation including coal, nuclear, gas and other (which provides for renewables such as solar, wind and hydro), as illustrated in **Error! Reference source not found.**. The linkage of the model to an external emissions database, similar to the strategy first introduced for UPGEM in Van Heerden et al. (2006), allows for environmental analysis. Elements of the detailed treatment of taxes in the model are based on Roos et al. (2020). UPGEM is solved using the GEMPACK suite of programs described in Harrison & Pearson (1996). GEMPACK eliminates linearisation errors by implementing shocks in a series of small steps and updating the database between steps.

			Absorption Matrix					
			1	2	3	4	5	6
			Producers	Investors	Household	Export	Government	Inventories
		Size	IND	IND	1	1	1	1
1	Basic Flows	CxS	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS
2	Margins	CxSxM	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	n/a
3	Taxes	CxS	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	n/a
4	Labour	OCC	V1LAB					
5	Capital	1	V1CAP					
6	Land	1	V1LND					
7	Production Taxes	1	V1PTX					
8	Other Cost Tickets	1	V1OCT					

C = Number of commodities

IND = Number of industries

S = Number of sources (domestic, imported)

M = Number of commodities used as margins

OCC = Number of occupation types

	Joint Production Matrix
Size	IND
C	MAKE

	Tariffs
Size	1
COM	V0TAR

Source: Adapted from Horridge (2000)

Figure 1: Stylised representation of the core UPGEM database

Following the CoPS-style of implementing a CGE model, inspired by the pioneering work of Johansen (1960), the general equilibrium core of UPGEM is made up of a linearised system of equations describing the theory underlying the behaviour of participants in the economy. The specifications in UPGEM recognise each industry as producing one or more commodities, using as inputs combinations of domestic and imported commodities, different types of labour, capital and land. The multi-input, multi-output production specification is manageable by a series of separability assumptions, as illustrated in **Error! Reference source not found.**. The primary-factor composite is a CES aggregate of composite labour, capital and, in the case of primary sector industries, land. Composite labour demand is itself a CES aggregate of the different types of labour distinguished in the model's database. In UPGEM, all industries share this common production structure, but input proportions and behavioural parameters vary between industries based on base year data and available econometric estimates, respectively.

The demand and supply equations in UPGEM are derived from the solutions to the optimisation problems which are assumed to underlie the behaviour of private sector agents in conventional neo-classical microeconomics. Each industry minimises cost subject to given input prices and a constant returns to scale production function. Zero pure profits are assumed for all industries. Households maximise a Klein-Rubin utility function subject to their budget constraint. The current UPGEM identifies a single representative household, one of the main contributions of this study is the introduction of multiple households by including a top-down household split by taking into account the household expenditure function so households' consumption can be measured as directly linked to income. Units of new industry-specific capital are constructed as cost-minimising combinations of domestic and imported commodities. The export demand for any locally produced commodity is inversely related to its foreign-currency price. Government consumption typically set exogenously in the baseline or linked to changes in household consumption in policy simulations, and the details of direct and indirect taxation are also recognised in the model. This nested production structure reduces the number of estimated parameters required by the model. Optimising equations determining the commodity composition of industry output are derived subject to a CET function, whilst functions determining industry inputs are determined by a series of CES nests. At the top level of this nesting structure intermediate commodity composites and a primary-factor composite are combined using a Leontief or fixed-proportions production function. Consequently, they are all demanded in direct proportion to industry output or activity. Each commodity composite is a CES function of a domestic good and its imported equivalent. This incorporates Armington's assumption of imperfect substitutability for goods by place of production (Armington, 1969).

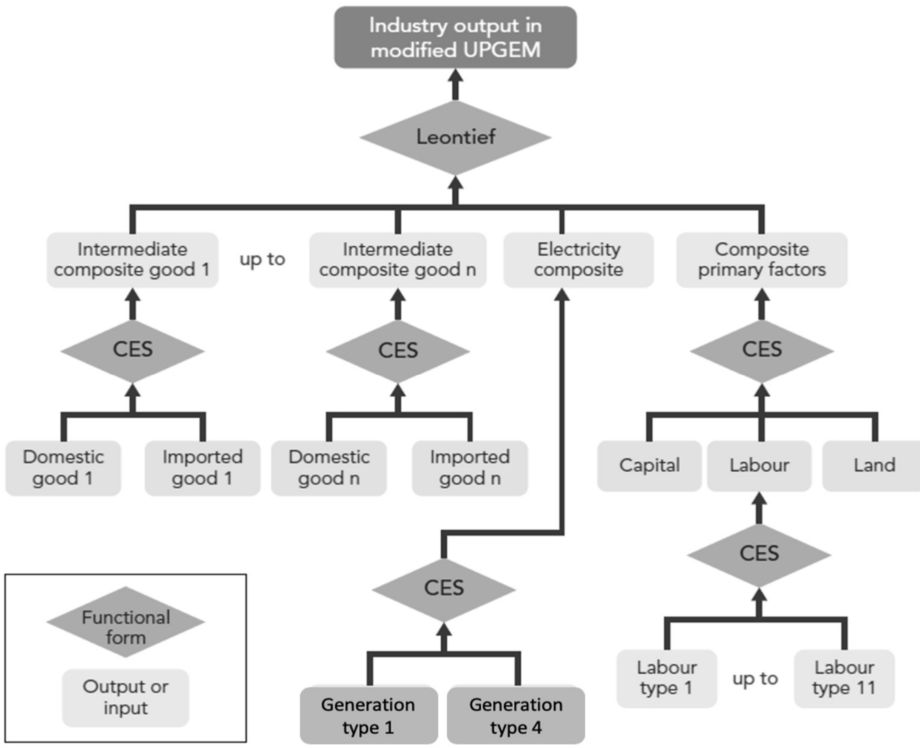

Figure 2:Nested production structure in UPGEM

Source: Adapted from van Heerden et al. (2016)

The recursive-dynamic behaviour in UPGEM is specified through equations describing physical capital accumulation; lagged adjustment processes in the labour market; and changes in the current account and net foreign liability positions. Capital accumulation is specified separately for each industry and linked to industry-specific net investment in the preceding period. Investment in each industry is positively related to its expected rate of return on capital, reflecting the price of capital rentals relative to the price of capital creation. For the government's fiscal accounts, a similar mechanism for financial asset/liability accumulation is specified. Changes in the public sector debt are related to the public sector debt incurred during a particular year and the interest payable on previous debt. Adjustments to the national net foreign liability position are related to the annual investment/savings imbalance, revaluations of assets and liabilities and remittance flows during the year. In policy simulations, the labour market follows a lagged adjustment path where wage rates respond over time to gaps between demand and supply for labour across each of the different occupation groups.

Dynamic CGE models such as UPGEM are designed to quantify the effects of a policy change, or exogenous shock, to the economy, over a period of time. The standard CGE methodology described in Dixon et al. (2013) which determines that the best way to examine the effects of an exogenous shock is to compute the differences between a scenario in which the shock has occurred – the policy simulation – and a counterfactual scenario in which the particular shock under examination did not occur – the baseline scenario is followed.[**] Results are then reported as percentage change deviations over time

[**] A baseline forecast of the economy is done,, the closure of the model is changed to the policy closure that will be used later in the policy simulation, and re-generate the baseline forecast with it. From here, any set of additional policy shocks may be applied to the exogenous variables. If a policy simulation where no additional shocks are applied to the policy variables is done, then the original baseline forecast values would be the result of the simulation. This makes it legitimate to interpret differences between results in the policy and baseline runs as the effects of the policy shocks.

between the first 'baseline' simulation run and the second 'policy' simulation run. The nominal exchange rate is set as the numeraire in the policy run.

To measure the impact of the policies designed to reduce GHG emissions in the South African economy, it is necessary for the model to have GHG emissions in the database. The external emissions database linked to the UPGEM model in this study is based on methods employed in Van Heerden et al. (2006) and Van Heerden et al. (2016). The emissions database includes: an energy and emissions accounting model; different equations that allow for inter-fuel substitution in electricity generation; and different mechanisms that allow for the evaluation of emissions reduction in response to policy measures designed to reduce GHG. The emissions database in UPGEM is designed to evaluate emissions according to emitting agent and emitting activity – it does not include the ability to track emissions at a regional level as is the case with MMRF (Adams et al. 2014). Importantly, the model allows for input-saving technological progress. The emissions and energy data methods used to develop the emissions database in the model is based on Blignaut et al. (2005) and Seymore et al. (2014) who developed energy inventories for South Africa. The emissions database has been updated with the latest available data to reflect South Africa's current emission levels.

Following Roos et al. (2020), this version of the UPGEM database includes various indirect tax rates paid on the use of commodities, including environmental taxes (the carbon tax falls within this category). Different tax types are explicitly modelled, thereby allowing for analysis of detailed changes in tax policy, such as the introduction of the carbon tax and its subsequent increases.

Tax revenue collected on each commodity, from each source, paid by each user across all tax types in UPGEM is calculated as follows:

$$TAX(c,s,u,t) = USE(c,s,u) * TAXRATE(c,s,u,t) \quad (1)$$

for all c∈COM, s∈SRC, u∈USER,t∈TAXTYPE

where USE is the delivered value, including margins, of commodity c from source s to user u,

and where TAXRATE is a specific tax t levied on each commodity c from source s. These tax rates are naturally exogenous.

Our focus is on is on the sales tax term (that includes environmental taxes as one of the tax types t), which in ordinary change form can be written as

$$\Delta TAX(c,s,u,t) = 0.01 * TAX(c,s,u,t) * [xuse(c,s,u) + puse(c,s)] + USE(c,s,u) * \Delta TAXRATE(c,s,u,t) \quad (2)$$

for all c∈COM, s∈SRC, u∈USER,t∈TAXTYPE

where xuse is the percentage change in the use of commodity c, from source s by user u; puse is the percentage change in the delivered price of commodity c from source s by used u; and ΔTAXRATE is the ordinary change in the tax rate on commodity c, from source s, paid by user u.

Taxes collected on each commodity adds to the final purchasers' price paid by consumers. In applying the tax shock (an increase in environmental tax revenue collected related to the introduction of a carbon tax) to the model, the first-round effect will be to raise the purchasers' price of the directly affected goods and services. The model, through its system of equations, will subsequently determine the overall effects, considering the various inter-linkages and general equilibrium effects. Since the model is too large to be fully documented in this paper, readers interested in the finer details of the core model theory are encouraged to consult the original publication of the standard MONASH model in Dixon & Rimmer (2002).

3.2. Simulation design

Many of the simulation design aspects in this study follow the standard CGE methodology and customs as described in the literature. As noted earlier, applying a dynamic CGE model entails running two simulations: First is the baseline run that plots a business-as-usual path for the economy based on available macroeconomic forecast data, that excludes the policy shock under consideration (in this case, the introduction of a carbon tax and associated technical change in the electricity generation). Second is the policy run that incorporates all the features of the base run, plus the policy shock under consideration. Results for the policy simulation are then typically reported as percentage change deviations in the value of the underlying variable between the two runs. In this study, the policy simulation period runs up to 2030.

Basic macroeconomic assumptions in the policy run, as imposed through the model closure, include the sticky real wages with flexible employment in the short-run versus flexible real wages in the long-run that adjust to move employment back to its long-run baseline level. Industry-specific capital stocks are fixed in the first year of the policy shock, and subsequently adjust based on changes in the expected rate of return of investments. In the long-run, the model theory dictates that the building of new capital stock through investment expenditure push rates of return across industries back to equilibrium, that is, equal across all industries.

This study's shock raises environmental tax revenue collected, via an increase in the underlying tax rate, as a result of the introduction of the carbon tax. This approach is slightly different to some of the earlier literature on carbon taxes previously cited where a direct increase in tax rates were applied. Here, the strategy in Roos et al. (2020) is followed where an increase in the VAT rate was indirectly achieved by increasing VAT revenue collected by the targeted amount. Therefore, in this study, the carbon tax is implemented through an increase in tax revenue collected under the environmental tax category in the model for 2020 by R1.75bn, as per the target amount in the Budget Review (National Treasury, 2020). In subsequent years up to 2030, the carbon tax to be collected is increased in line with the published removal of exemptions in the Carbon Tax Bill (Republic of South Africa, 2019). The model endogenously, and permanently, raises the associated tax rate to an appropriate level.

Further insight is added to this scenario by running two versions of the same carbon tax shock. The first (simulation 1A) assumes that all other tax rates remain unchanged and that government income and the budget deficit is allowed to adjust, that is, no tax recycling occurs. The second (simulation 1B) assumes that the government's budget deficit position remain unchanged relative to the baseline and that all additional tax revenue collected from the carbon tax is recycled back into the economy. The second version (simulation 1B) of the shock aligns closest to National Treasury's intended implementation of the carbon tax and its results for households will be looked at in more detail.

4. Empirical Results

Simulation results are shown in percentage change deviation form for the two scenarios in **Table 1** to **Table 3**. Scenario 1A shows selected macro results for the carbon tax simulation without tax recycling. Scenario 1B shows results for the carbon tax simulation with tax recycling.

Table 1 Macro comparison between carbon tax with and without revenue recycling

Macros	**Year t**	**t+1**	**t+2**	**t+3**	**t+4**	**t+5**	**t+6**	**t+7**	**t+8**	**t+9**	**t+10**
Real GDP without	-0.16	-0.37	-0.63	-0.94	-1.27	-1.61	-1.97	-2.34	-2.71	-3.10	-3.49
Real GDP with	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.04
Emissions without	-1.17	-2.67	-4.36	-6.20	-8.18	-10.22	-12.27	-14.34	-16.46	-18.63	-20.82
Emissions with	-0.97	-2.23	-3.61	-5.14	-6.78	-8.48	-10.19	-11.94	-13.74	-15.60	-17.50

The most striking result when comparing the results of scenarios 1A and 1B is the large contrast in impact between the carbon tax with and without recycling scenarios. This highlights the importance of – as designed by the National Treasury and modelled in Van Heerden et al. (2016) – the tax revenue is recycled back into the economy. Without recycling, real GDP and associated macro variables, such as household expenditure and employment fall by around 3 per cent relative to the baseline in year t+10 of the policy run, in line with Van Heerden et al. (2016). With effective recycling, the negative impact on GDP is reduced to less than 0.04 per cent or approximately R2.4 billion in real terms (Refer to **Table 1**).

Van Heerden et al. (2016) indicate different recycling strategies may show slightly different results, but on a macroeconomic level, results are broadly comparable. The reason for the slightly larger drop in emissions in the without-recycling scenario is that economic activity is more suppressed relative to the with-recycling scenario. All things equal, less economic activity will result in fewer emissions. However, the goal of sound policy making is to achieve the desired drop in carbon emissions with the least possible damage to the economy, particularly vulnerable households.

Table 2 Carbon tax with revenue recycling: Output

Output	**Year t**	**t+1**	**t+2**	**t+3**	**t+4**	**t+5**	**t+6**	**t+7**	**t+8**	**t+9**	**t+10**
Real GDP	0.002	-0.004	-0.009	-0.013	-0.016	-0.020	-0.023	-0.026	-0.030	-0.033	-0.036
Refined Petroleum Products	-0.058	-0.115	-0.162	-0.204	-0.242	-0.278	-0.313	-0.347	-0.380	-0.412	-0.444
Coal Mining	-0.064	-0.074	-0.082	-0.090	-0.097	-0.104	-0.110	-0.116	-0.121	-0.125	-0.129
Iron & Steel Manufacturing	-0.063	-0.083	-0.101	-0.117	-0.132	-0.146	-0.160	-0.172	-0.184	-0.195	-0.204
Electricity	-0.052	-0.084	-0.108	-0.128	-0.147	-0.164	-0.180	-0.196	-0.211	-0.225	-0.238
Food Production	-0.004	-0.007	-0.010	-0.013	-0.016	-0.019	-0.022	-0.025	-0.028	-0.030	-0.033
Transport Services	-0.015	-0.024	-0.033	-0.041	-0.050	-0.059	-0.067	-0.076	-0.084	-0.092	-0.100

Scenario 1A is mainly of academic importance since the carbon tax is not designed or implemented like this in practice. Its purpose is merely to reiterate the impact of tax revenue recycling, and it impacts households in particular. Scenario 1B is, a more realistic version of the carbon tax simulation. The results for simulation 1B in **Table 2** show a much smaller impact on key economic variables. The first-round effect of the shock is to increase the price of commodities directly affected by the carbon tax, including coal, gas and petroleum products. This occurs through the shock to environmental tax revenue in the model that raises the associated tax rates and, ultimately, the final purchasers' price of these goods. The new tax revenue that is collected is recycled back into the economy, mitigating the tax's macroeconomic impact to a large extent. On an industry level, winners and losers are more apparent. The output of heavy carbon-emitting industries that are now taxed falls significantly more relative to the baseline than other goods and services. Further mitigation is facilitated by the model's ability to distinguish between different types of electricity generators and a partial substitution towards the now relatively cheaper non-coal generators. The price increase in other goods, such as *iron & steel manufacturing* or *refined petroleum products*, directly impacts local production given the model's Leontief structure in the top nest (see **Error! Reference source not found.**).

Table 2 shows the impact of the carbon tax as modelled in Scenario 1B on the overall GDP and output of selected industries. The chosen shown sectors are essential because they are either directly affected by the tax or are important components in households' consumption basket (e.g. *food production* and *transport services*).

The initial increase, albeit very small, in GDP in year t can be explained by the increased spending by the government relative to the baseline as a result of the increased tax revenue collection stemming from the newly introduced carbon tax. This offsets the negative impact on virtually other key macroeconomic variables. Beyond year t+1, with only moderate increases in the carbon tax, overall real GDP falls relative to the baseline. It should be noted that no change in investor confidence or preferences is assumed; that is, the required rate of return by investors is not affected by the tax. This assumption is in line with a post-Paris agreement world where the relative rate of return between countries who impose climate change mitigating policies does not change significantly.

The second-round impact of the shock sees various supply and demand dynamics generate general equilibrium effects in accordance with the model's theoretical specification. Given the focus on households in this study, the impact on household expenditure on both an aggregate and individual income group level is very important. A-priori expectations indicate that poorer household groups (P1-P5) will be slightly more affected than more affluent household groups because poorer groups spend a relatively larger share of their income on energy-related goods and services, as indicated by household expenditure data from the Social Accounting Matrix (SAM) incorporated in the model's database. Higher indirect tax rates on goods and services, such as environmental taxes, are, at least partially, passed on to final consumers who face higher prices. At any given income level, this reduces the real spending power of households.

Table 3 Carbon tax with revenue recycling: Households

Households	Year t	t+1	t+2	t+3	t+4	t+5	t+6	t+7	t+8	t+9	t+10
Aggregate Household Expenditure	-0.008	-0.016	-0.024	-0.031	-0.037	-0.044	-0.050	-0.057	-0.063	-0.069	-0.075
P1	-0.011	-0.020	-0.027	-0.034	-0.041	-0.047	-0.054	-0.060	-0.066	-0.072	-0.078
P2	-0.015	-0.025	-0.034	-0.042	-0.049	-0.057	-0.064	-0.071	-0.077	-0.084	-0.090
P3	-0.017	-0.028	-0.037	-0.045	-0.053	-0.061	-0.068	-0.076	-0.083	-0.089	-0.096
P4	-0.018	-0.029	-0.038	-0.047	-0.055	-0.063	-0.071	-0.078	-0.085	-0.092	-0.099
P5	-0.016	-0.027	-0.036	-0.044	-0.052	-0.060	-0.067	-0.074	-0.082	-0.088	-0.095
P6	-0.013	-0.023	-0.031	-0.039	-0.046	-0.053	-0.060	-0.067	-0.074	-0.081	-0.087
P7	-0.009	-0.018	-0.025	-0.033	-0.039	-0.046	-0.052	-0.059	-0.065	-0.071	-0.077
P8	-0.006	-0.014	-0.021	-0.028	-0.034	-0.040	-0.046	-0.053	-0.059	-0.064	-0.070
P9	-0.003	-0.011	-0.018	-0.024	-0.030	-0.036	-0.042	-0.048	-0.053	-0.059	-0.065
P10	-0.002	-0.009	-0.016	-0.022	-0.028	-0.034	-0.039	-0.045	-0.051	-0.057	-0.063
P11	-0.003	-0.011	-0.017	-0.024	-0.030	-0.036	-0.042	-0.048	-0.054	-0.060	-0.066
P12	-0.001	-0.006	-0.012	-0.018	-0.024	-0.030	-0.036	-0.042	-0.048	-0.055	-0.061

Where P1=poorest and P12=richest

Table 3 shows the impact of the carbon tax as modelled in Scenario 1B on both aggregate households and individual income groups. It should be noted that the effects in percentage change form are minimal. The reasons for this include the initially conservative implementation of the carbon tax that provides for various exemptions and ultimately lower than published effective carbon tax rates. The impacts become more noticeable after year t+5 when most exemptions have expired; however, more significant mitigation in the form of substitution towards cleaner sources of energy that are not taxed (or to a lesser extent) serves as a mitigating factor in the long run. Regardless of the nominal size of the impacts, for this study and to better understand the effects of environmental taxes, such as the carbon tax on households, the relative implications between households, and the overall impact on household expenditure relative to GDP, is of greater importance.

With this in mind, the impact on households should be considered important and worth studying. Most notable is that overall household expenditure falls by more than double compared to GDP (0.075 v.

0.036). The importance of the relatively significant drop in overall household expenditure flows through to analysis on an income group level. As seen in **Figure 3**, poorer households (P1-P5) are worse off than richer households. Whilst the richest households' expenditure is hardly affected by the introduction of a carbon tax, poorer households with limited room for substitution are much worse off. As noted earlier, this is mainly a function of the fact that poorer households spend a relatively more significant fraction of their income on energy/electricity than richer households, as per the model database. Interestingly, P1 households are les affected than P3-P5 household, this can be attributed to the fact that poorer household's energy consumption does not include a big share of grid-based electricity compared to middle-income households that consume more grid-based electricity and less of other types of energy such as paraffin and wood - as shown in Bohlmann and Inglesi-Lotz (2018).

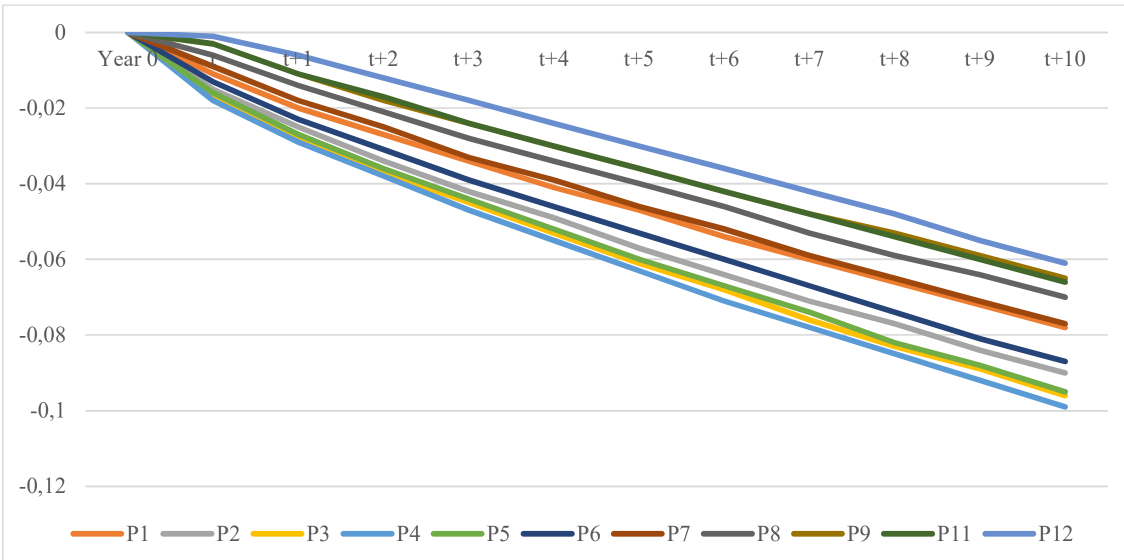

Figure 3: Carbon tax with revenue recycling: Households

Where P1=poorest and P12=richest

5. Conclusion and policy recommendations

This paper evaluated the impact of a carbon tax across different South African households, including low-income households, which are said to be the least responsible for climate change. A dynamic CGE model of the South African economy, linked to an emissions database and includes detailed tax information that allows for accurate measurement of the effects of the carbon tax, was used to conduct the modelling simulations.

Results show that the effects of the carbon tax on economic growth are minimised when the revenue collected from the carbon tax is recycled back into the economy. Additionally, low-income households are shown to be more affected by the carbon tax implementation than high-income households.

The research conducted in this study contributes to the literature through an in-depth analysis of the impact of the recently introduced carbon tax on different household groups in South Africa. The recent availability of revenue collection estimates for the carbon tax by the National Treasury (2020) allowed for the design of policy scenarios in line with the modelling strategy in Roos et al. (2020) concerning the implementation of the policy shock. The study investigates the role technology and cost-saving in non-coal electricity generation could have on the macro economy and household groups.

The results confirm that policymakers need to be careful in introducing new taxes on goods that form a large part of the consumption bundle of vulnerable households, such as energy and transport. Due to the carbon tax, poorer household groups are most exposed to rising energy costs. Despite its design challenges, the socio-economic and environmental considerations of the carbon tax make it a necessary intervention to correct for the unaccounted negative externalities of the current fossil-fuel-dominated status quo. However, mitigating policies such as additional PAMs and further relief for vulnerable households in energy subsidies should be considered.

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