A general equilibrium analysis of the effects of carbon tax policy on South Africa's agricultural industries

By

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Submitted in partial fulfillment of the requirements for the degree

Doctor of Philosophy in Agricultural Economics

In the Faculty of Natural & Agricultural Sciences

Department of Agricutlural Economics, Extension & Rural Development

University of Pretoria, South Africa

September 2018

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DECLARATION

I, Sifiso Mboneni Ntombela, herein declare that this thesis, which I hereby submit for the degree of Doctor of Philosophy (Ph.D) in Agricultural Economics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature: ……………………………. Date:

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ACKNOWLEDGMENTS

Praise to the almighty God, who gave me the strength and wisdom to research on a critical topic that enlightens our policymakers to make decisions that will sustain our environment. A heartfelt appreciation goes to my supervisors, Dr. Mmatlou Kalaba and Dr. Heinrich Bohlmann – this study could not have been completed without their assistance and leadership. Their collective supervision was instrumental throughout the study journey, more so in overcoming difficulties with data collection, model specification and striking a balance between school and work responsibilities. I am particularly indebted to Heinrich for sharpening my technical knowledge in building and operating a computable general equilibrium (CGE) model.

I thank my friends and family for their undying support and inspiration throughout my study. Most importantly, a special thanks to my paragon of beauty, Mrs. Tshegofatso Ntombela, for all the love, prayers and support – she has been and will always be my pillar of strength. To my parents, your continuous preaching for better education has always been a great motivation, and I am thankful.

I take this opportunity to record my sincere thanks to Dr. Simphiwe Ngqangweni for his role in providing initial comments to the thesis and journal articles that have come out of this study. I value the continuous encouragement from other Ph.D candidates in our university, all who, directly or indirectly, lent their hands and ears during my study journey.

ABSTRACT

The South African government has committed under the Paris Agreement to mitigate the growing emissions by 42 percent below the business-as-usual scenario in 2025. A carbon tax is one of the policy tools used to mitigate emissions. The carbon tax will be introduced at one hundred and twenty rands per ton of carbon dioxide equivalent (R120/tCO_2-eq). The National Treasury released a carbon tax draft bill in December 2017, which contains policy features such as higher tax-free allowances intended to minimise the tax impact on agriculture and other industries. From the literature, it was deduced that the impacts of the tax have not been assessed, particularly on individual agricultural and food industries in the county. To examine the effects, a modified version of the dynamic University of Pretoria General Equilibrium Model (UPGEM) was used, which has the same theoretical structure as the MONASH-style model.

Four important changes were made to the standard UPGEM, which are the creation of a database with disaggregated agriculture and food industries, additional equations to allow environmental enhancements analysis, account for technology improvements in the baseline of the non-coal electricity, and estimation of new trade elasticities for the individual agriculture and food products for use in the modified UPGEM model. After the four modifications, the effects of the carbon tax on agriculture and other industries were tested under three sets of assumptions represented by three policy scenarios. The first scenario measured the impact of policy features prescribed in the carbon tax bill, whereas the second and third scenarios tested the effects of removing the tax-free allowances and not recycling the tax revenue back into the economy, respectively. All three policy scenarios were simulated and interpreted against the baseline scenario.

The simulation results show that one the carbon tax, the country’s emissions would reduce by 33 percent below the baseline over the next 20 years. However, carbon tax implementation also leads to a welfare loss of approximately -0.91 percent below the baseline by 2035, driven by a contraction in aggregate employment and investments. The results suggest that the South African economy will incur some adjustment costs as the country transforms into a low-carbon economy. The sectoral results indicate that heavy emitting industries such as coal electricity, steel, metal, petroleum, and transport services will be significantly affected, with output declining by an average of 34 percent relative to the baseline by 2035. In contrast, the results on individual agricultural and food industries indicate a positive effect as output, employment and exports improve relative to the baseline when the carbon tax is implemented.

The positive effects on agricultural industries are caused by full tax-free allowances provided to this sector coupled with the revenue recycling scheme, which minimise both the direct and indirect effects on agricultural industries. The obtained positive effects on the agricultural and food industries suggest that policymakers have designed a carbon tax policy that cushions them against high negative effects. Worth noting is that the policy effects on agricultural industries and the economy as a whole become substantially high and negative under when the tax-free allowance are removed as well as when the revenue is not recycled back into the economy. This means that the manner in which the state removes the tax-free allowances and treats the revenue collected will determine the direction and magnitude of the effects on agricultural, food and other industries in the economy.

ISIFINYEZO

Uhulumeni waseNingizimu Afrika usezibophezele ngaphansi kwesivumelwano saseParis ukunciphisa ukukhiqizwa kwegesi yekhabhoni ngamaphesenti angu-42 makuqhathaniswa nendlela ejwayelekile yokulawula amabhizinisi ngonyaka ka-2025. Intela yekhabhoni ingenye yemigomo ezosetshenziswa ukwehlisa amazinga okukhiqiza igesi engcolisakho emkhathini. Intela yekhabhoni izolinganiselwa ekhulwini namashumi amabili ngenxenye yethani lekhabhoni (R120/tCO2-eq). Umgcinimafa kazwelonke ubesekhipha umqulu wenqubomgomo yentela ngo Zibandlela wezi-2017, equkethe iziphakamiso ezihlanganisa izaphulelo ekukhokheni intela embonini yezolimo nakwezinye ngenhloso yokunciphisa umthelela ongalindeleka embonini yezolimo nakweminye imikhakha.

Njengoba intela yekhabhoni izoqaliswa, kulolu cwaningo, sibheka umthelela ongase ubekhona ezimbonini ezahlukene kumontho wezwe. Ucwaningo lugxila emkhakheni wezolimo lusebenzisa imodeli yezomnotho (CGE) ekhandwe enyuvesi yasePitoli ibambisane ne Centre of Policy Studies yaseMelbourne e-Asustralia. Senza izinguquko ezine ezibalulekile uma kuqhathaniswa ne UPGEM modeli ejwayelekile. Lezinguquko zibala okwaka i-database entsha equkethe imininingwane yezimboni ezahlukahlukene kumkhakha wezolimo, ukukwa amafomula amasha avumela ucwaningo kwezokuthuthukiswa kwezemvelo, ukuvumela izinguquko zobuchwepheshe embonini ephehla ugesi ngaphandle kwelahle, Kanye nokubala ama-elasticities ezohwebo amasha akhombisa uzwelo kwezohwebo ngenxa yezinguquko kumanani ezohwebo. Emuva kwalezinguquko, sibe sesihlola umthelela wentela yekhabhoni ngaphansi kwezimo ezinthathu. Isimo sokuqala siveza iziphakamiso ezilotshwe kwinqubomgobo eyathulwa ngoZibandlela wezi-2017, kanti esesibili sihlola umthelela ongalindeleka uma uhulumeni okuhoxisa izaphulelo ezibikwe kumqubo mgomo. Esesithathu sihlola umthelela ongalindeleka uma uhulumeni enquma ukungayitshali imali yentela emonthothweni wezwe emva kokuyiqoqa ezimbonini eziyikhokhayo. Zontathu izimo ezihlola umthelela ziqhathaniswa nesimo lapho khona intela ingekho. Lesisimo esibizwa nge-Baseline sikhombisa ukukhula komnotho ngaphandle kokwethulwa kwentela.

Imiphumela yocwaningo ibonisa ukuthi intela yekhabhoni izokunciphisa amazinga wamagesi angcolisakho emkhathini. Uma intela yekhabhoni ithulwa emnothweni, yehlisa emagesi emkhathini ngamaphecenti angu-33 ngaphansi kwesimo se-Focus ngowezi-2035, uma iqhathaniswa nesimo esijwayelekile. Yize intela yekhabhoni yehlisa amagesi emkhathini, iphinde iholele ekulahlekelweni kwezenhlalakahle cishe ezilinganiselwa kumaphecenti angu-0.91 uma sibala sisebenzisa umkhiqizo wangempela womnotho (GDP) ngowezi-2035 ngaphansi kwesimo seFocus.

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Ukwehla komnotho kubonisa ukuthi izwe lizolahlekelwa amandla omnotho kodwa lizokwazi ukukhuculula umkhathi uma intela yekhabhoni ithulwa ezweni. Lokhu kusho ukuthi kuzoba nezindleko ezithile uma izwe liguquka liya ngaphansi komnotho enekhabhoni encane. Imikhakha ekhombisa ukuthikamezeka kakhula ngaphanis kwentela yekhabhoni ziholwa imboni yokuphehlwa kwagesi kusetshenziswa ilahle, imboni yensimbi, ezokuthutha kanye nezamandla ambiwa phansi. Imikhiqizo yazo izokwehla ngamaphesenti angu-34 makuqhathaniswa nesimo esijwayelekile ngonyaka wezi-2035.

Ucwaningo luveza ukuthi ezolimo kanye nezokudla zizo zuza ngaphansi kwentela yekhabhoni njengoba zikhombisa ukwenyuka kwimkhiqizo, imsebenzi kanye nezohwebo ngonyaka wezi 2035. Imiphumela emihle ezimbonini zolimo nezokudla zibangelwa izibonelelo zokungayikhokhi intela kanye nokutshalwa kwemali yentela eqoqiwe. Imiphumela etholakale embonini yezolimo nezokudla ibonisa ukuthi izishaya'methetho ziqophe inqubomgomo yentela yekhabhoni ekwazikho ukuvikela umkhakha wezolimo. Ngaleyondela imikhiqizo yokudla ayizukuthikamezeka kakhulu. Okubalulekile ukuthi uma uhulumeni ezisusa izibonelelo embonini yezolimo futhi uma engayitshali imali yentela emnothweni, imithelela yalokho emkhakheni wezolimo nasezweni lonkana iba mibi kakhulu.

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CHAPTER ONE
INTRODUCTION

1.1 Context

The climate change issue was first discussed as a global policy agenda at the first Earth Summit that took place in Stockholm, Sweden in 1972. However, it's prominence as a world policy agenda has gained momentum since 1988 when the Intergovernmental Panel on Climate Change (IPCC) was formed to collect and analyse information relating to climate change. The information produced by the IPCC assists in understanding the risks associated with a changing climate, thus enabling global policymakers to formulate realistic response policies to climate risks. Among the first tasks of the IPCC was to develop a climate change definition and in 1990, it was defined as a change in the state of the climate that can be identified, for example by using statistical tests, by changes in the mean and/or the variability of its properties and that persist for an extended period (IPCC, 1990).

The same report of IPCC (1990) established that anthropogenic (e.g. fossil fuel combustion and deforestation) and natural (e.g. volcanoes and earthquakes) activities produce greenhouse gas (GHG) emissions such as a carbon dioxide (CO_2). The anthropogenic GHG emissions are a major contributor to a changing climate in the world. Due to intensifying anthropogenic activities, global emissions increased by 35 percent in the past two and half decades to reach a total of 49 gigatons of carbon dioxide equivalents ($GtCO_2$-eq) in 2014 (IPCC, 2014). Subsequent to growing emissions, the world average temperature increased by 0.6 degrees Celsius (ºC) between 1900 and 1990 with the warmest periods recorded from 1940 to 1950 as well as between 1983 and 2012 (IPCC, 2014).

While the scientific evidence is consistent that the growing emissions are a major contributor to a changing climate, the exact impact on global economic systems remains uncertain as different scholars estimate varying degree of effects across regions and sectors. For example, Nelson, Rosegrant, Robertson, Sulser, Zhu, Ringler, Msangi, Palazzo, Batka, Magalhaes, Valmonte-Santos, Ewing, and Lee (2009) assessed the likely effects of a changing climate on food production across different regions in the world. Their analysis showed that wheat production will be negatively affected in sub-Saharan Africa and South Asia, declining by 44 and 15 percent respectively, while increasing by 11.4 percent in Latin America by 2050. Mixed impacts were also found on maize, rice and sorghum products across the world. Stern (2006) evaluated the effects of climate change on the world economy and found that the cost of mitigating the GHG emissions and shifting into a low-carbon economy is equivalent to one percent of the global GDP per annum. However, the cost of no action against climate change risks is equal to five percent of world GDP per annum. The Stern review by Stern (2006) is often credited in literature for increasing awareness on climate change risk and potential damages on the world economy. However, researchers such as Nordhaus, (2007) and Weitzman, (2007) find that the Stern review relied on a low time discount rate and other utility issues which overestimate the risk of climate change. The use of lower time discount rate is found to be inconsistent with marketplace rates that are often used in studies that applied a similar dataset and analytical structures. As a result, both Nordhaus, (2007) and Weitzman, (2007) argue that the question of how costly would climate change remain unanswered. Despite this uncertainty, the risk of climate change is evident from literature (IPCC, 2014) and policymakers should take coordinated efforts to reduce it.

Another important risk of climate change is on international trade. To determined the extent of this risk, the World Trade Organisation (WTO), which administers the global rules of trade, together with the United Nations Environment Programme (UNEP), examined the impact of climate change on international trade growth in 2009. They found that climate change policies create a risk for trade because countries tend to introduce climate-related trade barriers that discriminate products from countries with high GHG emissions. WTO and UNEP (2009) also found that trade-related activities like transportation do contribute to rising emissions. The growing evidence of climate change risk has compelled policymakers to formulate mitigation and adaptation strategies that tackle growing emissions in the world.

IPCC (2001) defined adaptation as the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploit beneficial opportunities. Mitigation was defined as an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Most observed adaptation approaches include conservation of the environment, whereas mitigation strategies include regulatory measures and market-based policy measures. Examples of regulatory measures include carbon emission standards, whereas market-based measures include border carbon adjustments (BCAs), carbon tax and emissions trading systems (ETSs). According to NT (2013), the BCAs refer to levying taxes on both domestically produced goods and imported goods while providing rebates on exported goods whereas carbon tax refers to a standard rate of tax levied on the carbon content of commodities. Moreover, the ETSs entail setting a cap on emissions allowed in a region or market, then providing economic incentives for achieving such reduction targets.

The South African government has selected the carbon tax as a preferred measure to mitigate the country's growing emissions. According to NT (2013), this decision was informed by the evidence generated from socio-economic studies conducted by government and independent researchers, including Van Heerden, Gerlagh, Blignaut, Horridge, Hees, and Mabugu (2006), Deverajan, Robinson, and Thierfelder (2011) and Alton, Channing and Davies (2012). Based on their evidence, NT (2013) explained that regulatory measures often prove to be economically inefficient since it requires all firms in the economy to comply with set GHG emission regulations regardless of the costs of compliance. On the other hand, market-based measures like a carbon tax offer firms flexibility in reducing their emissions.

The government has committed to reducing GHG emissions through a peak, plateau, and decline (PPD) strategy. According to the Department of Environmental Affairs (DEA, 2017), this strategy anticipates the emissions to reach a peak in 2025, stagnate between 2025 and 2035, and then decline post-2035. The strategy forms part of the country's Nationally Determined Contribution (NDC) targets committed under the Paris Climate Agreement. This agreement is a legally binding framework for 196-member countries of the United Nations Framework Convention on Climate Change (UNFCCC). Through the Paris Agreement, they aim to resolve a climate change issue in an internationally coordinated manner. Under the Paris Agreement, South Africa committed to reducing its emissions by 42 percent relative to the normal emission growth (DEA, 2017).

South Africa's emissions are estimated at 0.551 $GtCO_2$-eq, which equates to 1.2 percent of global GHG emissions in 2015 (WRI, 2015). This makes the country among the world's top fifteen largest producers of emissions per capita and the largest non-oil-producing emitter in the world (DEA, 2017; WRI, 2015). The country's preferred mitigation policy is the carbon tax and in December 2017, the NT (2017) released the carbon tax bill pronouncing a carbon charge of one hundred and twenty rands per ton of carbon dioxide equivalent (R120/tCO_2-eq). According to the NT (2015 and 2017), this tax rate was informed by many socio-economic impact studies (some mentioned earlier) and will assist in transforming into a less carbon economy without severely disturbing the economy growth. It must be noted that various organisations including labour, business, and civil society have expressed concerns regarding the affordability of a carbon charge of R120/tCO_2-eq. Through a rigorous consultation process, the government has designed policy features that aim to alleviate the concerns of different taxpaying groups and industries in the country. A detailed explanation of the carbon tax policy will be discussed later in the thesis, but it focuses on the energy sector's emissions.

According to DEA (2017) and WRI (2015), over 84 percent of the country's emissions are from the energy sector which comprises of electricity and petroleum production. Eskom which is a national power utility is responsible for generating and distributing over 94 percent of the total country's electricity consumption and 86 percent of Eskom's electricity is generated from coal-fired plants (Arndt, Davies, Gabriel, Makrelov, Merven, Hartley, & Thurlow, 2016). Moreover, the petroleum industry is also dominated by few players such as Sasol, PretoSA, and Shell indicating that the energy sector is oligopolistic in nature. Due to an oligopolistic energy sector, it makes the carbon tax a suitable measure to effectively mitigate GHG emissions as compared to the ETS measure. This is because the ETS needs a relatively large number of firms with large quantities of emissions for it to operate sufficiently in the economy or market. Moreover, a carbon tax entails fixing a price of emissions while ETS fixes the quantity of emission; as such a carbon tax policy provides a better signal to investors. There are a few studies such as Van Heerden *et al.* (2006), Deverajan *et al.* (2011), Alton *et al.* (2012), Alton, Arndt, Davies, Hartley, Mekrelov, Thurlow, and Ubogu (2014), Arndt *et al.* (2016) and Van Heerden, Blignaut, Bohlmann, Cartwright, Diederich, and Mander (2016) which have assessed the implications of introducing a carbon tax on the South African economy. The next section provides a brief review of these studies.

1.2 Knowledge gap identification

South African policymakers have decided that implementing a carbon tax is a proactive approach towards mitigating emissions in order to protect the environment and transform the country into a low-carbon economy. According to NT (2013), introducing a carbon charge would act as an incentive for investors to make future investment decisions that promote a green economy. It also reduces the market access risk that can arise if South Africa's trading partners decide to implement border carbon adjustment measures against products originating from South Africa. This market access risk was also noted by Arndt, Davies, Markelow, and Thurlow (2013), when they found that up to 40 percent of the country's export products would likely face taxation if markets such as the European Union (EU) adopt a carbon emission consumption tax or BCA policy measures. In addition, the study by Arndt *et al.* (2013), which measured the emission intensity of products, showed that products with high emission content are also export-oriented such as mining products. These studies illustrated one common factor: that South Africa needs to address its high emissions.

Van Heerden *et al.* (2006) were among the first to demonstrate that environmental taxes can control growing emissions without substantially affecting economic growth. They showed that if environmental taxes are introduced and the revenue generated from these taxes is recycled through a reduction in food prices, the economy could still grow positively while simultaneously reducing emissions. The study by Van Heerden *et al.* (2006) did not focus on specific environmental taxes, whereas Deverajan *et al*. (2011) focused on a carbon tax as a policy measure to mitigate emissions. Deverajan *et al.* (2011) suggested that a carbon tax is a useful market-based measure to mitigate growing emissions within the South African context. A key shortcoming, as identified by Deverajan *et al.* (2011), is that they did not distinguish between different energy technologies which partly explain the larger adjustment costs found when the country transforms into a low-carbon economy.

Alton *et al.* (2014) noticed this shortcoming and addressed it by having a detailed treatment of the energy sector that distinguishes five electricity technologies and three petroleum products. They obtained an adjustment cost that is equivalent to a 1.2 percent decline in GDP relative to the baseline. The reason for this low welfare loss is that they did not know the exact carbon charge that will be implemented. As a result, they assumed an initial carbon tax of R21/tCO_2-eq which is lower than the R120/tCO_2-eq carbon charge pronounced in the 2017 carbon tax bill draft released by the National Treasury. An importantly finding from Alton et al. (2014) study is that it suggested a low carbon charge that gradually increase in the medium to long term. This is similar to an approach suggested by Nordhaus (2007) where he calls for a climate-policy ramp, in which policies seeking to reduce emission start modest and increasingly tighten over time. The advantage of such an approach allows industries an opportunity to adjust to a carbon charge over time.

Van Heerden *et al.* (2016) assessed the potential impact of a carbon tax on the economy by applying a correct R120/tCO_2-eq carbon charge, distinguished between different energy technologies, and accounting for tax-free exemptions such as the full exemption in the aggregate agricultural sector. The results of Van Heerden *et al.* (2016) showed that GHG emissions will reduce by 38.3 percent relative to the baseline, which will assist the country to come close in reaching its emissions targets committed under the Paris Agreement. They also note that the adjustment cost could be equivalent to a 13.7 percent decline in GDP relative to the baseline. However, if the government recycles the revenue back into the economy the welfare loss narrows to just a four percent decline in the GDP relative to the baseline.

Whilst Van Heerden *et al.* (2016), shared good insight into the expected carbon tax implications, they did not account for the technology improvement in the baseline of non-coal[1] electricity which might be the partial cause for higher adjustment costs found in their analysis. The International

[1] Non-coal electricity refers to wind, hydro, biomass, gas, and nuclear electricity whereas coal electricity refers to coal-generated electricity.

Energy Agency (IEA, 2017) reported that the renewable energy prices will decline by 40 percent over the next decade largely because of technology changes – hence considering technological changes in non-coal electricity could improve the analysis. The lack of accounting for technology changes in the baseline of non-coal electricity by the previous country studies is identified as a first limitation or knowledge gap in the existing literature.

Moreover, the previous studies, with the exception of Patridge, Cloete-Beests, and Barends (2015), focused their policy analysis on the energy, transport and manufacturing sectors but less so on disaggregated agricultural industries. Subsequently, they analysed the policy effects on the aggregated agricultural sector, assuming different agricultural industries are homogenous. Subsequently, they obtained a negative but minimal impact on aggregate agriculture largely due to the full tax exemptions provided to the sector. While full tax exemptions limit the direct impacts, it does not eliminate indirect impacts that can vary across different agricultural industries. Various agricultural industries are also not homogenous as they have different input and output structures, subsequently emitting varying levels of GHG emissions. Due to their different use of fuels, gas, electricity and other inputs, industries will likely be affected differently by the carbon tax, hence the need to examine its effects on different agricultural industries.

Patridge *et al.* (2015), recognised the importance of knowing both the direct and indirect policy impacts on individual agricultural industries, hence they examined the effects on different industries. They found that the policy will reduce the overall agricultural activity by 7.3 percent, with starches, dairy, sugar, and fish being the hardest hit industries. Though their study focused on agriculture, they found it difficult to simulate tax-free exemptions provided to various industries and decided to exclude them in the policy designs. Moreover, they did not distinguish between different electricity technologies, subsequently not accounting for potential benefits that could emanate from the technology changes in non-coal electricity.

While Patridge *et al.* (2015) focused on individual agricultural industries, it came short in terms of accounting for technology changes and tax-free allowances, hence they found substantially higher negative impacts on agricultural industries. For example, they estimated that the output for forest products will decline by 7 percent and 9.4 percent for starches below the baseline. The lack of policy analysis on individual agricultural and food industries, taking into account the potential benefit of technology improvement in the baseline of the non-coal electricity industry and tax-free exemptions pronounced in the 2017 carbon tax draft bill, is considered a second knowledge gap in the existing country literature.

South African agriculture is an export-oriented sector contributing nearly 10 percent to a total country's exports (Department of Agriculture, Forestry and Fisheries - DAFF, 2018). The carbon tax policy could increase the cost of products, thus affecting the competitiveness of agricultural industries in the international markets. This may affect agricultural trade and gives an unfair advantage to South Africa's competitors in the international markets, especially those countries with no climate policies. The South African policymakers recognised this competitiveness risk and created a trade-exposed tax-free exemption in the carbon tax bill. The potential benefits of trade-exposed tax-free allowances were accounted by Van Heerden *et al.* (2016) in the analysis; however, they relied on outdated elasticities for the agricultural products. The trade elasticities they used in their CGE model were last estimated by Gibson (2003) and Naude, Van der Merwe and Van Heerden (1999).

All the aforementioned reviewed studies used a computable general equilibrium model to assess the economy-wide effects of policies such as carbon taxes but they also used outdated elasticities estimated by Gibson (2003) and Naude *et al.* (1999). Moreover, these outdated elasticities were only available for the Armington elasticity, leaving researchers to make value judgments for the export supply and demand elasticities. Ogundeji, Jooste, and Uchezuba (2010) did estimate the Armington elasticity for individual meat and grain products; however, Armington elasticities for fruits, vegetables, and processed food are also required to enable detailed and comprehensive analyses of the carbon tax. The lack of trade elasticities (i.e. Armington, export supply and export demand) for major individual agricultural products is identified as a third limitation in the existing literature that constrains the assessment of policy effects on agricultural industries. The identified knowledge gaps in the literature limit the policymakers and industry captains' ability to understand the impacts of the proposed policy. Understanding such impacts are important because it allows policymakers to know the industries that will be winners and losers due to the proposed policy. This then enables policymakers to develop mechanisms that will assist the losing industries.

Guided by the three identified limitations, the problem statement was defined as: *expected effects of the carbon tax policy on individual South African agricultural industries, taking into account the technology improvement in the baseline of the non-coal electricity industry and tax-free exemptions pronounced in the carbon tax bill of 2017, are largely unknown or have not been estimated. Moreover, the lack of trade elasticities for individual agricultural products as well as disaggregated agricultural economic data that are required for UPGEM to analyse policy effects is limiting research execution and effective policy intervention in the country.*

1.3 Study objectives

This study focused on agricultural and food industries driven by the need to address one overarching question: *What are the implications of the proposed carbon tax on individual agricultural and food industries?*

The overarching question was set to meet three research objectives as follows;

(i) To expand the standard 25-sector database of the UPGEM to contain detailed treatments of individual food, agricultural and electricity industries;

(ii) To econometrically estimate trade elasticities (i.e. Armington, export supply and export demand) for individual agricultural and food products for use in a CGE model like the UPGEM;

(iii) To examine both the direct and indirect effects of the carbon tax policy on the individual (disaggregated) agricultural and food industries, taking into account projected technology improvements in the non-coal electricity industry;

1.4 Hypotheses

The following hypotheses were tested in this study:

(i) Individual agricultural, food and electricity industries have different input and output structures which could lead to different GHG emissions being emitted;

(ii) Estimating trade elasticities for individual agricultural and food products for use in the UPGEM could improve policy modelling and analysis;

(iii) The carbon tax policy is expected to have different and significant impacts on individual agricultural and food industries.

1.5 Methodology

A modified version of the dynamic UPGEM is used in this study which has a similar theoretical structure to the MONASH-style CGE model developed by the Centre of Policy Studies (CoPS) in Australia. The core UPGEM equations, flexible model-closures, and database structure are described in Dixon, Koopman and Rimmer (2013); Adams and Dixon (1997); and its applications within the South African context are described in Bohlmann, Van Heerden, Dixon and Rimmer

(2015) and Van Heerden *et al.* (2016). A UPGEM is well suited to analyse the effects of tax changes across a broad spectrum of economic variables and to identify possible winners and losers. CGE models have been used in literature to assess the effects of a carbon tax (Arndt *et al*., 2016) due to their ability to capture multiple sectoral linkages in an economy, and this research will adopt a CGE, specifically the UPGEM model that adapted to South African economic structures.

The UPGEM like any other MONASH-style CGE is solved in General Equilibrium Modelling Package (GEMPACK) software. According to Horridge, Meeraus, Pearson, and Rutherford (2013), the GEMPACK has better strength in handling CGE models as compared to other software such as the General Algebraic Modelling System (GAMS). To enable the simulation of carbon tax policy effects on individual agricultural industries, four important modifications are made in the standard UPGEM applications. The first modification is a detailed treatment of agricultural, food and electricity industries in the UPGEM database, thus expanding the standard 25 sectors to 33 sectors. Agriculture is split from a single sector into grains, horticulture, livestock, forestry, and fisheries while food is split into meat, cereals, sugar, beverages and dairy. The electricity sector is split into coal electricity and non-coal electricity. The expansion of the UPGEM database allows for the evaluation of tax on individual agricultural industries. The disaggregation and mapping processes are informed by data on emission intensity for different industries estimated by Arndt *et al.* (2013), DEA (2014) and Seymore, Inglesi-Lotz and Blignaut (2014).

The second change is extensions to model equations to allow for environmental analysis, which entails creating a mechanism that allows for an internal absorption of abatements measures in response to emission market-based tools. This mechanism is similar to that used by Van Heerden *et al.* (2006), Van Heerden *et al.* (2016), as well as Adams and Parmenter (2013). A third modification is changes made in the baseline of the non-coal electricity industry. We allow for improvements in technology innovations informed by projections made by the IEA (2017). This change was omitted by previous studies such as Van Heerden *et al.* (2016). Allowing technology changes in the baseline of the non-coal electricity industry reduces the capital cost of establishing the non-coal-generating plants, subsequently reducing the price of non-coal electricity relative to coal electricity. The model accounts for technology innovations' benefits but it does not explicitly model the direct costs associated with the adoption of technology in the country. It is assumed that the benefits of technology changes, which are imposed exogenously, will outweigh the adoption costs in the non-coal electricity industry.

The fourth change made in the UPGEM application is the use of newly estimated trade elasticities in the model. The details on the estimation procedure for trade elasticities and data required for estimation are discussed in Chapter four. The modifications made in the standard UPEGM improve the simulation of carbon tax effects on agriculture and other industries in the economy. The effects of the carbon tax are tested under three sets of policy assumptions captured under three scenarios, namely: the Focus (reflects all policy features described in the carbon tax bill of 2017), Allowances Removed (assumes tax-free allowances will be removed at 10 percent per annum after the first five-year window period of implementation), and No Revenue Recycling (assumes that government will not recycle the revenue generated). All three policy scenarios are simulated and interpreted relative to the baseline scenario. The tax is implemented as a tax on fuel usage on four commodities, namely coal, electricity, gas, and petroleum, initially charged at R120/tCO_2-eq then allowed to increase at 10 percent per annum in the first five years of implementation.

1.6 Study contributions

In this study, three important contributions are made. Firstly, is the advancement of policy modelling in the agricultural and food sectors using a CGE model. This is done by estimating new trade elasticities for individual and aggregate agricultural and food products. The new elasticities will allow CGE modellers to apply reliable and econometrically estimated trade elasticities, thus improving the functionality and the accuracy of CGE models. Secondly, the standard UPGEM database was modified to contain detailed agricultural and food industries which subsequently allows researchers to evaluate policy effects on individual agricultural and food industries. Lastly, it provides insight into the understanding of the expected policy effects, both direct and indirect, on different agricultural and food industries within a broader economic context. Understanding these effects has always been a primary focus for policymakers and industry captains because they rely on such empirical evidence to formulate response strategies for the sector to remain sustainable.

The remainder of the thesis is structured in the following manner: Chapter two provides a literature review on climate change science and policies formulated to reduce risks associated with climate change. Chapter three describes the methodology and the changes made to the standard UPGEM to enable the evaluation of a carbon tax on individual agricultural and food industries. Chapter four explains the econometric methods and properties of time series data used to estimate trade elasticities for individual agricultural and food products. Chapter five presents and provides the interpretation of simulation results whereas Chapter six gives the study conclusion, policy recommendations, and identified future research.

CHAPTER TWO
CLIMATE CHANGE AND EFFORTS TO MITIGATE EMISSIONS

2.1 Introduction

The scientific evidence is relatively consistent that carbon emissions stimulate the changing climate, particularly anthropogenic emissions (IPCC, 2014). The area of contention among policymakers is with regard to: who is responsible for the global emissions, how fast shall we respond to climate risks, and what measures must be implemented to mitigate the GHG emissions. This chapter seeks to recount the development in climate change science focusing on the causes and consequences. It provides a review of studies in the agricultural, water and health sectors with the intention of measuring the climate change effects on these sectors. These are just a few sectors; however, climate change is likely to impact many sectors in the world. The chapter also discusses the global and national measures such as the Kyoto Protocol and Paris Agreement that have been adopted to reduce the risks associated with climate change. Lastly, the specific policy measures adopted by South Africa to tackle the climate change risks are discussed in this chapter.

2.2 Definitions of climate-related terms

The term climate change is often used interchangeably with other related terms such as global warming and weather changes in the literature. It is useful to distinguish between these terms and provide proper definitions to avoid confusion. IPCC reports (1990, 2001, 2007, 2014) have over time provided the following definitions for terms that are often used in the literature:

- Adaptation is the process of adjustment to actual or expected climate and its effects. It seeks to moderate or avoid harm or exploit beneficial opportunities;
- Carbon emissions are mainly measured in the form of carbon dioxide (CO_2) which is a colourless, odourless and non-poisonous gas formed by combustion of carbon and in the respiration of living organisms and is considered a greenhouse gas. Emissions imply a release of gas and their precursors into the atmosphere over area and time;
- Carbon leakage is the phenomenon whereby the reduction in emissions (relative to a baseline) in a jurisdiction/sector associated with the implementation of mitigation policy is offset to some degree by an increase outside the jurisdiction/sector through induced changes in consumption, production, prices, land use and/or trade across the jurisdiction/sectors. Leakage can occur at a number of levels, be it a project, state, province, nation or world region;

- Carbon tax is a tax that explicitly states a price on greenhouse gas emissions or that uses a metric directly based on carbon (that is, price per tCO_2-eqv);
- Climate is the average weather in a given location over a long period of time;
- Climate change refers to a change in the state of the climate that can be identified, for example by using statistical tests, by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer;
- Emissions trading system (ETS) is an emission mitigating system that puts a price on carbon and fixes the maximum quantity of emissions in a jurisdiction/sector;
- Climate system is the highly complex system consisting of five major components: the atmosphere, hydrosphere, cryosphere, lithosphere and biosphere and their interactions;
- Global warming refers to a gradual rise, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emissions;
- Kyoto Protocol is an international agreement within the UNFCCC on climate change, which commits its parties by setting internationally binding emission reduction targets. It was adopted in Kyoto, Japan and entered into force on 16 February 2005;
- Mitigation is a human intervention to reduce the sources or enhance the sinks of GHGs;
- Paris Agreement is an accord within the UNFCCC on climate change, dealing with the greenhouse gas emissions mitigation, adaptation and finance starting in the year 2020. It was adopted in Paris, France and entered into force on 4 November 2016;
- Weather is a condition of the atmosphere at a particular space and time. It is usually measured in terms of wind; temperature; precipitation; and atmospheric pressure;
- Weather change refers to shifts in atmospheric conditions; let it be precipitation or temperature, at a particular place within a short period of time.

2.3 Evolution of climate change science

The scientific information on climate change has grown significantly since the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. From all five reports released by the IPCC in 1990, 1995, 2001, 2007 and 2014, the evidence is consistent that climate change is associated with growing emissions. The natural processes include volcanic eruptions, earthquakes, and solar irradiance, whereas anthropogenic processes include human activities such as fossil fuel combustion, deforestation and international trade. In 2010, natural emissions contributed two percent to world emissions whereas 98 percent was from anthropogenic emissions, implying that anthropogenic activities are the largest drivers of climate change (IPCC, 2014). Figure 2.1 indicates that anthropogenic emissions associated with fossil fuels and industrial activities have grown the fastest since the 1950s while deforestation and land use emissions have stabilised.

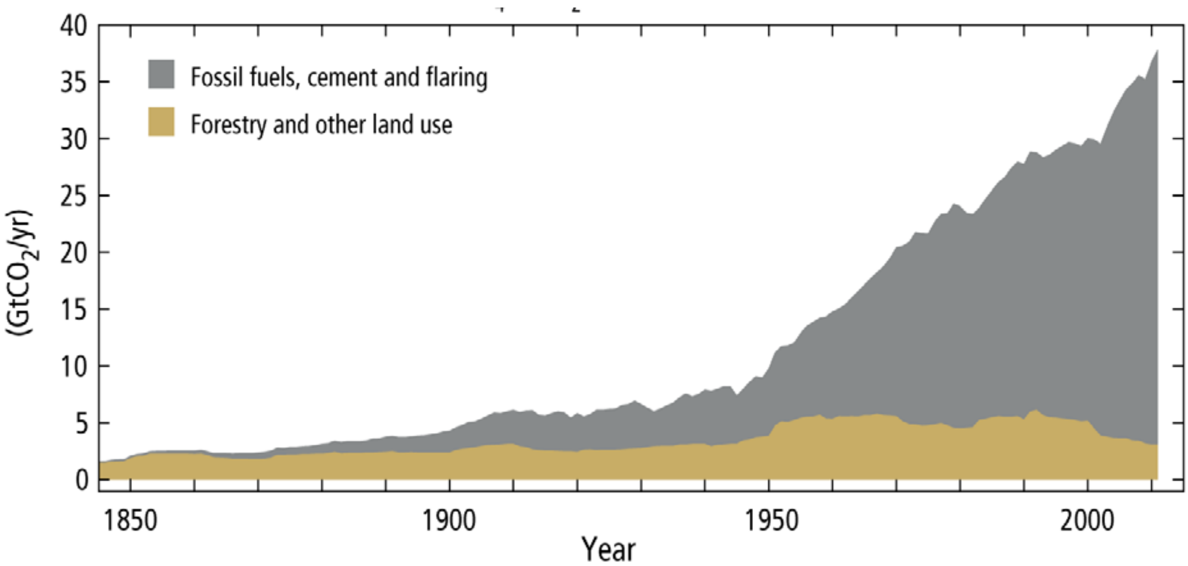

Figure 2.1: Global anthropogenic CO_2 emissions between 1850 and 2010
Source: IPCC (2014)

It is shown in Figure 2.1 that anthropogenic emissions from industrial activities have tripled with larger absolute increases in emissions observed between 1940 and 1960 and again between 2000 and 2010. Annual global emissions grew on average by 2.2 percent per annum in the last two decades. According to the IPCC (2014), the primary gas contributing to the anthropogenic emissions is CO_2, holding a share of 76 percent of global emissions in 2010. Other IPCC reports (IPCC, 1990; 1995; 2001; 2007) also showed a similar trend where CO_2 was a major contributing gas to global emissions. Other contributing gases are methane (CH_4) and nitrogen oxide (N_2O), accounting for 16 percent of anthropogenic emissions and the rest is from fluorinated gases (F-gases). The F-gases are manmade and they can stay in the atmosphere for centuries while causing climate change and they include hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), perfluorocarbons (PFCs), and nitrogen trifluoride (NF_3).

Whilst anthropogenic emissions are increasing, there are natural processes that help to reduce atmospheric emissions. For example, the ocean sinks and forest sinks help remove some emissions in the atmosphere. IPCC (2014) reported that oceans have mitigated the fast-growing anthropogenic emissions by sinking approximately 30 percent of global emissions emitted since 1750, but this sink process tends to cause ocean acidification which affects ocean life. From a sector perspective, the anthropogenic emissions are largely produced by the energy sector including activities such as fossil fuels and coal-generated electricity. Figure 2.2 shows that the energy and industrial sectors contribute 71 percent of total global emissions produced in 2014. This suggests that a primary focus by global policymakers should be on shifting from a heavy reliance on fossil energy to renewable energy in order to reduce global emissions. Figure 2.2 also indicates that GHG emissions from the energy sector increased by 10.6 percent between 2005 and 2010 and a further 7.9 percent to 2014.

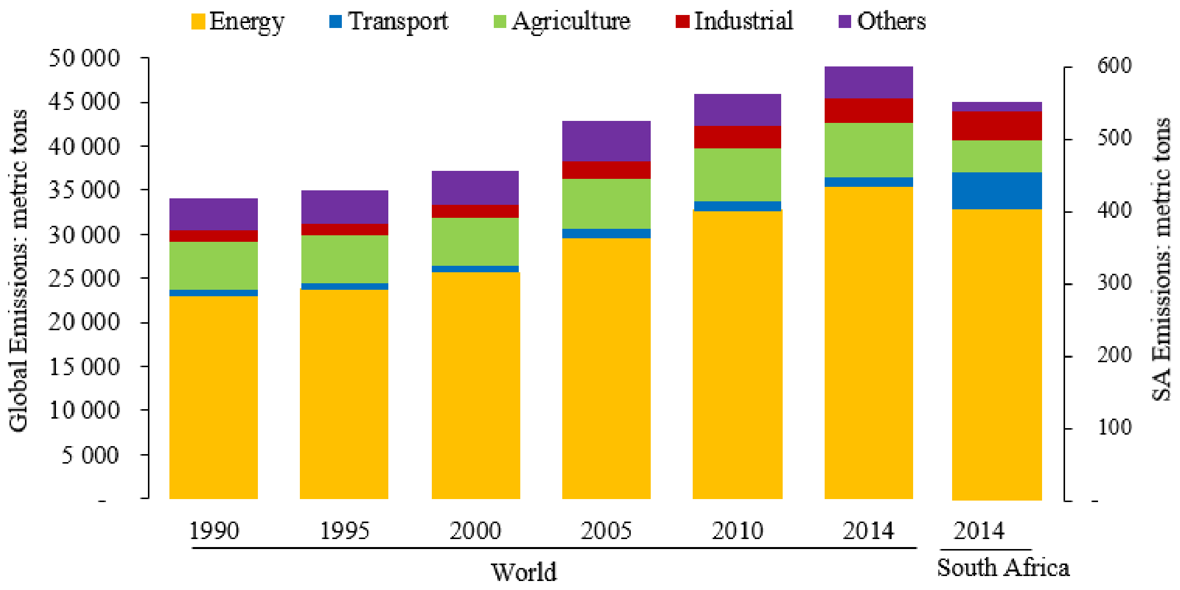

Figure 2.2: Global & South Africa's anthropogenic GHG emissions growth per sector
Source: DEA (2014), IPCC (2014) and WRI (2015)

It is evident from Figure 2.2 that the biggest emitting sectors in the world are similar to those emitting sectors in South Africa. For example, the energy sector contributes the largest share of over 84 percent, followed by transport with a nine percent share of total GHG emissions in South Africa. The country's emissions are equivalent to 1.2 percent of the world's missions, making the country the thirteenth largest emitter per capita in the world (Arndt *et al.*, 2013; WRI, 2015). The growing emissions are increasing the global surface temperature and the global temperature is expected to warm up by an additional 1.5°C in the 21st century when compared to corresponding temperature levels in 1900 (IPCC, 2014). The increasing global temperature is expected to have negative consequences on the world economic systems. The next section presents some scientific evidence on the potential consequences of rising temperatures.

2.4 Potential consequences of the changing climate

The exact effects of climate change on the global system remain uncertain; however, the IPCC (2014) and others such as Stern (2006) expect it to be negative, more so in poor countries or regions where adaptation is low. In terms of the expected climate change consequences, the IPCC (2014) summarises some findings as follows based on the available literature:

- It is likely to threaten the ecosystem, with coastal areas likely to be the worst affected regions because of their vulnerability to extreme weather like floods;
- Extremely dry and hot weather will lead to the frequent occurrence of drought and heat-wave conditions. These will negatively affect sensitive industries such as the agricultural and tourism industries, subsequently reducing economic welfare and increasing unemployment rates in developing countries;
- The impact of climate change is likely to vary across groups and regions but the impact will be most severe on poor people.

These three points outline the generally expected consequences; however, reviewing specific effects on individual sectors could also give some insight into the expected consequences on different economic and social sectors. The next section provides the expected consequences of climate change on a few selected sectors. The next segments share some expected impacts on the water, agricultural and health sectors. The selection criterion of sectors is informed by this study’s focus, which is agriculture. Agriculture depends on water availability for growing plants and on the health sector to obtain productive labour, hence these were also selected.

2.4.1 Water

According to the World Health Organisation (WHO, 2016), the warming global temperatures are enhancing the melting of the snow thus affecting the hydrological systems of the oceans and rivers in the world. The ultimate consequence of a changing hydrological system is deteriorating water quality and subsequent a loss of animals, plants, and humans that depend on water for life. Yu, Yang, and Wu (2002) found that rising temperatures and extreme weather patterns affect water resources in Southern Taiwan, leading to water scarcity during dry seasons. Moreover, the quality of water is deteriorating in that part of the world due to a changing climate. Middelkoop, Daamen, Gellens, Grabs, Kwadijk, Lang and Wilke (2001) studied the impact of climate change in the Rhine Basin. They found that higher temperatures will increase flood risk thus affecting the agricultural production in countries like Switzerland, Germany, and Liechtenstein. Based on this review, it is evident that the quality and quantity of water will be negatively affected by a changing climate.

2.4.2 Agriculture

Climate change has been found to reduce agricultural yields, exacerbating the food insecurity problem in the world. Nelson *et al.* (2009) noted that the majority of grain productions in developing countries are rain-fed productions making them extremely sensitive to changing the weather. As a result of changing weather patterns, grain yields could be reduced by up to 44 percent in developing countries by 2050. To illustrate the sensitivity of agricultural production to changing the weather in Africa, Nhemachena, Hassan and Kurukulasuriya (2010) evaluated the impacts on crop and livestock farms in 11 African countries. They found that warmer and drier weather conditions negatively affect crop yields and weaken animal health, subjecting them to diseases. As a result of low yields, the net farm revenue declines especially for small-scale farmers who are more vulnerable to weather variability.

Kahsay, Kuik, Brouwer and Van der Zaag (2017) assessed the impact on farms located along the Nile River. They found that climate change could have negative consequences for agriculture due to water scarcity that will heighten with increasing temperatures. The climate-induced water scarcity will reduce agricultural yields in countries like Ethiopia and Egypt. Cline (2007) applied a crops model to examine the impact of climate change in 116 countries covering both developed and developing nations. Cline (2007) found that climate change reduces crop yields because crops tend to speed through their development process, which causes smaller grain sizes. This study also found that, on average, grain yields in countries like South Africa, Brazil and Mexico will suffer a decline of 20, 29 and 35 percent respectively by 2080 due to increasing temperatures.

Nelson *et al.* (2009) also used crop models when they found that grain production in developing countries could decline by up to 44 percent by the year 2050 if global temperatures increase by 1.5ºC or beyond. Both Cline (2007) and Nelson *et al.* (2009) found that the impact of climate change is much higher on small-scale farmers located in developing countries. They recommended that farmer progression from small-scale towards large-scale commercial level will increase farmers' ability to cope with a changing climate. This is because large commercial farms are better equipped with infrastructure and capital that improve resistance to a changing climate.

2.4.3 Health

The WHO (2016) reported that approximately 12.6 million deaths (equivalent to 23 percent of all deaths in 2012) were attributed to the deteriorating environment. This indicates the total number of deaths that can be prevented by reducing the degradation of the environment. The WHO (2016) cautioned that increasing global temperatures will increase the number of heat-related mortalities in the world. Haines, Koyats, Campbell-Lendrum, and Corvalan (2006) illustrated that climate change tends to increase heat-related diseases and deaths, which subsequently increases public spending on health. Bosello, Roson, and Tol (2006) found that welfare and investment in the world economy will decline as human health deteriorates due to climate change. They noted that climate-induced health risks will result in a weakening labour force in the world and consequently affect labour productivity and result in welfare loss in the world.

Generally, the scientific evidence suggests the growing issues of climate change will have undesirable effects in the world, more so for developing countries which have low adaptation capabilities. While the exact consequences of a changing climate remain uncertain, there is adequate evidence from the literature that a non-action scenario against the risks associated with climate change will be costlier as compared to taking strong actions to tackle climate change (IPCC, 2014; Stern, 2006). The reviewed expected consequences of climate change imply a need for an internationally coordinated effort to mitigate emissions. The mitigation of climate change risks caries some abatement costs. Various studies have estimated the abatement costs of reducing GHG emissions including Stern (2006) and Den Elzen, Hof, Beltran, Grassi, Roelfsema, Van Ruijven, Van Vliet and Van Vuuren (2011). The next section discusses the cost of reducing climate risks.

2.5 Costs of mitigating climate change risks

The literature has a number of studies that have used economy-wide models to estimate the costs of reducing greenhouse gas in the atmosphere. It is evident from the reviewed literature that abatement cost estimates vary greatly from one study to another. Fischer and Morgenstern (2005) attribute this variation in abatement cost estimates to the type of assumptions made in the models. They note that assumptions about perfectly foresighted consumers and Armington trade elasticities generate lower estimates of marginal abatement costs, whereas assumptions about perfectly mobile capital, including technology, and greater disaggregation among regions and sectors tend to lead to higher estimates of marginal abatement costs (Fischer and Morgenstern, 2005).

Arguably one of the popular studies that have estimated the costs of reducing climate change risks is the Stern Review conducted by Sir Nicholas Stern (Stern, 2006). He found that the cost of mitigating the GHG emissions and shifting into a low-carbon economy is equivalent to one percent of the global GDP per annum. However, the cost of no action against climate change risks is equal to five percent of world GDP per annum. Following the adoption of Copenhagen climate treaty in

2009 which set legally binding international GHG reduction targets and sought to replace the Kyoto Protocol, more GHG reduction costs estimates were conducted. For example, Den Elzen *et al*. (2011), estimated the abatement costs of reaching the reduction targets set under the Copenhagen treaty. The GHG emission reduction targets under the Copenhagen were on average between 12-18 percent below 1990 levels for annexure 1 countries and 11-14 percent below baseline for Non-Annexure 1 countries. In brief, Annexure I countries includes mainly the developed nations while Non-Annexure I countries involve developing and underdeveloped countries. Den Elzen *et al*. (2011) found that the global abatement costs to reach the reduction targets under Copenhagen treaty by 2020 would be equivalent to US$ 60-100 billion, assuming that at least two-thirds of Annexure I emission reduction targets are achieved. The Annexure I costs are assessed to be about US$50 billion (equivalent to 0.12 percent of GDP) in 2020 and abatement costs appears to be the same for Non-annexure I countries (Den Elzen *et al*., 2011).

The Stern review by Stern (2006) is often credited in literature for increasing awareness on climate change risk and potential damages on the world economy. However, researchers such as Nordhaus, (2007) and Weitzman, (2007) find that the Stern review relied on a low time discount rate and other utility issues which overestimate the abatement costs of reducing emissions. The use of lower time discount rate is found to be inconsistent with marketplace rates that are often used in studies that applied a similar dataset and analytical structures. As a result, both Nordhaus, (2007) and Weitzman, (2007) argue that the question of how costly would climate change remain unanswered. Despite this uncertainty, the risk of climate change is evident from literature (IPCC, 2014) and policymakers should take coordinated efforts to reduce it. The next section discusses global efforts that have been initiated to mitigate growing GHG emissions.

2.6 Global efforts to mitigate growing GHG emissions

The international debate on climate change policy has to a large extent been shaped by the information collected and published by the IPCC over the last 29 years. For example, the IPCC (1990) recommended that international cooperation should be initiated to collaborate global efforts in reducing world GHG emissions. This recommendation led to the formation of the UNFCCC in 1991 which was signed by 166 nations. The ultimate objective of the UNFCCC is to promote international cooperation in reducing the growing global GHG emissions. The UNFCCC did not specify the emissions reduction targets for countries – instead it laid down principles that should be adopted to reduce emissions as follows (UN, 1992):

- Countries should protect the climate system for the benefit of the present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities;
- The specific needs and special circumstances of developing countries, especially those that are particularly vulnerable to the adverse effects of climate change, should be given full consideration;
- Countries should take precautionary measures to anticipate, prevent the causes of climate change and mitigate its adverse effects;
- Countries have a right to, and should, promote sustainable development;
- Policies and measures to protect the climate system should be integrated with national development programmers; and
- Countries should cooperate to promote a supportive and open international economic system that would lead to sustainable economic growth and development;

The success of the UNFCCC in reducing global emissions has been somewhat limited because of its failure to set binding targets for countries. Scholars such as Babiker (2005), Fischer and Fox (2012) and McKibbin and Wilcoxen (2002), who evaluated its success, concur that the failure to set binding reduction targets was a weakness of the UNFCCC. However, they commend the UNFCCC for creating a platform that allowed subsequent negotiations on global climate policies, which is the Conference of Parties (COP). The COP is hosted annually by the members of the UNFCCC to advance climate negotiations and assess the implementation of global climate policies. The first COP1 was hosted in Berlin, Germany in 1995, but COP3 hosted in Kyoto, Japan in 1997 and COP21 hosted in Paris, France in 2015 are arguably the most influential ones in history because they adopted legally binding agreements called the Kyoto Protocol and Paris Agreement respectively. The next sections discuss the importance of the Kyoto Protocol and the Paris Agreement.

2.6.1 Kyoto Protocol

The Kyoto Protocol sets out the legally binding carbon emissions targets for developed countries, known as Annexure I, which was negotiated and adopted in Japan in 1997. The target for individual countries on average ranged between 6 and 8 percent below 1990 levels. Annexure I countries were required to achieve these reduction targets between 2008 and 2012 (McKibbin & Wilcoxen, 2002). Most developing and underdeveloped countries were categorised as non-Annexure I and they had no legally binding targets. However, they were required to voluntary participate in the global effort to reduce emissions. Part of COP3 outcomes was the adoption of three flexible mechanisms that countries can use to meet their reduction targets. These are the clean development mechanism (CDM), joint implementation mechanism (JIM), and emission trading mechanism (ETM).

2.6.1.1 Clean development mechanism (CDM)

The CDM is considered a flexible mechanism that allows non-Annexure I or developing countries to take action against the growing global emissions in order to contribute to a coordinated global effort to mitigate emissions. According to Murphy, Drexhage, and Wooders (2009), the CDM has two goals: first, to assist developed countries in cutting emissions in a cost-effective manner and, secondly, to assist developing countries in achieving sustainable development. CDM enables Annexure I countries to receive GHG emissions credits when they invest and participate in mitigation actions or programmes in non-Annexure I nations to reduce their emissions.

2.6.1.2 Joint implementation mechanism (JIM)

The JIM is a project-based option which assists Annexure I nations to receive emission credits towards their own reduction targets by investing and participating in actions or programmes in other developed nations. The purpose of the JIM is to increase market efficiency by allowing developed countries to meet part of their obligation by investing in abatement projects in another Annexure I country if the cost of abatement is lower in the other country (UN, 1998).

2.6.1.3 Emission trading mechanism (ETM)

The ETM assists developed nations to purchase emissions credits from other Annexure I countries. Some countries will be below the emissions targets assigned to them under the Protocol and, as such, will have spare emissions credits. The spare emissions can be sold to other participating Annexure I nations which need more emissions to meet their signed reduction targets (Murphy *et al.*, 2009).

The CDM and JIM mechanisms have been criticized for encouraging the carbon leakage problem in the world. For example, Peters (2010) estimated that 48 percent of global GHG emissions are attributed to the carbon leakage problem which does not help the world to reduce emissions but merely relocates the production of emissions from one region to another. Fischer and Fox (2012) also estimated that 35 percent of global GHG emissions are attributed to the carbon leakage problem, suggesting that carbon leakage continues to be the biggest problem in the global effort to reduce emissions. The ETM is considered less problematic as it avoids the carbon leakage problem by placing a carbon price on carbon emissions within a region or nation. ETMs and carbon taxes have some similarities such as that they both put a price on carbon thus providing a direct financial incentive to mitigate emissions. The ETM and the carbon tax differ in the sense that a carbon tax fixes the price on carbon while ETM fixes the maximum quantity of emissions. In practice, the ETM is often implemented as an emissions trading scheme (ETS) like the European Union's ETS.

The Kyoto Protocol has been instrumental in mobilising international collaboration to mitigate growing emissions; however, it has received criticism for excluding some developing countries like China from being legally obliged to reduce emissions. The emissions data released by the Union of Concerned Scientists (2015) and the WRI (2015) showed that China is the biggest polluter, emitting about 9040.74 million metric tons of emissions in 2014, thus placing it above the United States of America and Germany. This has led to the UNFCCC adopting a new international mitigation agreement in its COP21. The next section explains the objectives of the Paris Agreement.

2.6.2 Paris Agreement

This is a latest legally binding global climate agreement, which was negotiated and signed by 196 members of the UNFCCC in COP21 to control global emissions and also make provision for financing individual countries' mitigation plans and strategies. The Agreement came into force on 4 November 2016, setting legally binding emissions reduction targets for countries that are signatories to the accord, hence it is generally viewed as an improvement and expansion from the Kyoto Protocol that only focused on developed nations. The Paris Agreement aims to strengthen the global response to the threat of climate change by keeping temperature rise this century well below 2°C above pre-industrial level and to pursue efforts to limit the temperature rise to 1.5°C.

The Paris Agreement requires that all signatories develop their own domestic mitigation plans, which are called Nationally Determined Contributions (NDCs). These act as contractual agreements for each signatory and they outline how each member plans to contribute to an internationally coordinated GHG emissions reduction. South Africa is one of the signatories of the Paris Agreement and it has compiled its NDCs targets which are explained by the DEA (2017). South Africa's NDCs are informed by the country's PPD emissions trajectory range. As part of the PPD strategy the country has selected a carbon tax policy as a preferred policy instrument to reach its emissions reduction targets; however, carbon taxes will form part of the composite policy tools created to reduce emissions. The next section discusses South Africa's efforts in tackling the growing emissions and climate change issues.

2.7 South Africa's efforts to mitigate GHG emissions

South Africa is one of the large carbon dioxide emitters per capita in the world due to its heavy reliance on coal-generated electricity and intensive mining industry. DEA (2017) and WRI (2015) found that the country's emissions amounted to 0.551 $GtCO_2$-eq in 2014, making it amongst the top fifteen largest emitters per capita in the world over the past decade. Arndt *et al.* (2013) also calculated the same amount of emissions for South Africa and they labelled it as the world's most carbon-intensive non-oil-producing developing country. Given the history of South Africa's relatively large emissions, it has always been a focus of the democratic government to reduce emissions, since 1994 (NT, 2013).

Noticing the need to formulate climate mitigation policies, the country opened a debate on climate policy in the early 2000s. According to Vorster, Winkler, and Jooste (2011), the South African climate change policy debate was characterized by a vibrant engagement involving government, business, labour and civil society. These vibrant climate engagements led to the first climate change policy discussion document which was released in 2003 titled National Climate Change Response Strategy. This discussion document presented broad strategies that can be adopted by South Africa in reducing GHG emissions. However, this strategy did not have any regulatory nature and it was weak in outlining the specific policy that the country should adopt to reduce emissions. It is important to note that the document did mention electricity, mining, agriculture, and transport as key sectors that drive the country's growing emissions.

In 2007, the Department of Environmental Affairs decided to determine the country's emissions reduction targets and also explore various policy options that can be adopted to address emissions. From this excise, a second policy document was released in 2008 called Long-Term-Mitigation-Scenarios – LTMS (Kearney, 2008). This document produced the country's emissions stock and also projected that under a Business-As-Usual (BAU) scenario, South Africa's emissions stock will quadruple by 2050. The BAU scenario refers to a situation where there is no strong action taken to reduce growing emissions. Subsequent to the LTMS, the state announced a mitigation strategy called "peak, plateau and decline trajectory". According to the then Department of Environment Affairs and Tourism (DEAT, 2009), the plan aimed to stop growing emissions by the 2020-2025 period, then attempt to stabilise for up to 10 years, and then decline in absolute terms.

At the COP15 in 2009 in Copenhagen, Denmark, South Africa committed to a reduction of GHG emissions by 34 percent below the BAU emissions scenario by 2020, and by 42 percent below the BAU scenario by 2025 (NT, 2013). While these government targets are vigorous, they are conditioned on (i) a fair, ambitious and effective agreement in the international climate change negotiations under the UNFCCC, and (ii) the provision of support, particularly in terms of financing and technology, from the international community for capacity building (NT, 2013). In 2009 the DEAT together with NT commissioned a study to assess the optimal strategy or policy that will reduce emissions without causing large disruption to the economy. In short, this study suggested that the policy option with the greatest potential for reducing emissions and having a less damaging effect on the economy is a carbon tax. In 2015, South Africa signed the Paris Agreement and has since submitted its NDC to the UNFCCC which outlines the country's plans and strategies for GHG emissions reduction. It will be implemented together with other adaptation mechanisms that do not damage the economy.

2.7.1 Climate policy options available to South Africa

South Africa is a small open economy that promotes a market efficiency system and as such, the country favours climate policy instruments that are market-based. There are three prominent market-based mitigation measures, namely the carbon tax, emissions trading, and border carbon adjustments. Regulatory measures are also a policy option that can be implemented to mitigate growing GHG emissions. It is important to understand the advantages and disadvantages between these policy options.

2.7.1.1 Regulatory measures

The regulatory measures include carbon labelling on products, environmental standards, and certifications. It also includes the banning of deleterious goods, practices, and services that emit higher emissions (WTO, 2013). The regulatory measures set standards or limits on environmental degradation, for example, maximum amount of carbon emissions embodied in the commodity. The advantage of regulatory measures is that they provide a clear control on environmental pollution and it is simple to monitor compliance by industries. These measures also increase the awareness of consumers on the amount of carbon content embodied in products, subsequently promoting the demand of environmentally friendly goods. Regulatory measures can drive consumers to purchase environmentally friendly goods (Dinda, 2004).

The disadvantage of regulatory measures is that they can be expensive to implement and government institutions charged with carrying the regulatory mandate often find it difficult to collect accurate information that informs regulatory standards (WTO and UNEP, 2009). Since regulatory measures need to be enforced consistently on all emitting sectors, they often prove to be a disruptive method on the economy because some firms struggle to cope with the cost of compliance to standards, subsequently resulting in job losses. Apart from regulatory measures, there are market-based measures which place a price on carbon emissions emitted, thus incentivising economic agents to produce fewer emissions. Below is a brief explanation of available market-based measures in the country.

2.7.1.2 Carbon emissions trading

Carbon emissions trading refers to a market-based policy approach that is used to control emissions by providing economic incentives for achieving reduction targets and involves fixing a cap on total emissions that can be produced in a country or region (WTO and UNEP, 2009). The cap on allowed emissions within a country or region is then made available for auction at a market price that is set by market forces. The advantage of ETM is its ability to control the production of emissions by setting a cap on emissions allowed within a juristic region or market. However, it often suffers from market failures which limit its success. For example, excessive availability of emissions allowed for trade can drive the price down, thus distorting the emissions trading scheme. Another disadvantage of ETM is that it requires a sufficient number of firms with relatively large emissions quantities within a region or market for it to function effectively.

The largest functioning emissions trading scheme in the world is the European Union Emissions Trading Scheme (EU-ETS), which was started in 2005 and covers 45 percent of GHG emissions in the Eurozone. Based on the evidence presented by NT (2013) and WTO and UNEP (2009), implementing the carbon emissions trading system is complex as it requires detailed emissions data and is subjected to market imperfections such as over-allocation of allowances. Complexities of implementing ETS were observed in Australia when the policy become unpopular among firms and was eventually repealed after a change of government in 2014.

2.7.1.3 Carbon taxes

Carbon tax refers to a standard rate of tax levied on the carbon content of commodities and it is calculated by measuring the carbon content of fossil fuels, which is directly proportional to the amount of CO_2 that is produced during their combustion (NT, 2013). Carbon taxes provide certainty with respect to the price of emissions but are weaker in directly controlling the emissions produced. As a result, carbon taxes are considered efficient in improving the allocation of resources and they reduce possible market distortions discussed under the ETS policy measure above. One dominant disadvantage of the carbon tax is the potential negative impact on firms’ competitiveness in cases where a firm is trade exposed like agriculture, mining and manufacturing in the South African context. When firms are export-oriented, carbon taxes raise the cost of products produced by the firm paying tax.

Carbon tax gained popularity in the early 1990s, with Finland adopting it in 1990 and Norway in 1991. According to Partnership for Market Readiness (PMR, 2016), there are currently 16 countries that have carbon taxes in operation, three nations with carbon taxes scheduled for implementation including South Africa, and two countries currently considering the carbon tax policy to mitigate emissions. The literature on carbon taxes is consistence that taxes are an effective measure to reduce emissions in a specific country or region without causing significant harm on the economy. Moreover, the introduction of carbon taxes can invoke serious resistance from civil society if they are implemented without a full consultation of all players involved in the policy formulations. This was the case in Australia where the tax legislation was repealed due to concerns from industries and civil society. The main concerns were the impact taxes have on the competitiveness of Australian companies.

To guard against serious resistance of tax policies, the revenue recycling schemes are usually put in place to cushion industry against the effects of carbon tax such as declining competitiveness. The different types of revenue recycling schemes implemented by different countries in the world are discussed in section 2.7.1.5. Some of these revenue recycling schemes have been adopted in Finland, Britain and other parts of the world to ensure that the effects of introducing the carbon policy are minimised on households, industries and investors. For a successful implementation of the carbon tax in South Africa, the policy makers will need to ensure the consultation process is inclusive to get the views and concerns of all those that can be affected by the tax. Furthermore, the tax policy design should entail a revenue recycling scheme to minimize the negative impacts on the competitiveness of industry and price pressures on the households. The NT (2013) argues that these lessons learned from other countries have been the guiding framework when formulating the carbon tax. As results, in South Africa, the carbon tax policy has the following designs as prescribed in the carbon tax draft bill of 2017 released by the NT (2017):

(i) In the initial five-year window, the agricultural, forestry, waste handling and land-use sectors are fully exempted but the food manufacturing activities are not fully exempted;
(ii) The trade exposure allowance which is up to 10 percent will help protect the competitiveness of South African industries and prevent the carbon leakage problem. Trade-exposed industries

are those that have exports and imports with a combined value making up more than 40 percent of domestic output value;

(iii) The tax is effectively a fossil-fuel input tax levied on scope 1 emissions, that is, emissions that result from fuel combustion, gasification, and non-energy industry processes;

(iv) The tax is levied at R120/tCO_2-eq and set to increase by 10 percent per annum over the first five years. Thereafter will increase in line with inflation. The revenue from the proposed tax will be recycled via the national fiscus.

2.7.1.4 Border carbon adjustments

BCAs refer to levying taxes on both domestically produced goods and imported goods whilst providing rebates on exported goods and they are intended to encourage exports while not making imports excessively competitive against domestic goods. BCA measures can be useful to control for the competitiveness issue or the carbon leakage issue which usually arises under carbon taxes and emissions trading policy measures. Since the carbon taxes and emissions trading schemes reduce the quantity of domestic emissions produced in a specific country or regions, the BCA policy measures reduce both the domestic and imported emissions in a specific country or region. BCAs achieve this by applying a carbon charge on imported products originating from countries with high emissions and providing rebates on domestic products intended for export markets, thus making them not excessively expensive in the international markets. While BCAs policy measures are effective in tackling carbon leakage or competitiveness issues, they have high trade risks because other countries can institute retaliatory trade measures against a country implementing BCAs.

2.7.1.5 Rationale of selecting a carbon tax in South Africa

The National Treasury working together with the Department of Environmental Affairs has selected the carbon tax measure as key tool to drive the country’s emissions down by 42 percent below the business-as-usual scenario by 2025. The carbon tax is considered the most cost-effective measure as compared to other market-based measures such as emissions trading and border adjustments. Due to the oligopolistic nature of the energy sector, which is dominated by a few large firms such as Eskom and Sasol, it suggests that the emissions trading measure will not be suitable in the country. This is because emissions trading schemes work better when there is a relatively large number of firms emitting emissions in the country (NT, 2013). The international trade risk or the possibility of suffering from retaliatory measures also makes BCAs a less attractive measure as compared to carbon taxes.

The rationale behind the South African government's decision to select the carbon tax is due to the oligopolistic nature of the energy sector that constitutes 84 percent of total emissions, thus making the emissions trading measure an inappropriate measure to implement in the South African context. In addition, carbon taxes provide a flexible mechanism to firms, incentivising them to transform production technologies by focusing on green investments. While carbon tax policy may be suitable to reduce emission in South Africa, it could face resistance from industries and households that would be affected by the introduction of carbon tax. Study such as Baranzini, Goldemberg & Speck (2000), and Beck, Rivers, Wigle & Yonezawa (2015) found that a potential resistance from citizens towards the introduction of a carbon tax measure can be offset by implementing different revenue recycling schemes. The collected tax revenue may be redistributed in the economy through a household expenditure support program such as subsidizing energy purchases and goods that are consumed by poor households who are more vulnerable to price hikes. The tax revenue could also be distributed through labour tax breaks such as reducing income taxes (Baranzini *et al*,. 2000). In addition to these revenue recycling schemes, the option to subsidize the export-oriented industries in order t retain competitive in the international markets is also available to countries. Table 2.1 provides a comparative analysis of the available mitigating policy measures in the country.

Table 2.1: Assessments of the strengths and weaknesses of mitigation policy measures

Carbon mitigation policy option	Policy strengths	Policy weaknesses	Suitability in SA context
Regulatory measures	Sets allowed emissions standards on products thus being effective in controlling the amount of emitted emissions in a country	It can be very costly to implement emissions standards because of challenges in collecting emissions data to set accurate standards	In the short to medium term, the country does not have the capacity to regulate emissions standards
Carbon tax	Puts a tax rate on the emissions content embodied in a product thus incentivising economic agents to make	Likely to cause a carbon leakage within the economy or across nations in a region	Suitable for the South African economy due to the oligopolistic nature of the energy sector

	climate-wise investment decisions		
Border carbon adjustment	Controls emissions from domestic and imported products	Can trigger retaliatory actions from trading partners. Requires detailed emissions data from trading partners.	Due to data requirements, it might be difficult for South Africa to obtain the required emissions data
Emissions trading	Sets a cap on allowed emissions within a market which are then auctioned in a scheme setup.	Requires adequate firms with large emissions quantities to operate effectively.	Given the oligopolistic nature of the energy sector, it is not suitable for the South African economy

Source: adapted from NT (2013)

Noticing that market-based policy measures such as the carbon tax can affect international trade rules, the question arises: are market-based climate policies compatible with the World Trade Organisation's (WTO) general trade rules that promote free and fair international trade of goods and service? The next section discusses the compatibility of climate policies with WTO trade rules.

2.7.2 Compatibility of climate policies with the WTO trade rules

The increasing trend of adopting climate policies to reduce growing emissions in the world is good and necessary; however, they are also expanding the scope of non-tariff barriers and distorting international trade. One of the tasks of the report commissioned by the WTO and UNEP in 2009 was to determine the compatibility of climate change policies with general trade rules. They found evidence that climate change policy can be implemented in a manner that distorts trade, thus affecting the general rules of international trade. They also found that some general exceptions provided in Article XX of the General Agreement on Tariffs and Trade (GATT) are too broad and not clearly defined to administer trade distortions associated with climate policies. As a result of ambiguities in general trade rules, some countries use these exceptions to inhibit imports from other countries that have weak or no environmental policies. It also emerged that WTO rules permit, under certain conditions such as non-discrimination, national treatment, and trade neutrality principles, the use of market-based policies to avoid the damaging of the environment. The specific WTO rules that provide justification to climate-flexible mechanisms include Articles II (2a) and III that allow carbon taxation to be applied directly and indirectly to imported products that are like domestic products (WTO & UNEP, 2009).

Both Articles II (2a) and III promote a fair playing ground and address the competitiveness and carbon leakage issues. Furthermore, the Technical Barrier to Trade (TBT) Agreement allows for regulation measures like standards on product emissions especially for agricultural and industrial commodities (Gary & Jisun, 2010). Based on these WTO exemptions, climate change mitigation policies are permitted under general trade rules provided they are implemented in a manner that does not distort international trade. Unfortunately, there is an increasing trend of these climate policies being used to distort trade as reported in Khalid and Wei (2013), WTO (2014) and WTO and UNEP (2009).

2.7.3 South Africa's experience in preserving the environment

South Africa's commitment to preserving the environment has been growing since 2003 when a plastic levy policy was implemented to reduce plastic waste by imposing a levy of four cents per plastic bag (Hasson, Leiman & Visser, 2007). At the time, the country consumed eight billion plastic bags per annum. According to Dikgang, Leiman, and Visser (2012), the plastic bag levy was successful in reducing plastic consumption in the beginning since consumption declined by 58 percent in the first three years. But the effectiveness of the legislation diminished over time, largely because of the continued low levy rate that was charged, which customers got familiar with paying over time. The consumption of plastic bags declined from eight billion in 2003 to less than three billion in 2007. Since 2009, consumption gradually increased to 3.6 billion in 2012 (Dikang *et al*., 2012).

South Africa has also implemented other environmental policies including the electricity levy introduced in 2009 at a rate of two cents per kilowatt (kWh) per hour. Figure 2.3 indicates the revenue collected on all environmental levies between 2011 and 2016.

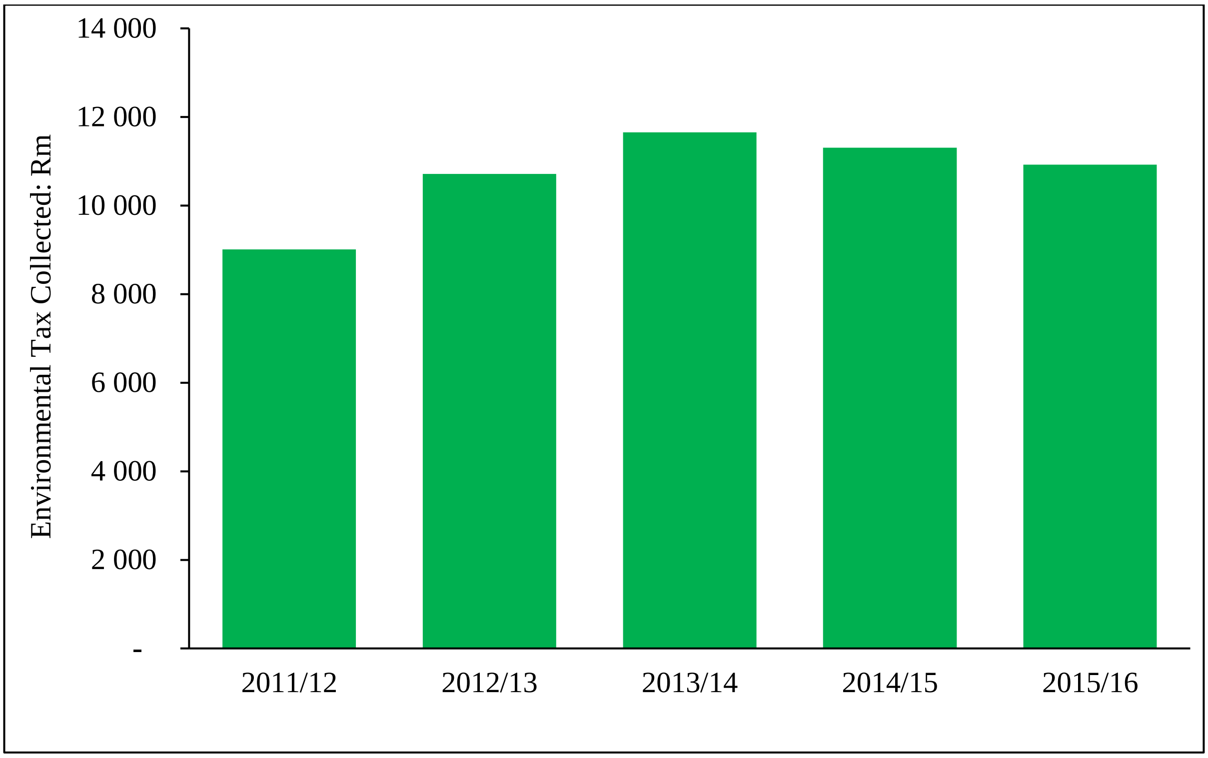

Figure 2.3: South African environmental taxes collected

Source: NT and SARS (2017)

The electricity levy is applied to electricity generated from non-renewable sources such as coal-generated electricity. The effectiveness of the electricity levy has not yet been determined in South Africa. According to the National Treasury and South African Revenue Services (NT & SARS, 2017) the share of existing environmental taxes on total tax collection increased from 0.7 percent (equivalent to R4 billion) in 2009 to 1.4 percent (equivalent to R10.9 billion) in 2016. NT and SARS (2017) emphasised that the primary goal of these taxes is not revenue generation but to preserve a clean environment. However, the National Treasury continues not to ring-fence the revenue collected from environmental taxes, instead opting for a flexible revenue allocation system where all collected taxes are put into one single pool.

Ring-fencing the environmental tax revenues for clean activities will improve the government's transparency in supporting the preservation of a clean environment in the country. It will also provide confidence on government's promise under the carbon tax bill of 2017 that government will recycle the proposed carbon tax revenue back into the economy. Most of the recent studies that have assessed the carbon tax policy, discussed in the next section, have relied on this promise but it is not clear what specific activities will be supported by government to ensure the impact of a carbon tax is minimised in the country.

2.7.4 Assessed carbon policy effects in South Africa

Various studies have been conducted in the country to examine the expected effects on the economy. Table 2.2 presents an analysis of these studies including Alton *et al.* (2014), PMR, (2016) and Van Heerden *et al.* (2016). All the reviewed studies applied CGE models to evaluate the impact of a carbon tax. They confirmed that it is a suitable measure to mitigate growing emissions in the country. This is because carbon taxes require fewer emission data as compared to other measures like the ETM and BCAs thus proving easier to implement. Secondly, they provide certainty on the price of emissions and create incentives to consumers and producers to make investment decisions that promote a green economy. According to the findings of Van Heerden *et al.* (2016), the country's emissions could decline by 38 percent below the baseline when carbon taxes are implemented, which could assist the country to meet its Paris Agreement targets.

While the carbon tax is effective in mitigating the country's growing emissions, the reviewed studies found that it also leads to welfare loss, where GDP could decline by up to 13 percent as compared to a business-as-usual scenario. However, studies like those of Van Heerden *et al.* (2016) have shown that this could be significantly reduced to between 1.5 and 4 percent decrease in GDP relative to the baseline if government recycles the revenue back into the economy. The various tax-free allowances such as full exemption in the agricultural and waste sectors were also found to be beneficial to the economy as they reduce the direct impact of the carbon tax on the sectors (Van Heerden *et al.*, 2016). Reducing the impact of the policy on the food sector will ensure there is no exacerbation of poverty in the country.

The reviewed studies shared good insight on the expected implications on the macroeconomic indicators such as GDP and its components. The review also indicated that heavy emitting sectors such as coal-generated electricity, steel, manufacturing, cement, petroleum, and mining will be significantly affected with output activity reducing to an average of 34 percent relative to the baseline. PMR (2016) found that the majority of economic sectors in the country will be less affected due to tax-free allowances provided. Generally, the reviewed studies, with the exception of Patridge *et al.* (2015), did not focus on the agricultural and food industries. As a result, they treated the agricultural sector as a homogenous sector which limits the full understanding of the policy impacts on the individual agricultural and food industries.

Secondly, they did not account for the expected technology improvements in the baseline of the non-coal electricity industry which partly explains the higher adjustment costs of up to 13 percent decline in GDP when the carbon tax is introduced. The International Energy Agency (IEA, 2017) reported that renewable energy prices will decline by 40 percent over the next decade largely because of technology improvements in the non-coal electricity industry. Therefore, allowing for technology changes is critical in the carbon tax analysis in order to obtain accurate and realistic results. Even though Patridge *et al*. (2015) approached agriculture on a relatively detailed level, they did not distinguish between different energy technologies because their focus was on the agricultural and food industries. They also found it difficult to account for all tax-free allowances provided to different sectors of the economy which partly caused higher policy impacts on agriculture due to unaccounted tax-free allowances on other industries. The lack of carbon tax policy assessment on the individual agricultural and food industries, taking into account the technology improvements in the non-coal electricity industry, is considered a knowledge gap in the literature and raised a need to conduct this study.

2.8 Summary

This chapter provided a review of studies assessing the evolution of science and factors affecting climate change, as well as policies formulated to respond to climate change risks. From this review, it is clear that anthropogenic GHG emissions are the main driver of increasing temperatures in the atmosphere. Anthropogenic emissions are driven by human activities such as fossil-fuel combustion, deforestation and agricultural production. The continuous growth in the world population and economic activities contributes to the growing world emissions. Between 2000 and 2010 the global emissions grew by 2.2 percent per annum which contributed to rising temperatures. It also emerged from the review that South Africa is responsible for approximately 1.2 percent of world emissions largely because of its coal-generated electricity and mining industry.

The increasing global temperatures and frequent occurrences of extreme weather events such as drought and floods are affecting the world economy, particularly sectors such as water, agriculture, tourism and health which are sensitive to climate change. The review showed that climate change could reduce agricultural yields by up to 40 percent in 2050 due to increasing temperatures. Furthermore, climate change and other environmental issues are claiming about 23 percent of annual deaths in the world and this could increase if climate change risks are not mitigated. IPCC (2014) and Stern (2006) found that climate change could reduce the world economy by anything between 2 to 5 percent by the end of the 21st century unless strong mitigation actions are taken to reduce the growing global GHG emissions.

Triggered by scientific evidence on climate change causes and consequences, the world – through the UNFCCC Kyoto Protocol and later the Paris Agreement – has decided to tackle the growing emissions in the world. South Africa is one of the signatories of the Paris Agreement and is committed to reducing emissions. The country has relatively good experience in applying market-based policy measures to address environmental degradation issues. In 2003, the country implemented a plastic levy to resolve the plastic waste problem and reduce plastic consumption in the country. This was followed by the electricity levy on non-renewable electricity in the country and other measures to preserve the environment. By 2016, environmental taxes implemented to preserve the environment equaled 1.4 percent of total tax revenues collected in the country. The proposed carbon tax policy will assist the country to reduce GHG emissions thus mitigating the risks associated with climate change.

Table 2.2: Review of both domestic and international carbon taxes studies

Authors	Sector	Method	Study findings	Implications for agriculture
South African studies on carbon tax policy implications				
Van Heerden *et al*. (2016)	All economic sectors	Dynamic CGE Model	The implementation of a carbon tax policy will assist the country to reduce emissions by 38 percent below baseline. But it will also reduce the GDP growth by as high as 13 percent in 2035 if the revenue generated and allowances provided are removed.	The study focused on energy, manufacturing and transport sectors but less so on agriculture. Agriculture will be marginally impacted. They did not account for technological changes in renewable energy which partially explains the high adjustment costs found
Arndt, Davies, Gabriel, Markrelov, Merven, Hartley and Thurlow (2016)	All economic sectors	Dynamic CGE Model	Results show a substantial emissions reduction relative to the baseline and about one percent decline in employment in the country. They found that the price of electricity increases by 50 percent due to the imposed carbon tax which results in the GDP and aggregate employment declining by 1 and 1.6 percent respectively in 2035.	Treated different agricultural industries as homogenous and focused on energy, mining and industrial sectors which limit a detailed analysis of policy implications on individual agricultural and food industries.
Patridge *et al*. (2015)	Agriculture and Food	Static CGE Model	They found that carbon tax will adversely affect agricultural exports thereby reducing employment and foreign earnings in the sector.	Agricultural output could decline by 7.3 percent or 7 percent if agricultural tax-free allowances are taken into account.
Alton *et al*. (2014)	All economic sectors	Dynamic CGE Model	The carbon tax is expected to affect economic growth by about 1.2 percent. The main affected sectors are energy, mining and industrial as well as transport whereas agriculture and food are not affected.	Also treated different agricultural industries as homogenous.

National Treasury (2013)	Energy and Industrial	Static and Dynamic CGE Models	The carbon tax is a preferred policy instrument to reduce GHG emissions. It reduces the national welfare in the short term. However, the impact is minimal when the country's economy transforms into a green economy.	Identified the lack of detail and reliable agricultural data as key constraints in the policy analysis, hence recommended to fully exempt it from the policy.
Devarajan *et al*. (2011)	Energy	Static CGE Model	Carbon tax reduces national welfare and raises energy costs. It is more efficient in reducing pollution than other policy instruments in energy sectors.	Limited attention was paid to the agricultural sector.
Winkler and Marquard (2011)	Energy and Industrial	Static CGE model	Carbon tax reduces national welfare; however, it is still a cost- effective measure to tackle greenhouse gas emissions.	Lack of time dimension of static CGE and focus on energy and industrial sectors. Limited analysis of the policy impact on agriculture.
International studies on carbon tax policy implications				
Allan, Lecca, MacGregor, and Swales (2014)	Energy	Static CGE Model	In the long term, carbon tax policy might yield to a double dividend i.e. reducing emissions and stimulating economic activities. However, this can only be achieved if revenue is recycled through income tax.	While the study focused on the energy sector, it also showed that the tax will affect food industries by raising prices and reducing household consumption.
Mathur and Morris (2014)	Energy	Input-Output Model	The negative impact of carbon tax on low-income households will be significantly higher in comparison to the low impact on higher income households due to adaptation capacity. Overall the introduction of the carbon tax will reduce economic growth due to declining competitiveness.	The study focused on the energy sector and used the Input-Output Model which does not take into account agents' behavioral changes to price. The Input-Output Model has been superseded by CGE models in policy analysis.

Nelson, Kelley and Orton (2012)	Energy and Industrial	Survey	Studies evaluating the impact of carbon tax on the Australian economy are inconsistent in their estimation. Some found large negative losses while others found a small decline in GDP	The extent to which carbon tax policy affects economic growth varies with different studies conducted in Australia. This could be attributed to different databases used by different studies.
Lu, Tong and Liu (2010)	Energy and Manufacturing	Dynamic CGE Model	Carbon taxes can assist countries to achieve a decline in emissions while not substantially affecting economic growth.	The study has a limited focus on the agricultural sector.

CHAPTER THREE
METHODOLOGY AND DATABASE

3.1 Introduction

As evidenced by the literature review in the previous chapter, Computable General Equilibrium (CGE) models have been used to assess the economy-wide effects of policies such as carbon taxes. CGE models are well suited to analysing the effects of tax changes across a broad spectrum of economic variables and to identifying possible winners and losers. This feature is enhanced when the database underpinning the CGE model contains a high degree of detail. The methodology's recognition of the various inter-linkages that exist between economic actors, resource constraints, relative price changes and its subsequent impact on economic behaviour, and flexibility in its application and simulation of different scenarios sets it apart from other modelling technologies such as input-output models or partial equilibrium models.

In addition, the credibility and validity of CGE models, such as the MONASH-style UPGEM used in this study, are enhanced by a long history of real-world policy applications and detailed documentation of the model's technical specifications and features in peer-reviewed publications such as Adams, Dixon, McDonald, Meagher and Parmenter (1994), Adams and Dixon (1997), Dixon and Rimmer (2002) and Dixon *et al.* (2013). Considering the nature of the research question posed in this study, the researcher is confident that a detailed CGE model such as UPGEM is the most suitable methodology with which to conduct the quantitative analysis. This choice is further supported by the extensive use of the methodology in the literature. This chapter will describe the theoretical framework and database of the UPGEM, with particular emphasis on the aforementioned modifications to the standard UPGEM.

3.2. Description of the UPGEM

The researcher applied a modified version of the UPGEM to analyse the implications of the carbon tax policy on individual agricultural and food industries within a broader economic context. The comprehensive description of underlying theories in the UPGEM are described in Dixon *et al.* (2013) and Dixon and Rimmer (2002), whereas Bohlmann *et al*. (2015) and Adams *et al.* (1994) show the application of the model in the South African and Australian context respectively. From these sources, the standard theoretical description of a MONASH-style CGE is given as a model that provides an industry-level disaggregation in a quantitative description of the whole economy.

It postulates neo-classical production functions and price-responsive demand functions, linked around a supply-use matrix in an equilibrium that endogenously determines prices and quantities. The demand and supply equations of the model are derived from the solution to the optimisation problems which are assumed to underlie the behaviour of private sector agents in a conventional neo-classical microeconomics. Each industry minimises cost subject to a given input prices and a constant return to scale production function. Zero pure profits are assumed for all industries.

In the model, households are designed to maximise a Klein-Rubin utility function subject to their budget constraint. Units of a 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. From this standard theoretical description, we make four modifications to allow for the assessment of the policy under consideration.

3.3. Modifications made in the standard UPGEM

There are four modifications made from the standard UPGEM. Firstly, the standard 25-sector UPGEM database is expanded to 33 sectors which include disaggregated agriculture, food and electricity industries. The database is based on the 2011 Social Accounting Matrix (SAM) and the Supply-Use Tables (SUT) published by Statistics South Africa (StatsSA). Secondly, the researcher allows for an environmental analysis by adding appropriate theoretical extensions which link the core UPGEM code and economic database to the external emissions data. Thirdly, the researcher allows for technology improvements in the baseline of the non-coal electricity industry. The changes in technology innovations is exogenously imposed in the baseline only. While the model account for benefits of technology changes, it does not explicitly account for the associated direct costs of adopting the technology. Lastly, the researcher estimates new trade elasticities, i.e. the Armington and export supply elasticities for the individual agricultural and food products, which improve the functionality and accuracy of the modified version of the UPGEM applied in this study.

3.3.1 Expanding the standard UPGEM database

Prior to explaining the database expansion and construction process, it could be beneficial to a reader to understand the basic structure of a MONASH-style CGE database. The formulation of a balanced database and estimation of behavioural parameters is called a calibration process in the model. The core model's database is calibrated to the latest available set of supply-use and Social Accounting Matrix data. For this study, 2011 SUT and SAM data were used to calibrate the model database. Once a balanced database together with parameters is achieved it is considered as an initial solution of the model which represent an economic equilibrium in a base year. The core database which is schematically presented in Table 3.1, in combination with the model's theoretical specification, discussed above and also illustrated in Figure 3.2, describes the main inter-linkages in the economy.

Table 3.1 presents a basic structure of the UPGEM database, which has three components namely the absorption matrix containing the data derived from the official Use-table, the production matrix containing the data derived from the official Supply-table and primary factors of production. The absorption matrix has intermediate and final users of products in the database. For computational purposes in the UPGEM model, each user is assigned a number to distinguish across different users of commodities. The following users are identified and assigned numbers in the model:

1. domestic producers divided into *i* industries;
2. investments (Gross Capital Formation) by *i* industries;
3. a single representative *h* household;
4. an aggregate foreign purchaser of exports;
5. government demand; and
6. change in inventories.

The theoretical behaviour of each user was briefly discussed in Section 3.2 above. For an example, the household is designed to maximise a Klein-Rubin utility function subject to budget constraint whereas the export demand for any locally produced commodity is inversely related to its foreign-currency price. In Table 3.1, the intermediate user is equivalent to a domestic producer and its theoretical behaviour is illustrated in Figure 3.2. Coming back to the database structure presented in Table 3.1, it is important to provide a basic meaning and interpretation of each coefficient. For a comprehensive description of each part of the database is documented in Dixon and Rimmer (2002) and Roos (2013). However, for the clarity of a reader, the first row in the absorption matrix, that is, V1BAS to V6BAS, represents direct flows of commodities, from all sources (imported and domestically produced) to users valued at basic prices. The first matrix (V1BAS) can be interpreted as the direct flow of commodity *c*, from source *s*, used by industry *i* as an input into current production. This implies that V1BAS to V6BAS represent intermediate products sourced from domestic or imported depending on relative prices.

The second row, V1MAR to V5MAR, shows the value of commodities used as margins to facilitate the basic flows identified in V1BAS to V6BAS. All margins are produced domestically and typically trade and transport service are margins used in facilitating the flows. V1MAR can be interpreted as a cost of margin service *m* used to facilitate the flow of commodity *c*, from source *s* to industry *i*. The third row, V1TAX to V5TAX, represents the taxes paid in the delivery of domestic and imported commodities to different users. The positive values will refer to taxes whereas negative values refer to subsidies. A positive value of V1TAX can be interpreted as the tax associated with the delivery of commodity *c* from source *s* used by industry *i* as an input into current production. The fourth row, V1PUR to V6PUR, will represent direct flows of commodities, from all sources to users valued at purchasers' prices.

Furthermore, in the database structure presented in Table 3.1 are primary factors used by industry in the current production. These matrices include the inputs of three factors of productions, that is, occupation-specific labour (V1LAB), fixed capital (V1CAP) and land use industries (V1LAD). The V1LAB shows the purchase of labour of skill *o* by industry *i* that is used as an input into current production. Information on production taxes such as business licenses, payroll taxes and stamp duties are represented in V1PTX. The production matrix in Table 3.1 illustrates the local production (MAKE) and imports. Each element in the MAKE matrix refers to the basic value of commodity *c* produced by industry *i*.

To enable the simulations in this study, a similar database structure to the one reflected in Table 3.1 was created but with disaggregated agricultural, food and electricity industries using data from SAM, SUT and other official statistics for South Africa. The steps taken to construct an expanded database are discussed below and the final and balanced database is presented in Appendix B. Table B3.1, B3.2 and B3.3 in Appendix B show the three components required to achieve a balanced UPGEM database. The data presented in these three tables in appendix B proves that the balancing conditions of the UPGEM database have been satisfied. For an example, industry costs are equal to industry sales, measured at R5 908 949, total commodity supply is equal to total commodity demand, equivalent to R7 091 555, and GDP income is equal to GDP expenditure, corresponding to R2 932 728. All numbers presented in Table B3.1, B3.2 and B3.3 are displayed in million rands.

Table 3.1: Basic structure of the UPGEM database

		ABSORPTION MATRIX (USE TABLE)						
		1	2	3	4	5	6	TOTALS
		PRODUCERS	INVESTORS	HOUSEHOLD	EXPORT	GOVERNMENT	INVENTORIES	
	Dimension	← IND →	← IND →	← HOU →	← 1 →	← 1 →	← 1 →	All Users
Basic Flows	COM x SRC	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS	Domestic + Imports
Margins	COM x SRC x MAR	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	ZERO	Net Margins
Indirect Taxes	COM x SRC	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	ZERO	Taxes less Subsidties
BAS + MAR + TAX = Purchase Values	COM	V1PUR Intermediate Use	V2PUR Investments	V3PUR Private Consumption	V4PUR Exports	V5PUR Public Consumption	V6PUR Stocks	Total Commodity Demand
Labour Costs	OCC	V1LAB						
Capital Rentals	1	V1CAP						
Land Rentals	1	V1LND						
Production Taxes	1	V1PTX						
Total Industry Costs	1	V1PUR + V1LAB + V1CAP + V1LND+ V1PTX						

	PRODUCTION MATRIX (SUPPLY TABLE)				
Dimension	← IND →	1	1	1	All Sources
COM ↕	MAKE	V0IMP IMPORTS	V0MAR MARGINS	V0TAX TLSP	Total Commodity Supply
1	Total Industry Sales				

Source: Adapted from Dixon and Rimmer (2002)

Notes: COM =Commodities; IND = Industries; SRC = Source (domestic & imported), MAR = Margins; OCC = Occupations types

Database Balancing Conditions: (i) Industry Cost *[V1PUR+V1LAB+V1CAP+V1LND+V1PTX]* = Industry Sales *[MAKE]*

(ii) Commodity Demand *[V1PUR+V2PUR+V3PUR+V4PUR+V5PUR+V6PUR]* = Commodity Supply *[MAKE + IMPORTS + TLSP + NET MARGINS]*

(iii) GDP Income *[V1LAB+V1CAP+V1PTX+TLSP]* = GDP Expenditure *[V2PUR + V3PUR + V4PUR + V6PUR -V0IMP]*

From the data presented in Appendix B, it is possible to note that the largest users of commodities are producers for intermediate use in their current production, household for private consumption and export for foreign markets. From the supply side, the business and manufacturing sectors are the biggest drivers of the South African economy because the bulk of economic output is generated by these sectors. It can also be deduced from the database that the country's exports are dominated by the mining, manufacturing and agricultural commodities. The raw data presented in Appendix B together with behavioral parameters estimated and discussed in Chapter 4, in combination with theoretical discussions provided in Section 3.2 and illustrated in Figure 3.2 forms an initial solution of the UPGEM model. The initial solution is also considered a Baseline and reflects a natural economic equilibrium without the introduction of a carbon tax policy on the country's economy.

The next section discusses the process followed to split the agricultural, food and electricity sectors in the database. Other sectors in the standard UPGEM database were kept unchanged. All steps in the database creation process were conducted using a code written in GEMPACK software. According to Harrison and Pearson (1996), the advantage of writing an automated code for the manipulation of data includes improved transparency because the code becomes a permanent document of the data manipulation process. Moreover, the code allows for easy adjustment and corrections to formulas as well as the fast replication of the data manipulation process when the new data becomes available. The disadvantage is the complexity of formulating a correct code that will produce a balanced database.

3.3.1.1 Mapping process and creation of sets

The first step is to map the industry disaggregation process. Industries and commodities, as they appear in the SUT of 2011, are mapped to 62 industries and 104 commodities based on the Standard Industrial Classification (SIC) of all economic activities and Central Product Classification (CPC) for goods and services. Figure 3.1 illustrates the disaggregation process for the agricultural, food and electricity sectors. It is important to note that all the simulations and analysis were conducted at this decomposed industry level. The decomposition of industries enables the analysis to isolate the impact of introducing a carbon tax on individual industries within the economy.

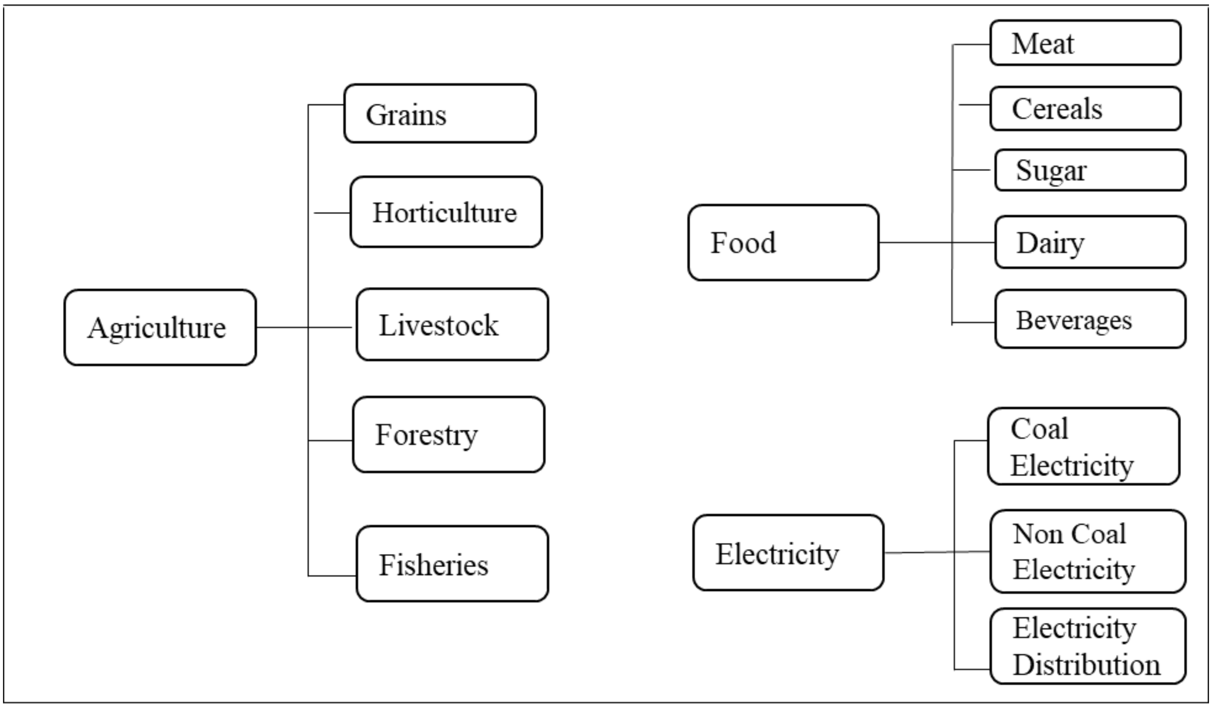

Figure 3.1: Industry disaggregation and mapping process

The mapping process is informed by the emission intensity of different industries and a need to monitor the effects of the carbon tax policy when it is introduced on the economy. The complete mapping of all industries and commodities in the database is presented in Table A3.1 and Table A3.2 in Appendix A. Following the splitting of the agriculture, food and electricity sectors, other sectors in the UPGEM database were aggregated to ensure the number of industries is kept manageable in the model. The advantages of having a relatively smaller set of industries include better management of the database and easier comparison of values in the database with the original value from the published official data. Other sets in the database include 11 occupation labour types (i.e. managers; professional; technicians; clerks; service; skilled agriculture; crafts; operators; elementary; domestic workers and unspecified), two sources (i.e. domestic and imported) as well as two margins (i.e. trade and transport services). Once the disaggregation of agricultural, food and electricity industries were complete, the researcher proceeded into creating the matrices discussed in Table 3.1 above. The researcher started with the land matrix where it was found that agriculture and mining are the biggest users of land. Agriculture uses approximately 93 percent of the total surface area in the country (DAFF, 2017).

3.3.1.2 Step 2: Creating land rentals

The official supply-use table published by the South African government or Statistics South Africa has no separate values for land rentals but are embedded in the gross operating surplus. This makes it extremely difficult to isolate the land rental values from the SUT data. To separate these values, the researcher decided to first calculate the actual land values based on hectares and land prices data presented in Table 3.2, based on data from DAFF (2017) and BFAP (2017). These two data sources have the land data available at a disaggregated level that suits the disaggregation made in step 1 above (Figure 3.1). The assumption is made that about 80 percent of the reported agricultural land is not fully utilised because of poor farm infrastructure, land reform programme failures, limited market access, soil erosion and increasing agricultural inputs (NAMC, 2013). Once the actual land values are calculated, taking into account the land utilisation assumption affected by land reform and soil erosion, they are subtracted from the gross operating surplus reported in the SUT.

Table 3.2: Number of hectares and land prices per agricultural industry

Industry	Hectares	Price: R/Ha
Forestry	1 556 210	5 000
Horticulture	3 898 486	21 000
Field Crops	9 528 309	18 000
Livestock	63 384 734	10 000

Source: Adapted from DAFF (2017) and BFAP (2017)

The land rental for the mining industry is adopted from the UPGEM current database. The land rental matrices show that the bulk of land in agriculture is used for livestock farming even though the value of this land is smaller relative to horticulture and field crops farming. This is due to the fact that livestock land has a low potential which makes it only suitable for animal grazing activities. To complete the primary factors of production, the employment (V1LAB) and gross fixed capital formation (V1CAP) are taken from SUT publication and allocated to the newly expanded industries. The next step is to create coefficients in the absorption and production matrices.

3.3.1.3 Step 3: Splitting total flows into sources

As mentioned earlier, the MONASH-style CGE model has an absorption matrix which entails creating basic flows, allocating sources in the basic flows, margins and taxes. The official SUT reports these flows but they are not reported on user-specific, which make it difficult to know the share in flows that originate from domestic or imported sources. To distribute the flows into sources the researcher adopted the strategy formulated by Roos (2013). This strategy assumes that the share of imports in total use of commodity *c* is the same for all users. For, example, if imported meat makes up 10 percent of total sales (use) of meat from both domestic and imported sources, then all users of meat will use 10 percent of imported meat in their meat purchase. The GEMPACK code used to calculate a share of each commodity that is then used to split total flows into sources is specified as follows:

$$IMP\_SHR_{(c)} = \frac{IMPORTS_{(c)} + V0TAR_{(c)}}{\sum_{u \in USERS} VPUR_{(c,u)}} \qquad \text{(Eq. 3.1)}$$

where *u* refers to the following users: (1) current production; (2) investments; (3) household; (4) exports; (5) government; and (6) change in inventories. In this step, an assumption is made that there are no exportation of the imported products. Once the basic flows have been split by sources, the next step is to create margins for commodities.

3.3.1.4 Step 4: Creating margin matrices

Margin matrix typically refers to trade and transport margins which are the difference between the purchaser's price and the producer's price of a product. To obtained margins, a simple technique is applied which involves three stages. The first stage is to determine user- and commodity-specific margins, that is, V1MAR to V5MAR. Secondly to split the user- and commodity-specific margins between trade and transport service margins commodities. To create commodity-specific margins an assumption is made that the margin user ratio is the same for all users, that is, if the margin use ratio for commodity *c* is 6 percent, it is then 6 percent for all users of commodity *c*. Thirdly, the margin rate is the same for both domestic and imported commodities. The margin use ratio is calculated using Equation 3.2.

$$MAR\_USERATIO_{(c)} = \frac{MARGIN_{(c)}}{\sum_{u \in USER} \sum_{s \in SRC} VPUR_{(u,c.s)}} \qquad \text{(Eq. 3.2)}$$

where *u* refers to the following users: (1) current production; (2) investors; (3) household; (4) exports; (5) government; and (6) change in inventories; and *s* refers to domestic and imports. The next step is to distribute the aggregate user-specific margin for each commodity between transport and trade margins. Since the total value of trade and transport margins is known, the share of trade and transport in total margins is calculated using Equation 3.3.

$$MARSHR_{(c)} = \frac{MARGIN_{(t)}}{\sum_{t=1}^{2} MARGINS_{(t)}} \qquad \text{(Eq. 3.3)}$$

where *t* is the margin commodity, *t =1* (transport services) and *t = 2* (trade). Again, it is assumed that all users use the same proportion of trade and transport margins. The margin commodity share is then multiplied with the aggregate user-specific margin. This yields margin matrix by commodity, sources and user for all margin commodities.

3.3.1.5 Step 5: Creating tax matrices

This step focuses on the creation of tax matrices, i.e. V1TAX to V5TAX, however, these also need to be distributed across users and the SUT does not report user-specific taxes. To create user-specific taxes, the researcher multiplied the commodity-specific taxes with a tax factor, which is the same strategy used by Roos (2013) and Roos, Adams and Van Heerden (2015) to create a database for the MONASH-style CGE model. The tax factor reflects users that pay the highest taxes by assigning them a bigger weight to be multiplied with commodity-specific taxes. In this study, a tax factor of 2 is assigned to producers and a tax factor of 3 is assigned to households, which creates the matrices of V1TAX to V5TAX, as well as the creation of V0TAR matrices.

3.3.1.6 Step 6: Creating basic flow matrices

The UPGEM requires the creation of the domestic flow values, that is, V1BAS to V6BAS matrices. Since the flows at purchaser's price include the basic value plus the margin costs plus taxes, it is easy to calculate the basic flows. The margins and taxes were calculated in step 4 and step 5 above and these are subtracted from purchasers' values to remain with basic flows. Equation 3.4 illustrates the calculation of domestic basic flows.

$$BAS_{(u,c,dom)} = \sum_{s \in SRC} VPUR_{(u,c,s)} - BAS_{(u,c,imp)} - \sum_{s \in SRC} \sum_{m \in MAR} MAR_{(u,c,s,m)} - \sum_{s \in SRC} TAX_{(u,c,s)}$$

(Eq. 3.4)

The final step of the database construction processes to examine if the database is still balanced after all the disaggregation and manipulation of data conducted in the aforementioned six steps. This step entails testing the conditions of market clears and zero profits which are adopted in this model.

3.3.1.7 Testing the balance of the database

To examine if the database is balanced, two tests are conducted which verify assumptions of zero-pure economic profits and market clearing conditions. Firstly, the assumption of no pure economic profit implies that industry costs should be equal to industry sale for each commodity in the database. This can be mathematically specified as:

$$IND\_COSTS_{(i)} = IND\_OUTPUT_{(i)} \qquad \text{(Eq. 3.5)}$$

where$IND_COSTS_{(i)} = \sum_{c \in COM} \sum_{s \in SRC} V1PUR_{(c,s,i)} + V1LAB_{(i)} + V1CAP_{(i)} + V1LAND_{(i)} + V1PTX_{(i)} + V1OCT_{(i)}$; and $IND\_OUTPUT_{(i)} = \sum_{c \in COM} MAKE_{(i,c)}$

The second test is examining the market clearing condition which implies that total commodity supply should be equal to total commodity demand. This test is explained in Equation 3.6

$$COM\_Supply_{(c)} = COM\_Demand_{(c)} \qquad \text{(Eq. 3.6)}$$

In cases where the balancing test failed, the RAS feature in the GEMPACK software is used to readjust the totals under each coefficient until all database tests are passed. RAS function is helpful to ensure the database is balanced to the third decimal, which is a task that is almost impossible to achieve with manual calculations. The RAS feature is one of the added advantages of using GEMPACK software. Once all the coefficients have been created in the format required by the MONASH-style CGE model, the attention turns to estimating the elasticities that are required for the functioning of the model and critical theoretical extensions to allow for environmental analysis.

3.3.2 Environmental enhancements

To allow for an assessment of carbon tax policy effects on emissions and welfare, environmental enhancements extensions are included in the UPGEM model, and these extensions are based on the extensions also used by Adams and Parmenter (2013) and Van Heerden *et al.* (2006). These environmental enhancements include:

- ❖ An accounting module for energy and greenhouse gas emissions that explicitly cover each emitting industry recognised in the model;
- ❖ Equations that allow for inter-fuel substitution in the electricity generation; and
- ❖ Mechanisms that allow for the endogenous take-up of various abetment measures in response to GHG policy measures.

The manner in which these environmental extensions work is that they track emissions on a detailed level and then break them down according to an emitting activity and/or emitting industry. Since the country's emissions is dominated by coal-generated electricity, it is important that different electricity-generating technologies are distinguished in the model. The researcher distinguishes between coal-generated and non-coal-generated electricity and allows for technology changes in the non-coal electricity industry. The inter-fuel substitution in electricity generation is handled using the technology bundle approach of Hinchy and Hanslow (1996). The modifications of the core UPGEM described here can also be explained schematically in the modified nested-production structure presented in Figure 3.2. This structure illustrates the theoretical behaviour of producers in the model, where a producer is one of the users in the absorption matrix discussed in the database presented in Tabe 3.1 above. Each user has a unique theoretical structure but the producer's theory is considered the most difficult and often warrants a need to be discussed alone. Dixon *el al.* (2013) and Dixon and Rimmer (2002) also makes the same point that it is useful to explicitly explain the theory of the producer in the model. Readers interested to learn more about the theory of other users (e.g. household, investor, export and government) over and above the description provided in Section 3.2 above can see Dixon and Rimmer (2002), Dixon *el al.* (2013) and Bohlmann *et al.* (2015).

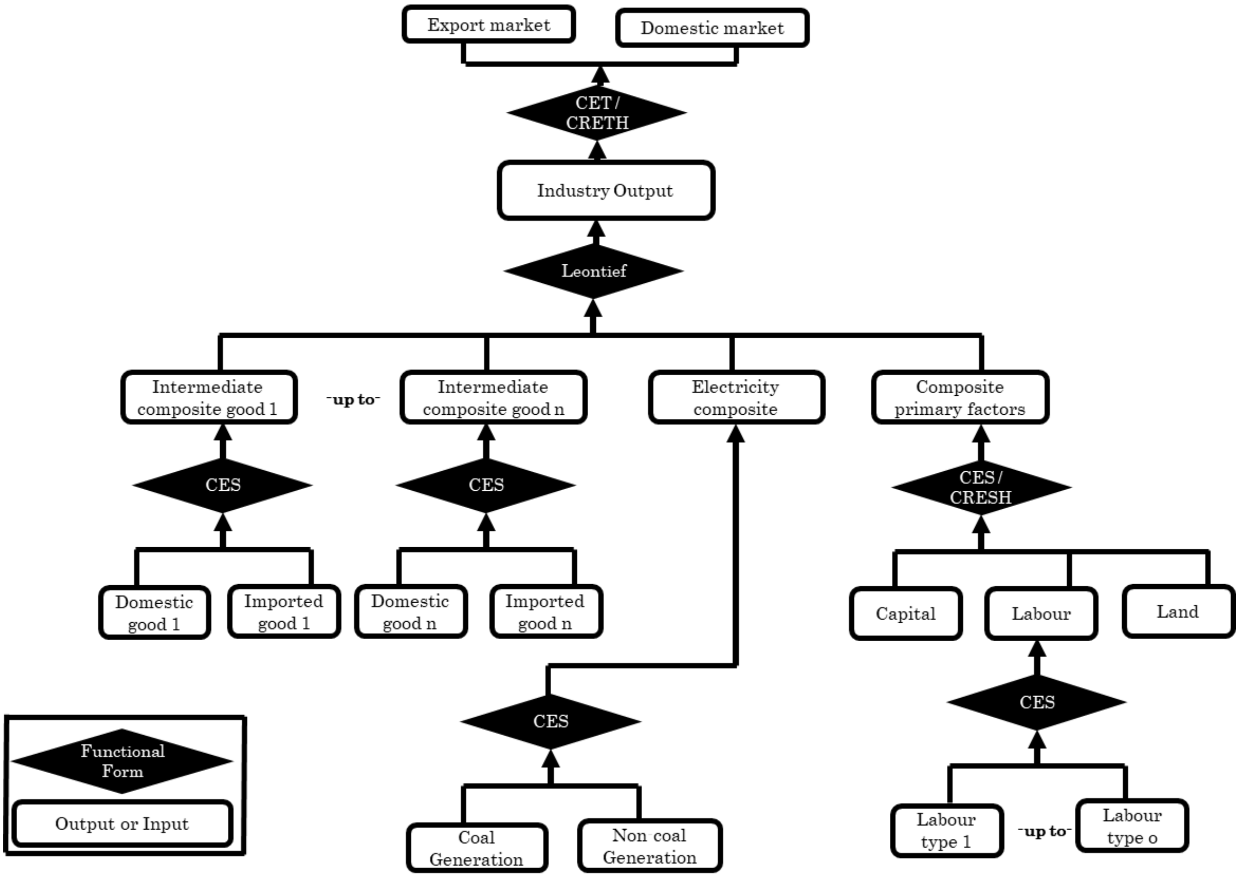

Figure 3.2: Modified nested production structure in the UPGEM

Source: Adapted from Bohlmann *et al.* (2015)

To explain the modified production structure, the researcher borrows from Dixon *et al.* (2013) and Bolhmann *et al.* (2015), in which they explained that at the top level of the structure the intermediate commodity composites and a primary-factor composite are combined using a Leontief or fixed-proportions production function. Consequently, they are all demanded by a producer in direct proportion to industry output or activity. This industry output is a composite of goods produced for export and domestic markets, which is governed by constant elasticity of transformation (CET) that determines the producers' trade-off between producing goods for export versus domestic markets. Each commodity composite is a constant elasticity of substitution (CES) function of a domestic good and its imported equivalent. This incorporates an imperfect Armington's assumption of an imperfect substitution of goods by place of production, an assumption which was first introduced by Armington (1969). The primary-factor composite is a CES aggregate of composite labour, capital, and land. Composite labour demand is itself a CES aggregate of the different types of labour distinguished into eleven different occupations. In the standard UPGEM, all industries share a common production structure presented in Figure 3.2, but without the separate bundle for the electricity technologies.

A modification was made from a standard production structure as shown in Figure 3.2, which include an electricity bundle constituting coal and non-coal electricity industries. The creation of the sub-production structure for electricity enables one to track the impact of a carbon tax in shifting the electricity demand from coal- to non-coal-generated electricity. Industries that procure electricity as part of the intermediate mix are likely to shift their demand to non-coal electricity as prices of this good could reduce relative to coal electricity because of the introduction of the carbon tax and assumed technology improvements in the baseline of the non-coal electricity industry. Once the model database and model code has been altered to allow for environmental enhancement analysis, the next step is to estimate new trade elasticities for the agricultural and food products. The primary reason for estimating new trade elasticities is that existing elasticities are outdated – last estimated by Gibson (2003) using data that dates back to the 1980s – which does not reflect the changes that have happened in the South African economy in the past 24 years.

3.3.3 Estimating new trade elasticities

Trade elasticities such as the Armington play a central role in CGE models to determine the demand substitution between commodities relative to price changes. Because of their role, modellers are keen to know the correct elasticities for use in CGE models. Despite their importance, elasticities are rarely available or often outdated for agricultural commodities, leaving researchers to rely on a value judgment. This is particularly true for export demand elasticity where local studies (e.g. Bohlmann *et al.*, 2015 and Punt, 2013) have used value judgments to assign elasticity values. This limitation is addressed by estimating new elasticities for the individual and aggregate agricultural and food commodities using updated time series data (1980-2016). The estimation methods, data characteristics, and new estimates are discussed in Chapter four.

3.4. Model closures

The UPGEM like any other CGE model has a very large number of equations and variables. As such the variables are more than the equations which require distribution of certain variables to be set exogenous and others to be set endogenous in order to simulate the policy scenarios against the baseline in an effective manner. The process of selecting exogenous and endogenous variables is called a model closure and is largely dependent on a CGE modeller and the specific policy under consideration. The model closure process enables the researcher to compute the differences between a scenario in which the shock has occurred (i.e. the policy simulation) and a counterfactual scenario in which the particular shock under examination did not occur (i.e. the baseline scenario). Results are then reported as percentage change deviations over time between the baseline simulation run and the policy simulation run.

The baseline simulation is calibrated using the latest available macroeconomic projections, which reflects a Business-As-Usual economic growth over a modelled period. In this study, the modelling period ranges from 2011 to 2035, hence the baseline is calibrated using actual data from 2011 to 2017, the short-term projections covering the period between 2018 and 2021, and the medium-long term projections covering the period from 2022 to 2035. Projections are soured from NT (2018), BFAP (2017), and IEA (2017) as reported in Table 3.5. For MONASH-style CGE models, Dixon and Rimmer (2002) created a flexible model closure system which assists modellers to create a plausible baseline as well as policy scenarios. There are three different closures, namely decomposition, forecast and policy, where the first two-assist to create a plausible baseline and the last one helps to create a policy scenario in the UPGEM.

According to Dixon and Rimmer (2002), the decomposition closure refers to a standard one-period long-run closure and it serves as a good base from where to develop other closures, such as the forecast (i.e. baseline) and policy closures. The majority of modellers using the MONASH-style CGE model adopt a standard decomposition closure described in Dixon and Rimmer (2002). The forecast closure is used in simulations to produce a believable business-as-usual or baseline scenario of the future evolution of an economy. The forecast closure incorporates all available macroeconomic forecast data presented in Table 3.5. The forecast closure is a short-run in nature and allows researchers to set exogenous all macroeconomic variables that have existing forecast data. To calibrate the baseline scenario with available projections presented in Table 3.5, we use a forecast model closure system, which enables the researcher to set exogenous the components of the GDP from the expenditure side as well as the consumer price index and population growth.

Then some naturally exogenous variables such as the average propensity to consumers and others are assumed to be endogenous. Care should always be taken in developing the forecast closure and swapping the naturally exogenous with endogenous variables as not any swap combination will be legitimate. In addition to a forecast closure that leads to a baseline scenario, we created a policy closure that enables policy simulations. To create a valid policy closure, the researcher set endogenous the naturally endogenous variables such as the components of GDP, which were set exogenous under the forecast closure to accommodate available macroeconomic forecast data. Setting the GDP components as endogenous is important because policymakers are often keen to know the effects of the policy on GDP and its components such as employment, investments, and trade. After setting the GDP components as endogenous, we exogenous variables such as the position of foreign demand curves or the average propensity to consume.

In the full UPGEM, a budget neutrality assumption is imposed which implies that there are no changes allowed to the public-sector debt as a result of the policy examined in this study. To achieve this assumption the consumption taxes are allowed to adjust to compensate for the change in government finances. It is important to note that in the policy closure, the exogenous variables selected are similar to that of decomposition closure; however, the only difference lies in the short-run nature of the policy closure versus the long-run nature of the decomposition closure. Once all three model closures are validated, the next step is to design policy shocks based on the carbon tax draft bill released by the National Treasury in December 2017. By the time of printing this thesis, the draft bill was already debated and passed by policymakers in the Parliament of South Africa.

3.5. Simulation design

To determine the implications of the carbon tax on agriculture, food and other industries, the economic data from 2011 SAM and SUT was entrenched with emission data calculated by Arndt *et al.* (2013), DEA (2017) and Seymore *et al.* (2014). According to NT (2017) the proposed carbon charge is effectively a fossil-fuel input tax, but one that is levied on industry-specific emissions such as coal, gas and petroleum. Because the emissions and energy content of fuels vary, the tax has to be applied to a fuel use. In order to assess the carbon tax effects, the emission and energy data need to be converted into fuel terms using industry-wide consumptions. To obtain the effective tax rate, a simple transformation approach is adopted to convert the R/tCO_2-eq charge into rand per terajoule (R/TJ). This is necessary to standardise the unit of measurement because the carbon charge is a tax on fossil-fuel consumption, but the tax bill describes a carbon charge rate in the form of R/tCO_2-eq.

The conversion of the carbon charge into TJ caters for differences in the emissions coefficients of each fuel input and helps address the issue of different fuel inputs. Table 3.3 contains the coefficients required to make the convention in tax rate from R/tCO_2-eq to R/TJ. The CO_2/TJ coefficient for the coal commodity is estimated at 95.60 tCO_2/TJ; for gas, it is estimated at 63.73 tCO_2/TJ; and for petroleum, it is estimated at 72.56 tCO_2/TJ (Van Heerden *et al.*, 2016). Multiplying these input fuel-specific coefficients with the carbon tax rate of R120/ tCO_2-eq, which is proposed in the carbon tax bill of 2017, gives the tax rate in R/TJ as provided in the last column of Table 3.3. These effective tax rates still need to take into account the tax-free allowances per sector as provided in the carbon tax bill of 2017 (NT, 2017:33).

Table 3.3: Conversion coefficients from carbon dioxide equivalent to terajoule

Fuel type	tCO_2-eq/TJ coefficient	R/tCO_2-eq	R/TJ
Coal	95.60	120	11 472
Gas	63.73	120	7 647
Petroleum	72.56	120	8 707

Source: Adapted from Van Heerden *et al.* (2016)

Once the tax rate is converted to R/TJ, the maximum allowances are applied and this is provided in Table 3.4 together with emissions as well as sector's energy consumption levels.

Tale 3.4: Industry energy consumption, emissions, tax allowances, and effective tax rate

Economic Sectors	Emissions (MtCO_2-eq)	Energy use (TJ)	Maximum Allowance (%)	Effective tax rate (R/TJ) after accounting for allowances		
				Coal	Gas	Petroleum
Agriculture	5.01	72 327	100	0	0	0
Food	0.10	4 115	95	574	382	435
Chemical, steel and plastic	58.57	729 574	95	574	382	435
Coal and lignite mining	2.36	49 671	95	574	382	435
Transport services	77.21	811 860	90	1 147	765	871
Petroleum refineries	83.51	687 019	90	1 147	765	871
Other economic sectors	36.51	625 174	90	1 147	765	871
Coal electricity	296.39	2 452 146	75	2 868	1 912	2 177
Non-coal electricity	2.82	23 298	75	2 868	1 912	2 177
Electricity distribution	1.51	12 492	75	2 868	1 912	2 177
Total	564	5 467 676				

Source: Own calculations based on DEA (2017), NT (2017) and Seymore *et al*. (2014).

Table 3.4 also indicates that the majority of South Africa's emissions are from the energy sectors such as petroleum and electricity which rely on fossil fuels and coal. The emissions from the agricultural and food sectors are largely emitted from livestock manure and food waste. Oelofse and Nahman (2013) have found that 30 percent of food is wasted per annum in South Africa which contributes to agricultural emissions. Looking at the international literature, Garnett (2011) and WRI (2015) also found that food waste contributes substantially to the global agricultural and food sectors' GHG emissions. The next step is to design the three policy scenarios which reflect the three sets of assumptions under which the policy is evaluated. The three policy scenarios are simulated against the baseline scenario that reflects business-as-usually economic growth.

3.5.1. Policy scenarios

Three policy scenarios were developed namely the Focus, Allowances Removed and No Revenue Recycling policy scenarios. All three scenarios take into account the potential risk on trade patterns by modelling the trade exposure allowance provided in the carbon tax bill. This allowance enables industries who are trade exposed[2] to qualify for a 10 percent carbon tax exemption. However, this trade allowance addresses the competitiveness issue from an exporter perspective. It is important to note that all policy scenarios do not assess the impact on imports coming from countries with no environmental policies which could make these imports unfairly competitive relative to domestic produce. Across all three scenarios, we assume that all countries, which are signatories to the Paris Agreement like South Africa will implement measures that reduce GHG emissions thus ensuring a fair playing ground in the international markets.

(i) **Focus policy scenario:** This is the main policy scenario where the tax rate is modelled to accurately reflect the policy features proposed in the carbon tax draft bill of December 2017. One of the key assumptions shaping this policy scenario is that the tax will be introduced at R120/tCO_2-eq which then increases by 10 percent per annum in the first five years of implementation; thereafter increasing in line with the inflation rate. Moreover, the maximum tax-free allowances per sector are retained for the duration of the modelling period. The modelling period is up to 2035 to enable a longer timeframe that illustrates the carbon tax impact in the short run and long run. The tax revenue recycling scheme is activated to reflect the proposal by NT (2017).

[2] Trade exposed industries are identified as industries, where the combined value of export and imports is more than 40 percent of industry's value added (NT, 2013)

(ii) **Allowances Removed policy scenario**: In this policy scenario, the carbon tax is introduced at R120/tCO_2-eq including the tax-free allowances per sector, as well as the recycling of revenue. However, after the first five years of implementation, the tax-free allowances are gradually reduced to accelerate the mitigation of emissions in the country. The reduction of tax-free allowances is maintained at 10 percent per annum up until the point where all industries are paying 100 percent tax rate.

(iii) **No Revenue Recycling policy scenario:** The tax and allowances are applied as in the Focus scenario but there is no revenue recycling scheme. The second and third scenarios aim to analyse the sensitivity of the economy to a carbon tax impact if the tax revenue recycling scheme and allowance are removed. All three policy scenarios are simulated and interpreted against the baseline scenario which reflects a naturally growing economy without the carbon tax.

3.5.2. Baseline scenario

The baseline scenario reflects a plausible evolution of the economy without the introduction of a carbon tax shock. The baseline scenario reflects the economic activities based on the available economic and emissions forecast data presented in Table 3.5. Besides incorporating the available macroeconomic forecast data into the baseline, technology improvements are allowed in the non-coal baseline scenario. Technology changes is exogenously imposed and free to reflect the expected innovation improvements in the non-coal industries. Allowing technology changes assist in terms of capturing the expected evolution thus generating more accurate results.

The technology in non-coal electricity, especially for renewable energy like wind and solar power, has improved significantly since 2011 (the base year of this study) and is set to continue improving as the world moves away from fossil reliance towards cleaning the world. The IEA (2017) estimated that renewable energy prices will decline by 40 percent over the next decade largely because of technology improvements in the non-coal electricity industry. Previous studies such as Van Heerden *et al.* (2016) did not account for technology improvements in the non-coal industries which partly explains the higher welfare loss found in their results relative to the baseline. By accounting for technology improvements in this study, the researcher seeks to examine and reflect a true expected cost of non-coal electricity relative to coal electricity.

Table 3.5: Macroeconomic and technology changes forecast data used to calibrate the baseline scenario

Variables	Source	Actuals							Short-medium term				Long term estimates			
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025 -2035
Real GDP (%)	NT, 2018	3.30	2.20	2.30	1.60	1.30	0.30	1.3	0.70	1.70	2.10	2.20	2.20	2.20	2.20	2.20
Household (%)	NT, 2018	3.70	3.40	2.90	1.40	1.80	0.70	2.20	1.60	1.90	2.16	2.16	2.16	2.16	2.16	2.16
Government (%)	NT, 2018	3.60	3.40	3.30	1.90	-0.30	1.90	0.60	0.80	0.20	1.2	1.73	1.73	1.73	1.73	1.73
Investment (%)	NT, 2018	5.54	3.60	7.60	1.40	3.40	-4.10	0.40	0.90	1.50	2.10	2.73	2.73	2.73	2.73	2.73
Exports (%)	NT, 2018	3.50	0.10	4.60	2.60	2.8	1.0	-0.1	1.00	2.7	2.9	3.33	3.33	3.33	3.33	3.33
Imports (%)	NT, 2018	4.22	6.00	1.80	-0.50	5.30	-3.80	1.60	2.20	2.90	3.24	3.44	3.44	3.44	3.44	3.44
Inflation (%)	NT, 2018	5.00	5.70	5.80	6.10	4.60	6.30	5.30	4.90	5.60	5.40	5.40	5.50	5.50	5.50	5.50
Interest Rates (%)	NT, 2018	8.50	9.00	9.25	9.75	11.25	11.50	11.50	10.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50
Current Account Balance	NT, 2018	-2.20	-5.10	-5.90	-5.30	-4.60	-2.80	-2.40	-3.20	-3.70	-3.90	-3.90	-3.90	-3.90	-3.90	-3.90
Population (%)	StatsSA 2017	1.30	1.40	1.40	1.40	1.30	1.30	1.20	1.20	1.20	1.20	1.10	1.10	1.10	1.10	1.10
Unemployment (%)	StatsSA 2017	24.80	24.50	24.10	24.30	25.70	26.90	27.2	27.00	26.00	26.00	26.00	26.00	26.00	26.00	26.00
Exchange Rate (R/$)	NT, 2018	0.08	0.18	0.12	0.18	0.17	-0.07	-0.10	-0.08	0.06	-0.03	0.03	0.03	0.03	0.03	0.03

3.6. Summary

This chapter illustrated the rationale of selecting the dynamic UPGEM as a method of choice to evaluate the policy implications on individual agricultural and food industries within a broader economic context. There were four important modifications made from the standard UPGEM, including the expansion of the database, theoretical extensions to allow environmental enhancements, accounting for technology improvements in the baseline of the non-coal electricity industry and the estimation of trade elasticities for individual agricultural and food commodities. The trade elasticity estimation methods, data and results will be discussed in the next chapter.

Moreover, the chapter described three policy scenarios reflecting three sets of assumptions in the policy effects. These three policy scenarios are: Focus; Allowance Removed; and No Revenue Recycling. The three policy scenarios are simulated and interpreted against a baseline scenario. A key assumption made in the baseline scenario was to allow for technology improvements in the non-coal electricity industry which reduce the amount of emissions emitted and make this industry more efficient relative to the coal electricity industry.

CHAPTER FOUR
ESTIMATING TRADE ELASTICITIES

4.1. Introduction

The computable general equilibrium (CGE) model is often used to analyse the effects of policy changes because of its ability to capture multisectoral interlinkages within the economy. The results of a CGE analysis largely depend on the database, policy shock and elasticities. The previous chapter discussed the construction of the database and the design of policy shocks. This chapter seeks to estimate the elasticities for use in the modified UPGEM model. Trade elasticities, such as the Armington, play a central role in CGE models to determine the demand substitution between commodities from different sources as a result of changes in relative prices (Hillberry & Hummels, 2013). Because of their role, modellers are keen to know the correct elasticities for use in CGE models. But despite their importance, elasticities are often outdated for South African agricultural commodities, leaving researchers to rely on a value judgment.

Most local studies such as McDonald & Kirsten (1999), Punt (2013); Bohlmann *et al.* (2015); and Van Heerdern *et al.* (2016) rely on the international literature such as GTAP literature, to determine the elasticities for use in a single-country CGE model. This value judgment approach often leads to different estimates applied by researchers which affect the accuracy of the model results. This chapter seeks to estimate the correct elasticities by using econometric models found in literature instead of relying on value judgment approaches. This also helps to estimate new elasticities to align with the latest economic data used in simulating the effects of a carbon tax policy. It must be highlighted that some of the elasticity estimations are very difficult due to data challenges and complexities of the estimation methods. Hillbery & Hummels (2013) and Annabi, Cockburn and Decaluwe (2006) also found that estimating elasticities is often constrained by data issues, hence most CGE modellers use value judgments approaches to determine estimates from the literature.

Despite these challenges, this chapter estimated trade elasticities for individual and aggregate agricultural commodities using updated time-series data (1980-2016). Trade elasticities refer to three sets of elasticities. First is the input demand elasticity also known as the Armington elasticity which is specified using a constant elasticity of substitution (CES) between imported and domestic products. Second is the export supply elasticity which is specified using a constant elasticity of transformation (CET) between products destined for domestic and export markets. Lastly is the export demand elasticity which is measured using a three-stage method developed by Tweeten (1967). This procedure starts by estimating price transmission elasticities (i.e. transmission from international price to domestic price), followed by the estimation of domestic demand and supply elasticities. The last step is to use estimates measured in the first two steps to calculate the export demand elasticities. Export demand elasticity measures the response in exports for a one percent change in export price. In this chapter, all three sets of elasticities are estimated.

4.2. Rationale for estimating new trade elasticities

It was illustrated in Chapter three, Figure 3.2, that CGE models contain a system of equations describing a theoretical behaviour of producers when deciding on a demand for intermediate goods. This system of equations is kept manageable by using elasticities in the CGE model. However, despite their importance in economic models, elasticities are often outdated or available at an aggregated level, which limits policy analysis at product level. For example, Gibson (2003) estimated Armington elasticities for agriculture and other products but largely at an aggregated level. The available Armington elasticities for individual South African agricultural products were calculated by Ogundeji, Jooste, and Uchezuba (2010) using quarterly data from 1995 to 2006, which is now considered outdated. Furthermore, they only estimated Armington elasticities for meat and grain products, leaving researchers to make value judgments for other agricultural products.

To further illustrate the difficulty in obtaining credible elasticities in South Africa's agricultural sector, there are no existing export supply and export demand elasticities for individual and aggregated agricultural products in the country. Most researchers rely on international literature to derive export supply elasticities for use in the single country CGE model for South Africa (Punt, 2013). However, this approach creates a problem as different researchers use different estimates thus affecting the functionality of models and results generated from these models. Armington and export supply elasticities are used in most CGE models whereas the export demand elasticity is mainly applied in MONASH-style CGE models like the UPGEM, where exports are modelled as downward-sloping export demand curves (Dixon *et al.*, 2013).

As mentioned, the rationale of this chapter is to estimate new trade elasticities using econometric methods. The researcher improves on Ogundeji *et al.* (2010) by updating the Armington elasticities and expanding the product range to cover grains (maize, wheat and sorghum); fruits (apples, grapes, oranges and avocados); vegetables (potatoes and tomatoes); meat (beef, poultry and swine); and processed food (milk, wine and sugar) products. In addition to Armington elasticities, the researcher estimated both the export supply elasticity and the export demand elasticity for all the aforementioned products. Table 4.1 presents the selected agricultural and food products which account for a 70 percent, 89 percent, and 58 percent share in the gross production value for field crops, horticulture and livestock respectively. They also account for large shares of agricultural exports and imports, measured in average share of total exports and imports from 2012 to 2016.

Table 4.1: Individual product's share in total agricultural production and trade

Agricultural sub-sector	Agricultural products	HS codes	2016 gross production value: 1 000 ZAR	2012-2016 average export share: %	2012-2016 average import share: %
Grains	Wheat	1001	7 107 286	1.75	6.92
	Maize	1005	29 824 219	2.27	3.35
	Sorghum	1007	459 167	0.01	0.24
Fruits	Avocados	080440	1 036 570	0.39	0.06
	Oranges	080510	10 176 160	6.98	0.03
	Grapes	080610	5 078 477	4.94	0.16
	Apples	080810	5 501 300	1.69	0.01
Vegetables	Potatoes	0701	6 132 450	0.35	0.00
	Tomatoes	0702	1 735 036	0.08	0.01
Meat	Beef	0201-02	10 272 080	0.51	0.66
	Swine	0203	5 793 659	0.17	1.06
	Poultry	0207	40 472 219	0.63	6.18
Processed	Sugar	1701	8 507 959	6.86	4.06
	Wine	2204	36 101 365	6.23	0.44
	Milk	0401	16 463 166	0.19	0.15
Other	Other agricultural products		81 961 984	67	77
Aggregated	Agriculture		266 623 097	100	100

Source: Department of Agriculture, Forestry and Fisheries (DAFF 2018)

The criteria for selecting products based on the share of total agricultural trade and production ensure that the products selected contribute the largest shares to agricultural production and trade. Prior to explaining the data and estimation methods used to estimate the three sets of trade elasticities, it is important to discuss the functional forms used to specify these elasticities.

4.3. Description of functional forms used in CGE model

The most commonly known functional form in the economic fraternity is the Cobb-Douglas function developed by Cobb and Douglas (1928). This functional form postulates that the elasticity of substitution is always one, implying a unit substitution between two inputs. This strong assumption does not always hold in practice, hence Arrow, Chenery, Minhas, and Solow (1961) developed a Constant Elasticity of Substitution (CES) functional form. Essentially the CES is a generalisation of the Cobb-Douglas functional form because it allows for any (non-negative) elasticity of substitution. CES implies that any change in the input factors results in a constant change in the output following the illustration by Arrow *et al.* (1961) where they proved that a production function with n-inputs has constant elasticity of substitution between every pair of inputs. The use of the CES functional form in CGE models has gained momentum since the late 1960s due to its ability to manage substitutability between input demands in the production function. For a detail discussion and specifications of the CES function, refer to Arrow *et al.* (1961).

The Constant Elasticity of Transformation (CET) is another functional form used in CGE models to determine the degree of optimal output combination. CET was first developed by Powel and Gruen (1968), on the production possibilities surface and demonstrated how it permits estimation of linear approximation to supply response along the surface. Shumway and Powel (1984) provided a modification in the CET functional form, allowing for the handling of three or more commodities in the production process. Other functional forms used in CGE models, especially the MONASH-stylised models, are Constant Ratios of Elasticities of Transformation Homothetic (CRETH) and Constant Ratios of Elasticities of Substitution Homothetic (CRESH).

Hanoch (1971) defined CRESH as a natural generalisation of the CES functional form which permits substitution elasticities to differ among different pairs of factors, without, however, introducing a large number of additional parameters. In complex CGE models the CRESH is preferred because it is well behaved in a wider range of n-factor input combinations. Furthermore, it is more adaptable to integration into current economic theory and practice, especially in studies of economic growth and technical changes. Dixon and Rimmer (2002) concur that the CRESH is the preferred functional form over CES function in complex CGE modelling. However, they notice that the slight drawback of the CRESH is that it cannot be obtained explicitly. The CRETH functional form is the extension of the CET functional form. For a detailed discussion and specifications of the CRESH and CRETH functional forms, refer to Dixon and Rimmer (2002), Hanoch (1971), Vincent, and Shumway and Powel (1984).

Going back to Figure 3.2 in Chapter three, which discussed the modified UPGEM production structure that is kept manageable by different elasticities, it was shown schematically how each functional form plays a critical role in this model. To elaborate, the UPGEM, like any other MONASH CGE model, uses CRESH and CRETH functional forms in the nested production structure. By using the CRESH specification for primary factor costs, it allows for differences in the elasticities of substitution between land and labour, land and capital, and capital and labour. However, the greater flexibility of CRESH has no full practical significance because in the model only agriculture and mining use land. For all other industries, with just labour and capital substitution elasticity to be specified, CRESH offers no practical advantage over CES; hence the model operates with CES (Dixon & Rimmer, 2002). Again, the CRETH specification only offers a potential advantage over CET in the model; hence the model is usually operated by the CET. The next sections turn the attention to the estimation procedures adopted in this study to estimate trade elasticities, discussing the data characteristics used to estimate the trade elasticities.

4.4. Data used and data sources

Three sets of trade elasticities were estimated using annual data series ranging from 1980 to 2016. The Armington elasticity is estimated using data series such as import quantities, import prices, domestic quantities, domestic prices, GDP, and the dummy variable. In the case of export supply elasticities, export quantities and export prices are required for the estimation. For a three-step estimation procedure of the export demand elasticity, the world price, population and domestic consumption are required in addition to the aforementioned variables. The dummy variable controls for market and trade policy reforms adopted in South African agriculture post-1994. The actual abolishment of control boards and other regulatory measures were implemented around 1997, hence the dummy variable is activated from 1998 in the simulations, meaning that it has a value of zero from 1980 to 1997 and a value of one from 1998 to 2016.

Various sources of data were used, including the Agricultural Abstracts, which provide official statistics for the agricultural sector and are published by the Department of Agriculture, Forestry and Fisheries on an annual basis (DAFF, 2018). Time-series data from Liebenberg, Pardey, Beddow and Kirsten (2015) was also used, and this provides the long-term series data on variables such as agricultural values and prices. Other data sources included the World Bank commodity database and the database of the Food and Agriculture Organisation (FAO) of the United Nations. These two global databases provide country-level commodity prices, including import and export prices as well as world trade flows. The usage of global databases allows a comparison with local data, which subsequently gives credibility to the data used in this study. In terms of evaluating and understanding data characteristics for each data series used, the Augmented Dickey Fuller (ADF) diagnostic test was performed on each logged-transformed data series. The ADF tests the null hypothesis of the presence of a unit root in a data series. Regressing a data series that has a unit root could cause the problem of a spurious regression; hence there is a need to test all data series for the presence of a unit root. The test results for the ADF unit root for all variables used in estimation are presented in Table 4.2.

Table 4.2: ADF unit root test results

ADF test		Domestic quantities		Domestic price		Import quantities		Import price		Export quantities		Export price		GDP		Population		World price	
		Level	1st difference	Level	1st difference	Level	1st difference	Level	1st difference	Level	1st difference	Level	1st difference	Level	1st difference	Level	1st Difference	Level	1st Difference
Grains	Maize	-2.232 (0.458)	-5.043 (0.001)	-5.592 (0.003)	-5.720 (0.000)	0.076 (0.700)	-5.466 (0.000)	-3.225 (0.095)	-4.959 (0.001)	-0.449 (0.512)	-6.584 (0.000)	-1.862 (0.345)	-6.013 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-0.540 (0.976)	-5.443 (0.000)
	Sorghum	-1.368 (0.586)	-7.189 (0.000)	-3.338 (0.078)	-6.145 (0.000)	0.145 (0.721)	-7.527 (0.000)	-0.999 (0.278)	-7.862 (0.000)	-1.111 (0.236)	-7.483 (0.000)	-2.741 (0.077)	-6.269 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-0.905 (0.997)	-4.336 (0.007)
	Wheat	-3.667 (0.037)	-8.830 (0.000)	-0.800 (0.806)	-5.457 (0.000)	-4.413 (0.001)	-10.332 (0.000)	-3.310 (0.027)	-6.662 (0.000)	-0.734 (0.391)	-6.735 (0.000)	-3.036 (0.041)	-7.768 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-0.061 (0.993)	-4.786 (0.002)
Fruits	Apples	-1.271 (0.183)	-10.121 (0.000)	-2.249 (0.449)	-7.280 (0.000)	-1.271 (0.1835)	-10.121 (0.000)	-0.8685 (0.785)	-9.584 (0.000)	-1.789 (0.379)	-10.247 (0.000)	-1.950 (0.306)	-6.625 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	1.751 (1.000)	-4.734 (0.002)
	Grapes	0.534 (0.826)	-6.417 (0.000)	-1.086 (0.710)	-11.430 (0.000)	0.274 (0.760)	-7.426 (0.000)	-0.888 (0.322)	-11.467 (0.000)	-1.228 (0.651)	-8.444 (0.000)	-1.671 (0.436)	-12.018 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	2.980 (1.100)	4.053 (0.000)
	Oranges	-1.620 (0.764)	-6.132 (0.000)	-1.592 (0.775)	-5.618 (0.000)	0.126 (0.716)	-9.394 (0.000)	0.804 (0.881)	-7.545 (0.000)	-3.089 (0.124)	-7.400 (0.000)	-3.662 (0.383)	-6.357 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-0.951 (0.938)	-5.474 (0.000)
	Avocados	-2.309 (0.418)	-12.129 (0.000)	-3.033 (0.037)	-6.476 (0.000)	-0.562 (0.974)	-4.642 (0.004)	0.029 (0.685)	-5.800 (0.000)	1.521 (0.965)	-5.001 (0.000)	-2.231 (0.458)	-6.233 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	1.156 (0.999)	-4.783 (0.002)
Vegetables	Potatoes	-0.703 (0.831)	-7.405 (0.000)	-0.082 (0.959)	-8.759 (0.000)	-0.424 (0.522)	-9.813 (0.000)	-0.263 (0.583)	-9.691 (0.000)	-3.181 (0.104)	-6.420 (0.000)	0.237 (0.749)	-7.982 (0.0000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-1.600 (1.100)	-4.378 (0.007)
	Tomatoes	-1.390 (0.575)	-8.603 (0.000)	0.434 (0.981)	-6.230 (0.000)	-2.590 (0.140)	-6.363 (0.000)	-0.692 (0.409)	-8.753 (0.000)	-0.720 (0.828)	-9.142 (0.000)	-0.376 (0.541)	-9.599 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	2.139 (0.998)	-4.886 (0.002)
Meat	Beef	-0.467 (0.886)	-6.102 (0.000)	-2.667 (0.255)	-5.082 (0.001)	-0.020 (0.669)	-5.112 (0.000)	-1.038 (0.925)	-4.788 (0.002)	-0.630 (0.851)	-6.453 (0.000)	0.335 (0.776)	-9.205 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	0.595 (0.999)	-4.475 (0.001)
	Poultry	-0.535 (0.871)	-3.943 (0.004)	-2.082 (0.252)	-5.979 (0.000)	-3.858 (0.026)	-5.846 (0.000)	-3.058 (0.401)	-7.821 (0.000)	-1.057 (0.721)	-5.034 (0.000)	-3.537 (0.012)	-7.820 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-3.218 (0.587)	-5.994 (0.000)
	Swine	-0.379 (0.902)	-5.570 (0.000)	-2.689 (0.872)	-8.530 (0.000)	-1.840 (0.664)	-4.787 (0.002)	-3.114 (0.034)	-9.795 (0.000)	-1.959 (0.302)	-7.068 (0.000)	-3.534 (0.056)	-7.101 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-2.165 (0.493)	-6.424 (0.000)
Processed food	Milk	-2.530 (0.312)	-7.591 (0.000)	-1.444 (0.548)	-6.261 (0.000)	-1.424 (0.559)	-6.770 (0.000)	0.111 (0.711)	-10.868 (0.000)	-0.423 (0.894)	-7.839 (0.000)	-0.178 (0.614)	-9.283 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-1.880 (0.695)	-4.309 (0.000)
	Sugar	-2.139 (0.231)	-8.311 (0.000)	-3.874 (0.024)	-5.5155 (0.001)	-2.0332 (0.272)	-8.235 (0.000)	-3.980 (0.040)	-11.01 (0.000)	-2.144 (0.229)	-5.476 (0.000)	-1.781 (0.383)	-5.011 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-2.833 (1.000)	-4.252 (0.003)
	Wine	-1.490 (0.526)	-5.646 (0.000)	-0.765 (0.816)	-5.166 (0.000)	-0.455 (0.690)	-6.061 (0.000)	-1.881 (0.336)	-6.761 (0.000)	-0.524 (0.874)	-6.039 (0.000)	-1.767 (0.390)	-6.486 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-0.275 (0.988)	-4.521 (0.005)
Aggregate	Agriculture	-2.217 (0.203)	-8.397 (0.000)	-1.688 (0.427)	-6.063 (0.000)	-3.659 (0.092)	-7.629 (0,000)	-0.0822 (0.673)	-5.536 (0.000)	-0.229 (0.596)	-8.003 (0.000)	-1.480 (0.532)	-8.065 (0.000)	1.515 (1.000)	-3.704 (0.035)	-1.153 (0.9040	-2.783 (0.023)	-3.271 (0.897)	-5.868 (0.000)

Note: p-values in parentheses

Looking at the results, it can be observed that the null hypothesis of a unit root cannot be rejected at a five percent significance level for GDP, population, domestic quantities, world price and export quantities for all individual products and aggregate agriculture at logged levels, suggesting the presence of a unit root. In addition, the null hypothesis for domestic price, import quantities, import price and export price series cannot be rejected for the majority of products, implying that the majority of these variables also have a unit root.

The data series that do not have a unit root at logged levels include domestic prices for maize, avocados, and sugar; import quantities for wheat and poultry; import prices for wheat, swine and sugar; and export prices for wheat and poultry products. When the data series are differenced, the ADF results indicate that the null hypothesis of a unit root can be rejected at the one percent and five percent levels of significance for all data series at the first difference level. This clearly suggests a need to difference some data series that have a unit root at the logged level. Controlling for a unit root through the method of differencing data series ensures that spurious regressions are avoided.

4.5. Trade elasticity estimation methods

4.5.1. Armington elasticity

To estimate the updated Armington elasticities for agricultural products, the researcher follows the method applied by Kapuscinski and Warr (1999), Ogundeji *et al.* (2010), and Reinert and Roland-Holst (1992). This method assumes a consumer with a well-behaved utility function. The hypothetical consumer obtains utility from a composite (Q) of imported (Q_M) and domestic (Q_D) goods, and it is assumed that there are continuous substitution possibilities. The consumer's decision problem is then to choose a mixture of Q_M and Q_D that minimises expenditure, given the respective import price (P_M) and domestic price (P_D) and the desired level *of* Q. The Armington specification of the composite goods demand is specified as:

$$Q = \mathrm{A}[\beta Q_M{}^{-\varphi} + (1-\beta) Q_D{}^{-\varphi}]^{-\frac{1}{\varphi}} \qquad \text{(Eq. 4.1)}$$

where Q is sub-utility over the domestic and import goods, A is an efficiency parameter, βs are share parameters in the demand function, and φ is the substitution parameter. The relationship between the substitution parameter and σ, which is the elasticity of substitution between imported and domestic commodities, is given by $\sigma = \frac{1}{1+\varphi}$. Following the standard assumptions of a well-behaved utility function, continuous substitution between two goods, as well as weak separability of product categories, the solution to the consumer's optimisation problem is to choose imports and domestic goods whose ratios satisfy the first-order condition given by:

$$\frac{Q_M}{Q_D} = \left[\frac{P_D}{P_M}\frac{\beta}{1-\beta}\right]^{\sigma} \qquad \text{(Eq. 4.2)}$$

Under the assumption that utilities in composite consumption are weakly separable, Armington elasticities can be estimated for disaggregated commodity categories by taking the logarithmic form of the above first-order condition, which yields the following:

$$ln\left(\frac{Q_M}{Q_D}\right) = \sigma_0 ln\left(\frac{\beta}{1-\beta}\right) + \sigma_1 ln\left(\frac{P_D}{P_M}\right) + \varepsilon \qquad \text{(Eq. 4.3)}$$

where Q_M is the quantity of imported goods, Q_D is the quantity of domestic goods, and ε is the error term, which is assumed to be independently and identically distributed with zero mean and constant variance. Equation 4.3 can be simplified as:

$$\mathrm{Y}_i = \phi_0 + \phi_1 X_i + \varepsilon \qquad \text{(Eq. 4.4)}$$

where $\mathrm{Y}_i = ln\left(\frac{Q_M}{Q_D}\right)$ is a dependent variable, $\phi_0 = \sigma_0 ln\left(\frac{\beta}{1-\beta}\right)$ is an arbitrary constant, $\phi_{1=}\sigma_1$ is the elasticity of substitution between imports and domestic goods, and $X_i = ln\left(\frac{P_D}{P_M}\right)$ is an explanatory variable. According to Kapuscinsky and Warr (1999: 262), the estimation of Equation 4.4 may potentially lead to problems because it does not adequately capture the dynamic relationships between imports, domestic production and prices. Furthermore, it does not capture factors such as the regulations and tariffs that affect imports entering the country. The researcher controls for the regulations and trade distortionary measures by including a dummy variable. The dummy variable captures the trade and market policy reforms adopted in the South African agricultural sector pre- and post-1994. Specifically, joining the World Trade Organisation (WTO) in 1995 and promulgating the Marketing of Agricultural Products Act 47 of 1996 led to the abolishment of marketing control boards, thus the removal of import quotas and tariff reductions, as well as other market regulations in the sector.

The dummy variable is activated in the year 1998, as the majority of deregulation measures took effect around 1997. In the estimation, the dummy variable has a value of zero between 1980 and 1997, and a value of one from 1998 to 2016. Annabi, Cockburn and Decaluwe (2006: 18) also argue that adding a variable that reflects the overall level of an economic activity, such as real GDP, can help to account for the pressures on demand. This variable also assists in controlling for the relationship between local economic activities and the demand for imported products. To distinguish between short-run and long-run Armington elasticities, Ogundeji *et al.* (2010: 128) show that Equation 4.4 can be further adjusted to distinguish between short-run and long-run elasticities by including a one-period lag of the dependent variable on the right-hand side of the equation. The modified Armington elasticity specification used in this paper, which takes into account trade distortionary measures and demand pressures on the economy, and distinguishes between short-run and long-run estimates, is given by:

$$\mathrm{Y}_i = \phi_0 + \phi_1 X_i + \phi_2 \mathrm{Y}_{i_{t-1}} + \phi_3 \mathrm{G} + \phi_4 \mathrm{Z} + \varepsilon \qquad (\text{Eq. } 4.5)$$

where $G = lnGDP$ is the variable capturing demand pressures and the relationship between local economic activities and import demand; Z is a dummy variable controlling for trade regime changes in the South African agricultural economy; and $\mathrm{Y}_{i_{t-1}}$ is a one-period lag in the dependent variable. The short-run elasticity is given by $\sigma_{short} = \phi_1$, and long-run elasticities can be calculated using $\sigma_{long} = \frac{\phi_1}{(1-\phi_2)}$, if $0 < \phi_2 < 1$. Both the short-run and long-run Armington elasticities are reported.

4.5.2. Export supply elasticity

According to De Melo and Robinson (1985: 15), exports and goods sold on the domestic market within the same sector classification are assumed to be imperfect substitutes. They argue that the domestic producer makes a composite commodity, Q, which is an aggregation of goods suitable for the domestic market, Q_D, and goods suitable for the export market, Q_E. The producer has a transformation function that determines the trade-off between producing goods with the same sectoral classification for the domestic and export markets. In the CGE context, the producer's decision is modelled using the export supply elasticity, which is specified using a constant elasticity of transformation. This elasticity measures the responsiveness of export supply to changes in the relative prices of domestic and export markets. The CET export supply elasticity is specified as follows:

$$Q = \mathrm{A}\left[\delta Q_E^{\rho} + (1+\delta) Q_D^{\rho}\right]^{\frac{1}{\rho}} \qquad (\text{Eq. } 4.6)$$

where A is an efficiency parameter, $\delta's$ are share parameters and ρ is the transformation parameter. The relationship between the transformation parameter and the transformation elasticity, Ω, is given by $\Omega = \frac{1}{\rho-1}$. Given this formulation, one can derive expressions for the derived demand for exports and domestic under the assumption that producers maximise profits, and hence, equate the marginal rate of transformation between exports and domestic to their price ratio (De Melo & Robinson, 1985: 15). Applying the algebra that is similar to that used in the case of the Armington elasticities, the optimal allocation depending on the ratio of export to domestic prices is given by the following first-order condition:

$$\frac{Q_E}{Q_D} = \left[\frac{P_E}{P_D}\frac{1-\delta}{\delta}\right]^{\Omega} \qquad \text{(Eq. 4.7)}$$

The CET export supply elasticities can be estimated for disaggregated commodity categories by taking the logarithmic form of the above first-order condition, which yields the following:

$$ln\left(\frac{Q_E}{Q_D}\right) = \Omega_0 ln\left(\frac{1-\delta}{\delta}\right) + \Omega_1 ln\left(\frac{P_E}{P_D}\right) + \varepsilon \qquad \text{(Eq. 4.8)}$$

where Q_E and P_E are export quantity and export price, Ω_1 is the elasticity of transformation and ε is the error term, which is assumed to be independently and identically distributed with zero mean and constant variance. Equation 4.8 can be simplified as:

$$\mathrm{Y}_E = \psi_0 + \psi_1 X_E + \varepsilon \qquad \text{(Eq. 4. 9)}$$

Where $\mathrm{Y}_E = ln\left(\frac{Q_E}{Q_D}\right)$is the dependent variable, $\psi_0 = \Omega_0 ln\left(\frac{1-\delta}{\delta}\right)$ is an arbitrary constant, $\psi_1 = \Omega_1$ is the transformation elasticity, and $X_E = ln\left(\frac{P_E}{P_D}\right)$ is an explanatory variable. To control for trade distortionary measures, the researcher included a dummy variable that is similar to that used in the specification of the Armington elasticity. The researcher also included the one-period lag of the dependent variable to distinguish between the short-run and long-run CET export supply elasticities. The export supply elasticity was then estimated using the following equation:

$$\mathrm{Y}_E = \psi_0 + \psi_1 X_E + \psi_2 \mathrm{Y}_{E_{t-1}} + \psi_3 Z + \varepsilon \qquad \text{(Eq. 4. 10)}$$

where $\mathrm{Y}_{E_{t-1}}$ is a one-period lag in the dependent variable, and Z is a dummy variable controlling for trade-distorting factors in South African agriculture. The short-run elasticity is given by $\Omega_{short} = \psi_1$, and long-run elasticities can be calculated using $\Omega_{long} = \frac{\psi_1}{(1-\psi_2)}$, if $0 < \psi_2 < 1$. Both the short-run and long-run export supply elasticities are reported.

4.5.3. Export demand elasticity

The export demand elasticities play a central role in MONASH-style CGE models to determine the effects on export volumes due to relative price changes. Since we used the UPGEM model, export demand elasticity is very critical to model the exports behaviour relative to price changes. The central aim of this section is to find appropriate export demand elasticities for agriculture and food commodities that measures the response in exports for a one percent change in export price. In the UPGEM model, the export price is determined endogenously as a function of purchasers' prices in foreign countries plus tariff and other charges separating South African ports of exit and foreign sites of use. The sensitivity of demand for exports to price changes is controlled by the export demand elasticity. In the original MONASH model for the Australian economy, this elasticity is assigned a value of -4 for agricultural commodities and set to -2 for non-traditional exports (Dixon and Rimmer, 2002). The literature review on export demand elasticities suggests that estimation of this elasticity is rare with few studies from the USA literature that is used to informed trade elasticities in models like the GTAP (Hillberry and Hummels, 2013). Given the scarcity of estimation studies, the researchers relied on the approach used by Tweeten (1967), Johnson (1977) and recently Reimer, Zheng and Gehlhar (2012), where they applied a three-stage method to estimate the foreign demand of major crops in the USA with the main trading partners. In this stud, we adjusted the specifications and data aggregation to estimate export demand elasticity for South Africa facing the world, as a single buyer of South African exports.

This section borrows from Reimer, Zheng, and Gehlhar (2012) in describing the procedure used to estimate the export demand elasticities for individual and aggregate agricultural commodities. However, in this study, the USA price is replaced with the world price faced by South African exports. The modelling framework entails dividing the world into major importing and exporting regions. Let i be an index of importers, $i=1,\ldots,m;$ and j be an index of exporters other than South Africa, $j=1,\ldots,x$. For any given commodity the price is denoted by P_i for importers; P_j for exporters and P_w for world price. Demand in a country is denoted by Q_{di} or Q_{dj} whereas supply is denoted by Q_{si} or Q_s. Let the level of the South African exports to the world be denoted by Q_{ef} which is defined as:

$$Q_{ef} = \sum_i (Q_{di} - Q_{si}) - \sum_j (Q_{sj} - Q_{dj}) \qquad \text{(Eq. 4.11)}$$

To understand the reaction on export demand if international price changes, one can take the derivative with respect to $P_{w.}$ and the following is obtained:

$$\frac{dQ_{ef}}{dP_{SA}} = \sum_{i}\left[\frac{dQ_{di}}{dP_i}\frac{dP_i}{dP_{SA}} - \frac{dQ_{si}}{dP_i}\frac{dP_i}{dP_{SA}}\right] - \sum_{j}\left[\frac{dQ_{sj}}{dP_j}\frac{dP_j}{dP_{SA}} - \frac{dQ_{dj}}{dP_j}\frac{dP_j}{dP_{SA}}\right] \qquad \text{(Eq. 4.12)}$$

Then multiply through and also divide by a number of terms to get:

$$\begin{aligned}\frac{dQ_{ef}}{dP_{SA}}\frac{P_{SA}}{Q_{ef}}Q_{ef} &= \sum_{i}\left[\frac{dP_i}{dP_{SA}}\frac{P_{SA}}{P_i}\left(\frac{dQ_{di}}{dP_i}\frac{P_i}{Q_{di}}Q_{di} - \frac{dQ_{si}}{dP_i}\frac{P_i}{Q_{si}}Q_{si}\right)\right] \\ &- \sum_{j}\left[\frac{dP_j}{dP_{SA}}\frac{P_{SA}}{P_j}\left(\frac{dQ_{sj}}{dP_j}\frac{P_j}{Q_{sj}}Q_{sj} - \frac{dQ_{dj}}{dP_j}\frac{P_j}{Q_{dj}}Q_{dj}\right)\right] \qquad \text{(Eq. 4.13)}\end{aligned}$$

Equation 4.13 allows one to present the derivation in percent changes as follows:

$$\begin{aligned}\frac{dlnQ_{ef}}{dlnP_{SA}} &= \sum_{i}\left[\frac{dlnP_i}{dlnP_{SA}}\left(\frac{dlnQ_{di}}{dlnP_i}\frac{Q_{di}}{Q_{ef}} - \frac{dlnQ_{si}}{dlnP_i}\frac{Q_{si}}{Q_{ef}}\right)\right] \\ &- \sum_{j}\left[\frac{dlnP_j}{dlnP_{SA}}\left(\frac{dlnQ_{sj}}{dlnP_j}\frac{Q_{sj}}{Q_{ef}} - \frac{dlnQ_{dj}}{dlnP_j}\frac{Q_{dj}}{Q_{ef}}\right)\right] \qquad \text{(Eq. 4.14)}\end{aligned}$$

Reimer *et al.* (2012) explained that Equation 4.14 can be expressed in the simplified way which appears in Equation 4.15.

$$E_f = \sum_{i} E_{pi}\left(E_{di}\frac{Q_{di}}{Q_{ef}} - E_{si}\frac{Q_{si}}{Q_{ef}}\right) - \sum_{j} E_{pj}\left(E_{sj}\frac{Q_{sj}}{Q_{ef}} - E_{dj}\frac{Q_{dj}}{Q_{ef}}\right) \qquad \text{(Eq. 4.15)}$$

From Equation 4.14, it is clear that there is no special need to explicitly distinguish importers *(i)* from exporters *(j)*. Then let $i = j$. Equation 4.15 has the simplified version given by Equation 14, which is similar to that applied by Tweeten (1967: 361), and Reimer et al. (2012: 503).

$$E_f = \sum_{i} E_{pi}\left(E_{di}\frac{Q_{di}}{Q_{ef}} - E_{si}\frac{Q_{si}}{Q_{ef}}\right) \qquad \text{(Eq. 4.16)}$$

where if country *i* is an importer, then the term in brackets in Equation 4.16 will be positive because Q_{di} exceeds Q_{si} at a given price. When country *i* is an exporter, the term in brackets will be negative because Q_{si} exceeds Q_{di} at a given price. To summarise all terms in Equation 4.16, E_f is the export demand elasticity facing South Africa; E_{pi} is the price transmission elasticities measuring the percentage change in a country's price associated with a percent change in the international prices. E_{di} *and* E_{si} are the elasticities of domestic demand and supply in country *i*; and Q_{di} and Q_{si} are the

i^{th} country's level of demand and supply; as well as Q_{ef} which is the level of exporting country exports.

The first step in estimating the export demand elasticity for agricultural commodities is to estimate price transmission elasticities (E_{pi}) for individual and aggregate agriculture. This elasticity measures the world price response to South Africa's price changes. To estimate the price transmission, Equation 4.17 is used, which regresses the world price of domestic prices. A trend is also added to allow for the possibility of general changes over time in price variables. Since price transmission elasticities are estimated for use in Equation 4.16 above, which will give export demand elasticities for use in CGE, the researcher distinguishes between short-run and long-run price transmission elasticities. To allow for estimation of short-run and long-rum elasticities, a one-period lag of the domestic price is added on the right-hand side of Equation 4.17 as follows:

$$lnp_i^t = \beta_0 + \beta_1 lnp_i^{t-1} + \beta_2 lnp_{SA}^t + \beta_3 TREND + \varepsilon_i{}^t \qquad \text{(Eq. 4.17)}$$

where p_i^t is the South Africa's domestic price at time t; p_i^{t-1} is one-period lagged domestic price; p_{SA}^t is the local price; *TREND* is an annual time trend *1,2,3…n*; and β_s are parameters to estimate. β_2 represents a short-run price transmission elasticity, and the long-run price transmission elasticity is calculated using $\frac{\beta_2}{(1-\beta_1)}$ if $0 < \beta_1 < 1$; otherwise only short-run elasticities are reported; and the error term is denoted by $\varepsilon_i{}^t$and it is assumed to be independently and identically distributed with mean zero and constant variance. There might be an endogeneity issue in Equation 4.17 because of lagged domestic price. However, Reimer *et al.* (2012: 505) argued that this is offset by the fact that Equation 4.17 is a partial-adjustment model. In this context, the parameters can be consistently and efficiently estimated by ordinary least squares.

The second step in the export demand elasticity estimation procedure is to find the domestic demand (Q_{di}) and supply (Q_{si}) elasticities within the exporting country. In the literature it was found that researchers such as Tweeten (1967) and Johnson (1977) did not estimate the domestic supply elasticities but instead assigned a value of 0.2, based on the work conducted by Heady and Tweeten (1963), on aggregate farm outputs in the USA. This study adopted a longer route and estimated both the aggregates of both rest of the world supply and demand elasticities. To estimate these, the researcher followed the methods applied by Reimer *et al*. (2012: 507). The procedure commences by letting Q_d^t denote consumption of agricultural commodities at time t and Q_s^t denote production of agricultural products at time t. In general, Q_d^t and Q_s^t will be different from each other as a result of international trade, thus $Q_d^t \neq Q_s^t$. Equations 4.18 and 4.19 represent equations used to calculate domestic demand and supply elasticities respectively.

$$lnQ_d^t = \delta_0 + \delta_1 lnp_d^t + \sum_{j=2}^{m} \delta_j lnY_j^t + \varepsilon^t \ \ (demand) \qquad \text{(Eq. 4.18)}$$

$$lnQ_s^t = \alpha_0 + \alpha_1 lnQ_s^{t-1} + \alpha_2 lnp_s^{t-1} + \sum_{j=3}^{n} \alpha_j lnZ_j^{t-1} + \mu^t \ \ (supply) \qquad \text{(Eq. 4.19)}$$

where p_d^t denotes the price of a representative buyer in year t; p_s^{t-1} is a one-period lag producer price expectation; δ_s and α_s are parameters to be estimated; Y_j^t is demand shifters such as the prices of substitutes, income, and populations; and Z_j^{t-1} is (lagged) supply shifters such as prices of alternative commodities to produce. In the demand Equation 4.18, δ_1 corresponds to the elasticity of domestic demand and it is expected to be negative. In the supply Equation 4.19, α_2 is the short-run elasticity of supply response to last period's price changes. The long-run transmission elasticity is calculated using $\frac{\alpha_2}{(1-\alpha_1)}$ if $0 < \alpha_1 < 1$; otherwise only short-run estimates are reported. Once the price transmission elasticity and the domestic demand and supply elasticities of the exporting country have been estimated, then the estimates are used to calibrate Equation 4.16 to calculate the export demand elasticity of South African agricultural products.

4.6. Results and discussions

4.6.1. Armington elasticity results

Using Equation 4.5 described above, the Armington elasticity results for the South African individual and aggregate agricultural commodities are presented in Table 4.3. Firstly, all the estimated elasticities show the expected positive sign, which implies that Equation 4.5 yielded the correct results. Secondly, most estimated elasticities are statistically significant at least at 95 percent confidence level, suggesting a good model fit; in other words, the model results are explained by the selected explanatory variables. In addition, the long-run elasticities for all products are found to be more elastic than the short-run estimates and significantly different from unity, which implies that agricultural imports are imperfect substitutes for domestic goods.

The measured short-run Armington elasticity for maize is 0.868, which can be interpreted as the level at which the maize industry substitutes imported goods with domestically produced goods if the price of the imported good increases by one percent relative to the price of the domestic good.

The long-run elasticity for maize products is 2.399, which is more elastic, indicating the high sensitivity of maize imports to relative price changes. Both the short- and long-run Armington elasticities for grain products are highly elastic, suggesting that grain imports are the most sensitive to relative price changes. Following grain products are processed food and meat products, indicating that they are also sensitive imports. Fruits and vegetables, with the exception of grapes and tomatoes, have inelastic import demand, implying their imports are less sensitive to price changes.

Table 4.3: CES Armington elasticities for individual and aggregate agricultural products

Sub-sector	Commodities	HS code	Armington elasticity		Dummy	GDP	R-square
			Short-run	Long-run			
Grains	Maize	1005	0.868*** (0.221)	2.399*** (0.119)	0.101 (0.087)	1.650 (2.403)	0.36
	Wheat	1001	0.98*** (0.268)	1.648*** (0.151)	0.189*** (0.055)	1.936 (1.548)	0.69
	Sorghum	1007	1.818*** (0.425)	2.171*** (0.138)	-0.250 (0.203)	-0.316 (4.223)	0.71
Fruits	Apples	080810	0.506*** (0.157)	0.604** (0.1468)	-0.017 (0.090)	-3.013 (2.506)	0.51
	Grapes	080610	0.717*** (0.203)	0.730 (0.166)	-0.009* (0.040)	-0.156 (1.114)	0.53
	Oranges	080510	0.245* (0.143)	0.252 (0.113)	0.031 (0.036)	-0.367 (0.729)	0.57
	Avocados	080440	0.270*** (0.107)	0.509* (0.138)	-0.006 (0.042)	-0.090 (1.162)	0.41
Vegetables	Potatoes	0701	0.430* (0.271)	0.522 (0.181)	-0.234*** (0.08)	-0.318 (2.237)	0.53
	Tomatoes	0702	0.761** (0.319)	0.810** (0.329)	-0.021 (0.1229)	-2.048 (3.456)	0.42
Meat	Beef	0201-2	0.911* (0.626)	1.306** (0.169)	-0.014 (0.062)	-1.391 (1.482)	0.32
	Poultry	0207	0.282** (0.030)	0.301 (0.173)	-0.006 (0.028)	-0.263 (0.318)	0.38
	Swine	0203	0.669* (0.512)	0.909** (0.165)	-0.004 (0.048)	-0.487 (0.467)	0.29
Processed	Milk	0401	0.415* (1.020)	0.506 (0.174)	0.273 (0.248)	1.950 (5.223)	0.27
	Wine	2204	1.971*** (0.176)	2.165** (0.083)	-0.009 (0.621)	-0.243 (0.533)	0.89

	Sugar	1701	0.817** (0.388)	1.140*** (0.155)	0.078 (0.059)	-0.030 (0.161)	0.39
Aggregated	Agriculture		0.329*** (0.038)	0.376 (0.172)	0.027** (0.012)	-0.623 (1.687)	0.62

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Looking at Table 4.3 above, the short-run results show that, when measuring the elasticities at the level of individual agricultural commodities, they are more elastic relative to the elasticities of an aggregated agricultural product. For example, the short-run elasticity for aggregated agricultural products is 0.329, while for an individual product such as sorghum it is 1.818. For beef, it is 0.911 and for grapes, it is 0.717. This suggests that individual imports are more sensitive to price changes as compared to aggregate agricultural imports.

The dummy variable was found to be statistically insignificant for the majority of individual products, except for wheat, grapes, and potatoes, as well as aggregate agriculture. This suggests that market deregulation and trade opening has had an effect on aggregate agriculture as well as on wheat, grapes and potato products. The abolishment of marketing control boards and the removal of tariff quotas and other trade distortionary measures led to an increase in trade for agriculture, hence the dummy variable is found to be statistically significant for aggregate agriculture. The real GDP variable, which captures the demand pressures on economic activities, is found to be statistically insignificant for all products. This can be attributed to the fact that agriculture contributes a relatively low share to total GDP in the country, measured at 2.5 percent in 2016 (DAFF, 2018). This means that the growth in real GDP is largely driven by other sectors and less so by agricultural products, hence the statistically insignificant results found for real GDP.

The Armington elasticities presented in Table 4.3 above are slightly lower than, but comparable with, the results obtained in the local literature. For example, Ogundeji *et al.* (2010) found short-run elasticities ranging between 0.79 and 3.47 but applied quarterly data series. The reason for the lower estimates found in this paper in comparison to previous studies could be that the researcher used annual data series, which tends to yield estimates that are closer to unity. Most importantly, the results shown in Table 4.3 above indicate that there are no outliers, which is a confidence booster for researchers who will use these elasticities to advance policy analysis and CGE modelling.

4.6.2. Export supply elasticity results

Using Equation 4.10 above, the short- and long-run results of CET export supply elasticities for South Africa's individual and aggregate agricultural commodities are presented in Table 4.4. The short-run estimates range from 0.005 in the case of apples to 1.219 in the case of poultry products. Similar to the Armington elasticities, grain products show relatively high elasticities, whereas fruits have inelastic CET export supply elasticities. For example, products such as sorghum and wheat have short-run elasticities of 1.108 and 0.995 respectively, suggesting that the domestic production of grain products is very responsive to annual price changes. The long-run elasticities for grains are even higher, ranging from 0.536 for maize to 1.799 for wheat. This indicates ease in transforming grain production that is destined for export markets versus domestic markets relative to changes in export prices. The low export supply elasticities for fruit products suggest that the response of fruit quantities to relative price changes is rather sluggish.

Table 4.4: CET export supply elasticities for individual and aggregate agricultural products

Sub-sector	Commodities	HS code	Export supply elasticity		Dummy	R-square
			Short-run	Long-run		
Grains	Maize	1005	0.491*** (0.183)	0.536*** (0.154)	-0.094*** (0.03)	0.57
	Wheat	1001	0.995*** (0.470)	1.707*** (0.156)	0.191*** (0.105)	0.57
	Sorghum	1007	1.108*** (0.406)	1.799** (0.172)	-0.106 (0.122)	0.61
Fruits	Apples	080810	0.005 (0.012)	0.013 (0.152)	0.007 (0.007)	0.52
	Grapes	080610	0.139*** (0.036)	0.143 (0.153)	-0.001 (0.736)	0.23
	Oranges	080510	0.028*** (0.099)	0.047 (0.169)	0.008 (0.0006)	0.38
	Avocados	080440	0.412*** (0.179)	0.685*** (0.148)	0.004 (0.010)	0.57
Vegetables	Potatoes	0701	0.279* (0.158)	0.360** (0.170)	0.007 (0.023)	0.39
	Tomatoes	0702	0.518*** (0.188)	1.064*** (0.080)	0.264 (0.053)	0.89
Meat	Beef	0201-2	0.497* (0.315)	0.505 (0.174)	-0.006 (0.028)	0.32
	Poultry	0207	1.219*** (0.428)	1.657*** (0.156)	-0.007 (0.028)	0.23
	Swine	0203	0.796** (0.664)	0.973** (0.172)	0.031 (0.040)	0.24

Processed	Milk	0401	0.849** (1.029)	1.213* (0.170)	0.051** (0.09)	0.42
	Wine	2204	1.039*** (0.576)	1.274** (0.166)	-0.006 (0.021)	0.37
	Sugar	1701	0.276* (0.174)	0.334*** (0.164)	0.083 (0.057)	0.49
Aggregated	Agriculture		0.450** (0.169)	0.634 (0.164)	0.135 (0.013)	0.53

Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The dummy variable for the majority of products, except for milk, maize and wheat, was found to be statistically insignificant. This suggests that the trade and market reforms adopted in South Africa post-1994 have had a limited impact in changing the production structure of many agricultural products. This could be attributed to the fact that South Africa's agricultural products have always been an export-oriented sector. However, the market and trade reforms assisted the sector to access new export markets post-1994. As was noted with the Armington elasticity for aggregate agriculture, the export supply elasticity for aggregate agriculture is lower than the majority of elasticities for individual agricultural products, implying the resistance of aggregate agricultural quantities to respond to changes in prices, keeping all other factors constant. Similarly, the long-run elasticities of all individual products, on average, are higher than the short-run elasticities. The results presented in Table 4.4 above provide the first econometrically estimated export supply elasticities for South Africa's agricultural products, and this will assist CGE modellers to use correct and reliable elasticities in their models.

4.6.3. Export demand elasticity results

In pursuit of estimating all variables required in Equation 4.16, price transmission elasticity results are presented in Table 4.5. The results are consistent with a priory expectation that the price transmissions for individual and aggregate agricultural commodities are significantly different from zero and unity. The short-run price transmission elasticities range from 0.137 in the case of swine to 0.485 in the case of sorghum products, whereas for aggregate agriculture it is 0.264. Similar, to other sets of trade elasticities, discussed earlier, the long-run price transmission elasticities are on average higher than short-run price transmission elasticities. This implies that in the long run, the price transmission from international to domestic prices tend to be stronger than in the short run.

It is evident from the results in Table 4.5 that the majority of price transmission elasticities are found to be statistically significant with the exception of avocadoes and potato products. The simple interpretation for the estimated price transmission elasticity, such as in the case of apples, is that a one percent increase in the international price of apples causes a 0.183 increase in the local price of apple in the short run, keeping all other factors constant. In general, the South Africa's price transmissions to the rest of the world are inelastic and imperfect because indicating that South Africa has limited influence on rest of the world prices.

Equation 4.16 also requires the estimation of domestic demand and supply elasticities for the individual and aggregate agricultural commodities. Using Equations 4.18 and 4.19 discussed earlier, the results are also included in Table 4.5. To interpret the results such as in the case of sugar products, the demand elasticity is -0.178, which implies that a one percent increase in the rest of the world price is associated with a 0.178 percent decline in the consumption of sugar products. The rest of the world demand elasticities vary from -0.038 for wheat to -1.248 for apple products. This suggests that the demand for staple food such as grains and vegetables is highly inelastic while the rest of the world demand for non-staple food like apples is relatively elastic in the country.

On the other hand, the short-run rest of the world supply elasticities for all the individual agricultural products ranges from 0.149 for wheat to 0.356 for sugar, suggesting that the price elasticity for food is inelastic. The long-run rest of the world supply elasticities are slightly higher than in the short run, implying that the rest of the world supply is more responsive to long-run price changes. At this point all the key parameters in Equation 4.16 have been estimated except for ratios of production and consumption, that is $\frac{Q_{di}}{Q_{ef}}\ and\ \frac{Q_{si}}{Q_{ef}}$. The ratios are easily obtained from world trade flow and consumption data taken from the data sources discussed in Section 4.4 above. Following the estimation of quantity ratios, the short-run and long-run export demand elasticities for individual and aggregate agricultural products are estimated and the results are also included in Table 4.5.

Table 4.5: Price transmission, domestic demand and supply, and export demand elasticities

Sub-sectors	Product	HS Code	Price Transmission		Domestic Elasticities			Export Demand	
			Short-run	Long-run	Demand	Supply		Short-run	Long-run
						Short-run	Long-run		
Grains	Maize	1005	0.240** (0.277)	0.279* (0.233)	-0.161* (0.043)	0.286* (0.351)	0.381* (0.201)	-2.240	-2.911
	Wheat	1001	0.428*** (0.154)	0.526* (0.174)	-0.038** (0.076)	0.149 (0.296)	0.206 (0.174)	-3.233	-4.422
	Sorghum	1007	0.485* (0.322)	0.623** (0.178)	-0.388** (0.160)	0.283** (0.284)	0.372** (0.164)	-3.117	-4.054

Fruits	Apples	080810	0.183* (0.078)	0.271* (0.178)	-1.248** (0.625)	0.188** (0.302)	0.265*** (0.158)	-3.392	-4.960
	Grapes	080610	0.152* (0.107)	0.186** (0.164)	-0.257 (0.221)	0.283** (0.145)	0.389* (0.163)	-3.683	-4.973
	Oranges	080510	0.322** (0.135)	0.372** (0.174)	-0.398* (0.596)	0.264 (0.267)	0.314 (0.198)	-3.245	-3.801
	Avocados	080440	0.140 (0.145)	0.142* (0.183)	-0.317*** (0.223)	0.296* (0.452)	0.521** (0.184)	-2.808	-4.339
Vegetables	Potatoes	0701	0.169 (0.136)	0.342*** (0.163)	-0.224** (0.067)	0.210** (0.178)	0.256 (0.045)	-1.628	-2.239
	Tomatoes	0702	0.226** (0.110)	0.266* (0.164)	-0.203 (0.196)	0.205** (0.088)	0.421*** (0.130)	-2.255	-4.268
Meat	Beef	0201-2	0.194* (0.134)	0.214** (0.168)	-0.166 (0.138)	0.298 (0.144)	0.322** (0.179)	-1.801	-1.955
	Poultry	0207	0.228*** (0.149)	0.235* (0.167)	-0.161 (0.091)	0.205** (0.107)	0.469*** (0.141)	-1.460	-3.001
	Swine	0203	0.137*** (0.130)	0.221** (0.161)	-0.179* (0.111)	0.188* (0.121)	0.196 (0.188)	-1.653	-1.917
Processed	Milk	0401	0.221** (0.101)	0.225 (0.163)	-0.193 (0.173)	0.173 (0.138)	0.226* (0.178)	-3.075	-3.778
	Wine	2204	0.129* (0.117)	0.142*** (0.006)	-0.128** (0.114)	0.191* (0.116)	0.223 (0.174)	-2.180	-2.522
	Sugar	1701	0.146** (0.240)	0.168** (0.046)	-0.178** (0.364)	0.356** (0.277)	0.415** (0.167)	-3.403	-3.965
Aggregate	Agriculture		0.264** (0.030)	0.287* (0.163)	-0.087* (0.07)	0.278* (0.10)	0.347** (1.693)	-2.610	-3.604

Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1

As in the case of the CET export supply elasticities discussed earlier, this section provides the first attempt in the South African context to determine the export demand elasticities for the individual and aggregate agricultural and food commodities using econometric methods. The short-run export demand elasticity for the aggregate agricultural product is measured at -2.61 which can be interpreted as a one percent change in export price causing a 2.61 percent response in aggregate agricultural exports, keeping all other factors constant. The long-run export demand elasticity for aggregate agriculture is measured at -3.604 which indicates that export volumes are more sensitive to price changes in the long run. Again, the long-run export demand elasticities are more elastic than short-run elasticities across all agricultural products. South African studies often use estimates from -1.5 to -4 for the agricultural sector in economic models (Bohlmann *et al.*, 2015). From the results in Table 4.5 it is clear that the estimated short-run export demand elasticities are within this range, but the long-run elasticities for some products such as wheat, sorghum, apples, grapes, avocados and tomatoes are slightly above the upper boundary of -4 elasticity.

The higher agricultural export demand elasticities can be explained by the fact that South Africa is a small and open economy relative to other countries in the world. This means that the country's exporters are price takers in the international market, thus being sensitive to international price changes. The results show that grain and fruit exports are the most sensitive to changes in international prices, whereas meat has the lowest elasticities – both short-run and long-run elasticities. South Africa is known to produce and export high-quality meat products; however, meat products tend to face stringent quality and safety standards in the international markets which limit the country's potential to export meat. As a result, South Africa's meat exports are mainly destined for niche markets and this could be the reason for slightly lower export demand elasticities for meat products.

When it comes to grains, South Africa's maize and sorghum exports are largely destined for SADC markets where they face competition from other SADC producers. This is partly the reason why grain products have high elasticities as compared to aggregate agricultural products. Horticultural exports also show higher elasticities ranging from -3.801 for avocados to 4.973 for grapes in the long run. These highly elastic elasticities suggest that South Africa's fruit exports face strong competition in the world market due to the availability of substitutes from South Africa's competitors in the international market. The strong competition implies that South African fruit products can easily be substituted in the international market, hence very high elasticities are obtained. The elasticities differ significantly across different agricultural commodities, which indicates that agricultural industries are not homogenous and will be affected differently by policy changes.

4.7. Conclusion

This chapter provided an update on the Armington elasticities for expanded agricultural commodities covering grains, fruits, vegetables, meat, and processed food products. The short-run Armington elasticities for agricultural products ranged from 0.245 for oranges to 1.971 for wine products and estimated at 0.329 for aggregate agricultural products. The short-run export supply elasticities were found to range from 0.005 in the case of apples to 1.219 in the case of poultry product and for aggregate agriculture was measured at 0.450. In terms of short-run export demand elasticities, they ranged between -1.460 for poultry to -3.683 for grape products and for aggregate agriculture was estimated at -2.61. Across all three sets of trade elasticities, the long-run estimates were found to be more elastic than short-run estimates, suggesting that in the long run the quantity demanded tends to be more responsive to price changes.

The results for all three sets of trade elasticities demonstrate that at an individual product level, commodities are more sensitive to changes in international prices than at aggregated product level. This shows that there was merit in estimating the elasticities at both aggregate and individual product level. The availability of estimates for individual and aggregate agricultural products will enable researchers, particularly CGE modellers, to conduct policy modelling and analysis at a detailed product level. More importantly, the researcher made the first attempt in the agricultural sector to estimate the export supply and export demand elasticities using econometric methods instead of relying on value judgment derived from the literature. As a result, this chapter has provided good insight into the appropriate elasticities that should be used in CGE models to analyse policy changes. The trade elasticity values estimated in this study are anticipated to assist researchers to improve the specification of CGE models by using reliable and updated estimates.

CHAPTER FIVE
SIMULATION RESULTS AND DISCUSSIONS

5.1 Introduction

The results of the simulations are presented in three sections. The first section discusses the macro results which reflect the expected impacts of the carbon tax policy on macroeconomic indicators such as the real GDP growth, aggregate GHG emissions, aggregate employment, and investments relative to the baseline. The second section presents the disaggregated industry results focusing on the winners and losers under each policy scenario. The third section provides a sensitivity analysis of the results on the estimated trade elasticities and different recycling schemes on the economy. The results presented in the following sections are shown in a graphical format but they are also presented in Table C.5.1 and C5.2 in Appendix B.

5.2 Macroeconomic results

The first important result to discuss is the impact of accounting for technology improvement in the baseline of the non-coal electricity industry. Allowing for technology improvement in the non-coal electricity industry, in line with the IEA's (2017) forecasted changes, leads to relatively higher investments due to efficiency gains in the non-coal electricity industry relative to the coal electricity industry. Subsequently, the output of the non-coal electricity industry grows by 126 percent relative to the base year by 2035, if technology improvement is allowed (Figure 5.1). The output growth is nearly double compared to the output level achieved when there are no technology changes.

From Figure 5.1, it is evident that if no technology improvements are allowed, the non-coal electricity output increases by 79.2 percent which is in line with the real GDP growth under the baseline scenario. The allowance of technology changes reduces the capital costs of establishing a non-coal generation plant relative to a coal generation plant, subsequently reducing the quantity of emissions emitted from the economy. This growth in non-coal electricity output, if changes in technology innovations is allowed, is comparable with international expectations that forecast a high growth in the output of non-coal electricity in the next decades. The positive effects of technology changes on the output of the non-coal electricity industry suggest that it can be able to cope with expected demand growth for non-coal electricity as the country shifts away from coal electricity to mitigate emissions. The changes in the baseline presented in Figure 5.1 do not account for the direct costs associated with the adoption of technology which was exogenously imposed.

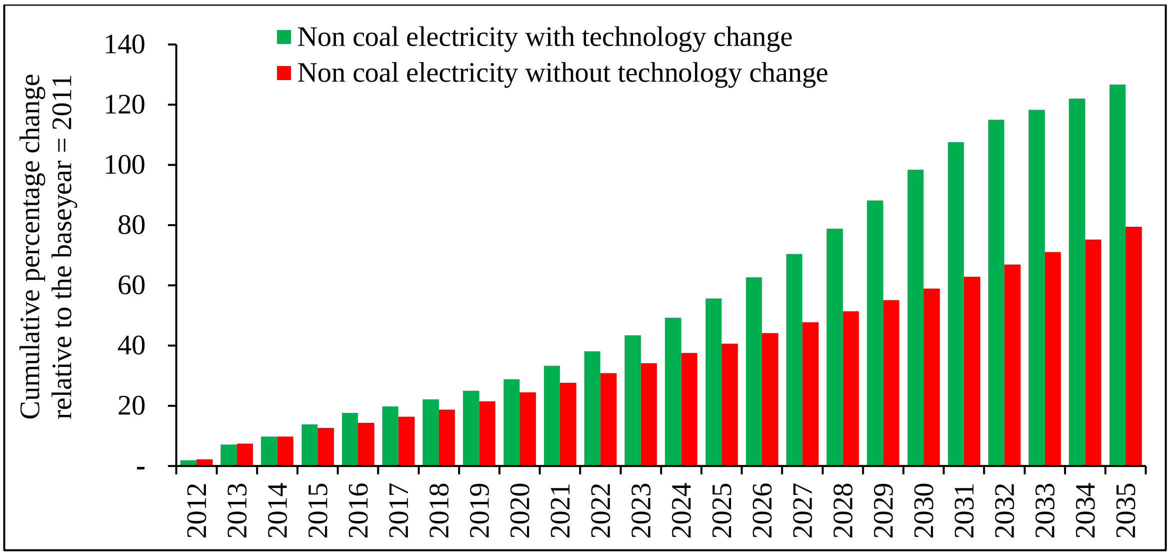

Figure 5.1: Expected impact of technology improvements on non-coal electricity output

The next step is to discuss the results on the macroeconomic indicators. The implementation of a carbon charge of R120/tCO_2-eq on fuel use leads to a high reduction of emissions in the country. From Figure 5.2, the GHG emissions decline by 32.9 percent under the Focus policy scenario which mirrors the policy designs as prescribed in the carbon tax bill of 2017. The emissions decline obtained in this study is lower than the 38.3 percent found by previous studies such as Van Herdeen *et al.* (2016). The main reason for this deviation is the allowance made for technological changes in the baseline of the non-coal electricity industry which reduces the amount of emissions the country is producing prior to introducing the carbon tax. Moreover, there are additional tax-free allowances that have been added in the latest policy bill which ease the tax burden on industries. As a result, the reduction from the baseline after introducing the carbon tax is narrowed as compared to bigger deviations found in the previous studies in the country.

Furthermore, Figure 5.2 shows that under the Allowance Removed policy scenario, emissions can be reduced to 45.4 percent relative to the baseline if the government gradually removes the tax-free allowances currently included in the policy bill. Both the Allowance Removed and No Revenue Recycling policy scenarios indicate the sensitivity of emissions results to policy designs. This suggests that the manner in which tax-free allowances are removed and the treatment of tax revenue will have a higher impact on the reduction of emissions in the country. It is important to note that the carbon tax policy alone under the current design (i.e. Focus policy scenario) is not sufficient to meet the country’s emissions reduction targets made under the Paris Climate Agreement. This is because carbon tax leads to 32.9 percent only by 2035 while the country committed to reach 42 percent reduction in emissions by 2025 under its Paris Agreement.

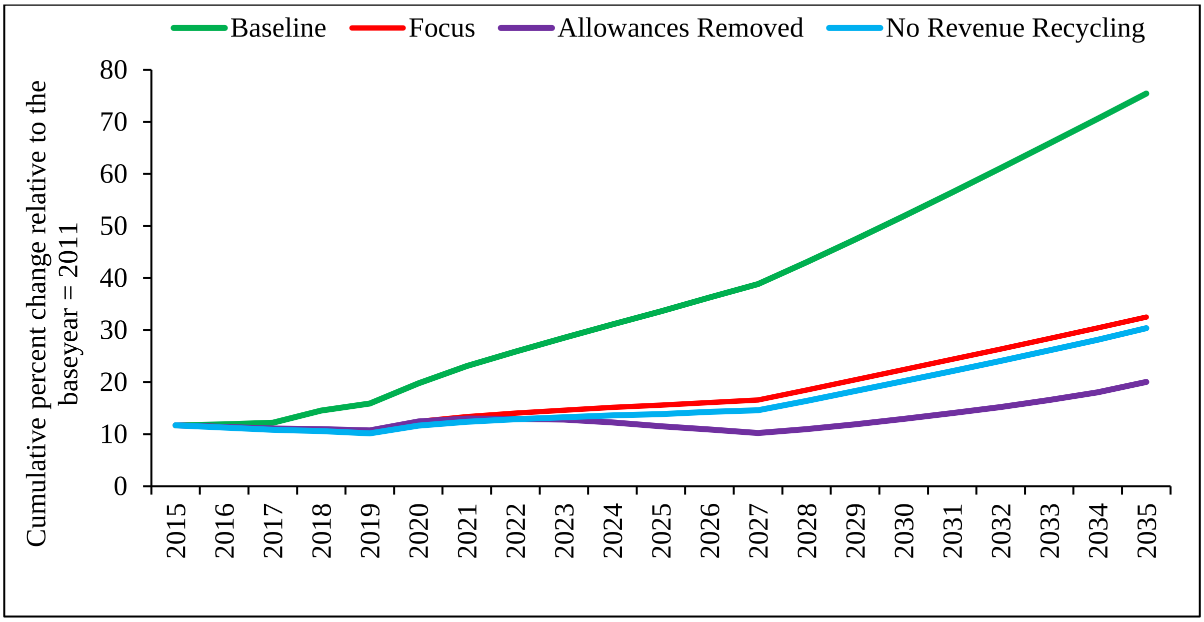

Figure 5.2: Expected impact of the carbon tax policy on the country's GHG emissions

The expected policy effects on the real GDP growth are presented in Figure 5.3. It is evident that the implementation of the carbon tax will lead to welfare loss, reducing the real GDP by 0.91 percent below to the baseline under the Focus scenario. The main factors contributing to real GDP decline are disinvestments in coal electricity and other higher emitting industries, dwindling household consumption and increasing imports into the country. The growing imports when the carbon tax is implemented are caused by diminishing competitiveness in the country over the short to medium term, as the economy adjusts to a low-carbon economy. This implies that the country will incur some adjustment cost when it transforms into a low carbon economy.

When evaluating the policy effects on real GDP under different policy assumptions, it is evident from Figure 5.3 that if tax-free allowances are removed at a 10 percent rate from 2021 onwards, the real GDP declines by 3.84 percent relative to the baseline. But if the government does not recycle the revenues back into the economy, the GDP is reduced by 2.07 percent below the baseline. The results imply that the amount of the adjustment cost (i.e. welfare loss) the country will incur to transform into a low-carbon economy largely depends on the manner in which government will treat the tax-free allowances, as well as the recycling of the revenue.

The results presented in Figure 5.2 and Figure 5.3 illustrate that the current carbon tax policy will have a minimal impact (approximately 0.91 declines in GDP under Focus policy scenario) on the economy whilst reducing emissions by nearly 33 percent below the baseline by 2035. This adjustment cost to a low-carbon economy is lower compared to that found by previous studies like Alton *et al.* (2014) and Van Heerden *et al.* (2016). This can be attributed to technological changes in the baseline of the non-coal electricity industry considered in this study as well as additional tax-free allowances which were not accounted for by the previous studies. A 0.91 percentage decline in real GDP relative to the baseline can be argued to be a minimal adjustment cost necessary to achieve a bigger goal of preserving the environment for both the current and future generations of the country and the world at large.

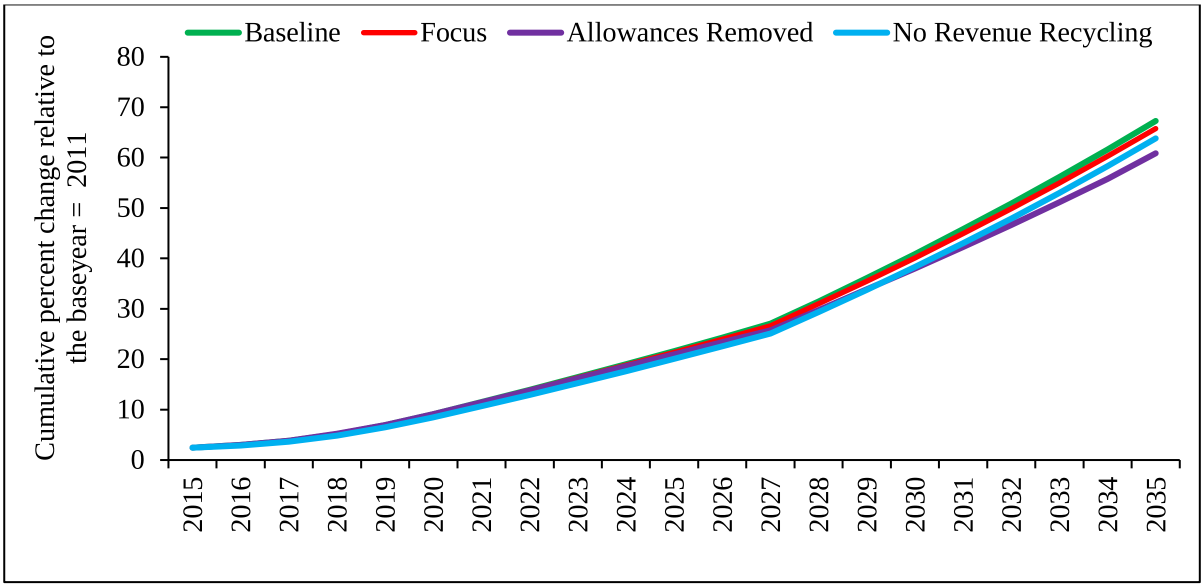

Figure 5.3: Expected impact of the carbon tax policy on real economic (GDP) growth

Arndt *et al.* (2013) found that green energy industries such as the non-coal electricity industry in South Africa will create jobs but not at the same intensity as the fossil-related sectors like the mining and coal electricity industries, at least in the short to medium term. The expected policy impacts on aggregate employment are presented in Figure 5.4, somehow confirming the finding of Arndt *et al.* (2013), that greening the economy will likely lead to job losses at the national level. The researcher found that aggregate employment will decline by 0.62 percent relative to the baseline when the carbon tax policy is implemented. This suggests that there will be employment losses when the economy transform towards less carbon-intensive industries because they create fewer job opportunities. The main industries contributing to job losses are coal mining and coal-generated electricity, steel and metal, as well as petroleum and transport services. While these industries are losing jobs relative to their baseline, others such as non-coal electricity and agriculture are gaining employment relative to their baseline. Important to note is that the employment losses will be small at a national level, indicating that the labour market will not be significantly affected by the introduction of the carbon tax in the country.

While the aggregate employment will be minimally affected with the introduction of the carbon tax at a national level, however, there will be substantial effects on regional employment. Recently, Bohlmann, Horridge, Inglesi-Lotz, Roos, and Stander (2018) assessed the regional impacts of changes in the country electricity mix. They found that semi-skilled workers in regions like the Mpumalanga province will be significantly and negatively affected while regions like the Northern Cape and Eastern Cape will experience employment gains. This is because Mpumalanga's employment is dominated by coal mining and coal generated electricity whereas Northern Cape has a large potential for renewable energy such as solar power. They found that skills from coal industries in Mpumalanga cannot be directly absorbed by new industries because they need new training and other policy interventions.

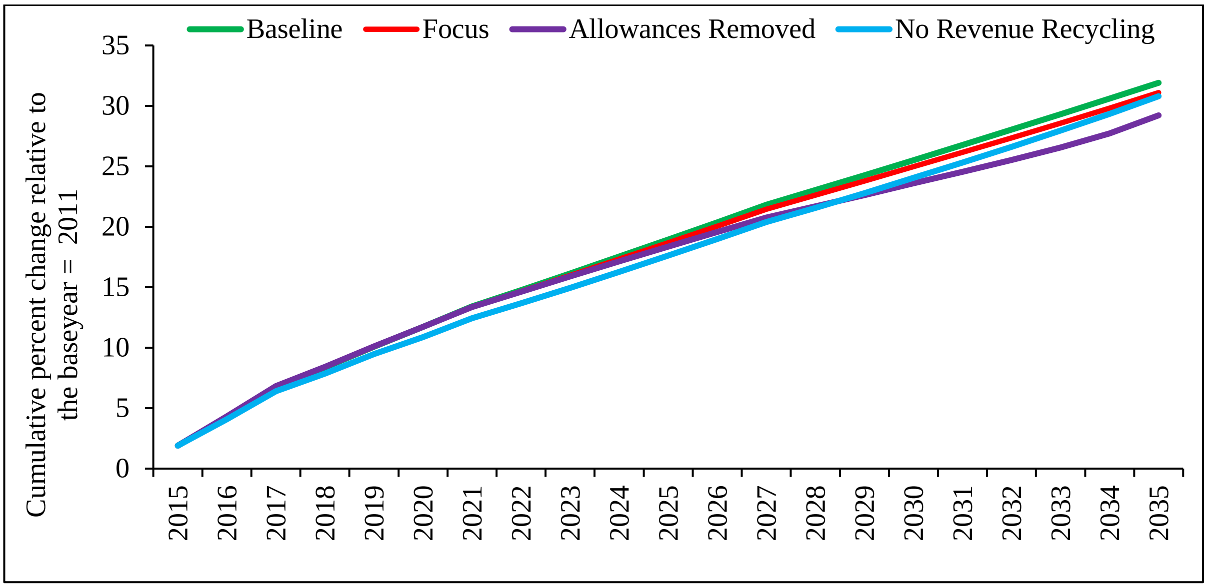

Figure 5.4: Expected impact of the carbon tax policy on aggregate employment

Figure 5.5 indicates the expected policy effect on aggregate investment in the country caused by the implementation of the carbon tax policy. In line with GDP impacts, the effects on investment will reduce by 1.83 percent relative to the baseline in the Focus scenario. This is due to disinvestments expected to occur mainly in the coal mining and coal-generated electricity industries, as well as in the metal and steel industries. These industries are the biggest emitters of emissions and would suffer the most when the carbon tax is implemented. Again, the impact of the carbon tax becomes higher when tax-free allowances are removed, implying that the support that government will give to industries to cope with structural adjustments from fossil energy reliance to clean energy will play a key role in how the economy will perform. When tax-free allowances are removed, aggregate investments reduce by 7.31 percent relative to the baseline by 2035.

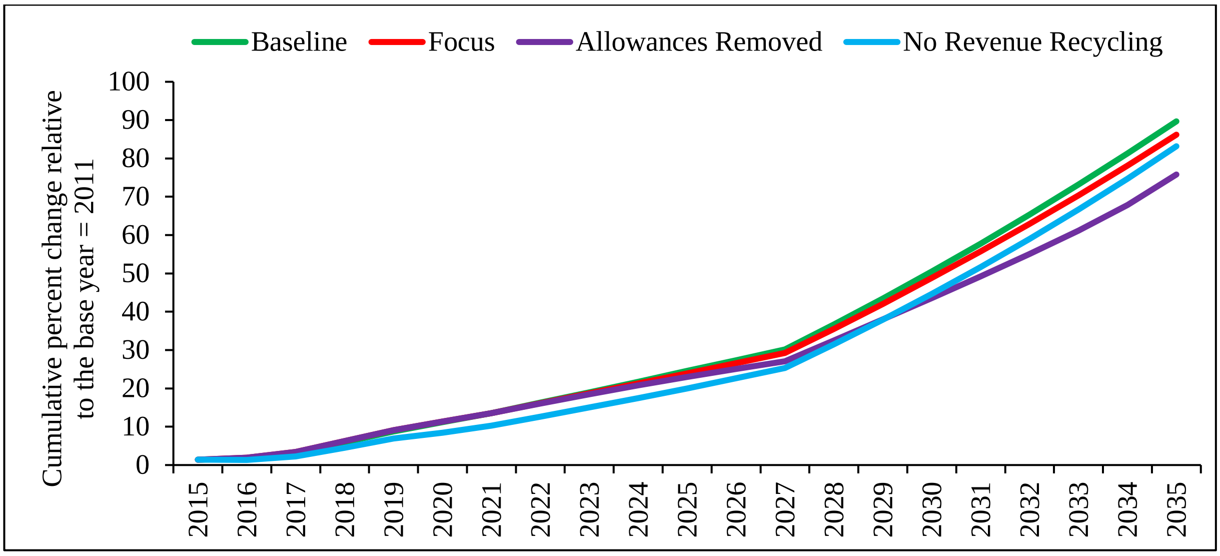

Figure 5.5: Expected impact of the carbon tax policy on aggregate investments

The macro results indicate that the carbon tax policy will assist in reducing the GHG emissions in the country. However, it will lead to a minimal welfare loss driven by a decline in aggregate investments, employment and other GDP components such as household consumption. Despite the expected minimum decline in the real GDP, the ability of the carbon tax to reduce GHG emissions by nearly 33 percent relative to the baseline is critical in helping the country achieve its commitments made under the Paris Climate Agreement. The next section discusses the disaggregated results focusing on the effects of the carbon tax on the agricultural, food and other economic sectors in the country.

5.3 Sectoral results

The industrial results assist in understanding the effects of the policy changes on the individual industries, thereby identifying the winners and losers of a policy change. Starting with the industry output presented in Figure 5.6 and Figure 5.7, the main difference between the two figures is that Figure 5.6 presents the impacts of a policy change on the individual agricultural and food industries as simulated under a Focus policy scenario whereas Figure 5.7 presents a long-run policy impacts on all industries' output by 2035. In addition, Figure 5.7 provides sensitivity-of-output results in different policy assumptions.

The results presented in Figure 5.6 indicate that the expected policy impacts on both the agricultural (i.e. field crops, horticulture, livestock, forestry, and fisheries) and food (i.e. meat, cereals, sugar, dairy and beverages) industries will be minimal but positive over the modelled period that goes to 2035. At an individual industry level, beverages, dairy and meat products are the biggest winners when the carbon tax policy is implemented. This is contrary to the findings obtained in previous studies such as Patridge *et al*. (2015) which found a production decline of up to 9.3 percent relative to the baseline on food starches and dairy products. The main reason for the positive policy effect on the agricultural and food industries found in this study is that allowances were made for tax-free exemptions, and revenue recycling schemes, which limit both the direct and indirect effects on the agricultural and food industries. These were not considered by previous studies, hence they found large and negative impacts on the agricultural industry.

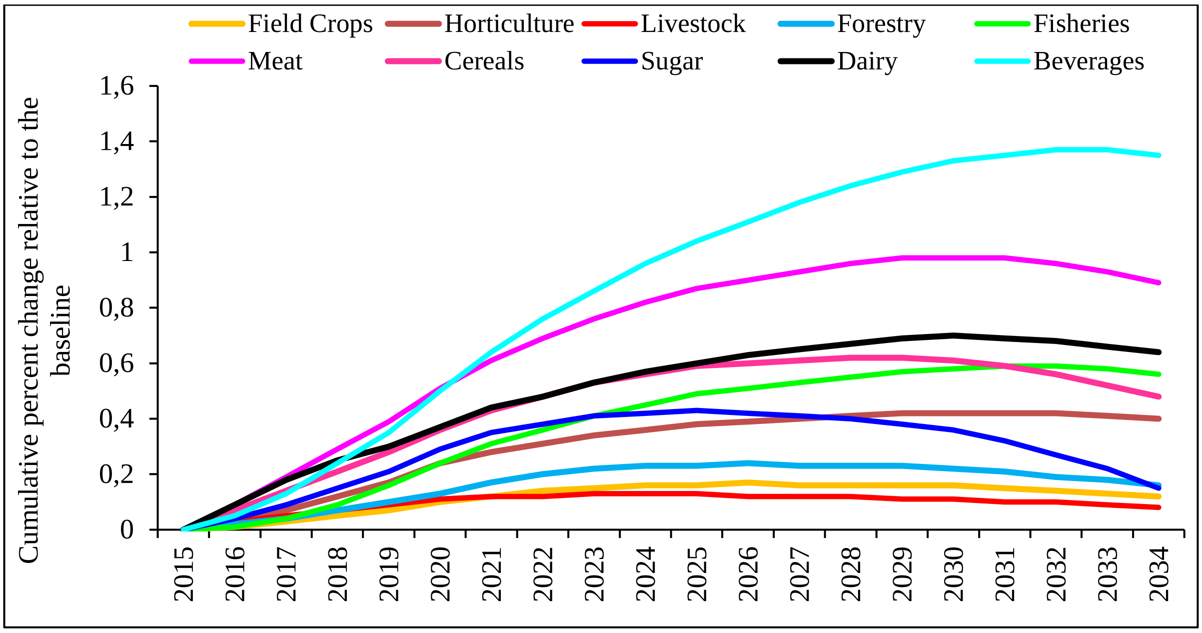

Figure 5.6: Expected impacts on individual agricultural and food industries' output

To understand the potential impact of not accounting for tax-free allowances and revenue recycling schemes, the expected impacts are presented in Figure 5.7. It is evident that the biggest winners are those industries with low levels of GHG emissions, that is, the non-coal electricity and business industries. Furthermore, the results presented in Figure 5.7 clearly show that when the South African government decides to implement the carbon tax policy without tax-free allowances and a revenue recycling scheme, the impact on different industries' output would be significant and negative, with the exception of the non-coal electricity industry. If the tax-free allowances are removed, the long-run impact on the individual agricultural and food industries' output becomes negative and this negative effect persists when the revenue recycling scheme is also removed. Other industries that are expected to experience output decline relative to the baseline in the long run when the carbon tax is implemented are the coal electricity, petroleum, steel and transport industries. The average long-run impact on these industries is measured at a 34 percent decline in output relative to the baseline by 2035.

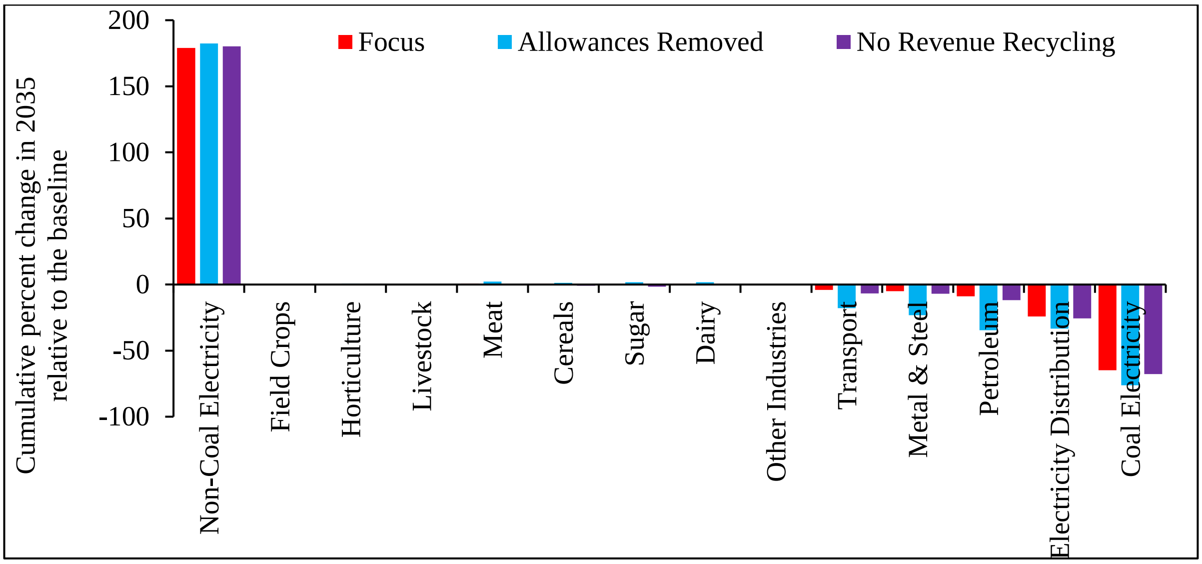

Figure 5.7: Expected long-term policy impact on all industries' output by 2035

The next sectoral results to be discussed pertain to the expected policy impacts on the individual agricultural and food industries' investment as well as on all industries which are provided in Figure 5.8 and Figure 5.9 respectively. On average, the long-run impact on investments in agriculture decline by 0.05 percent, led by field crops and livestock, whereas food is reduced by 0.47 percent, driven by the sugar, meat and dairy industries, by 2035 relative to the baseline. It is evident that the agricultural and food industries' investment is less affected, increasing slightly in the short run and then starting to decline over the long run (Figure 5.8).

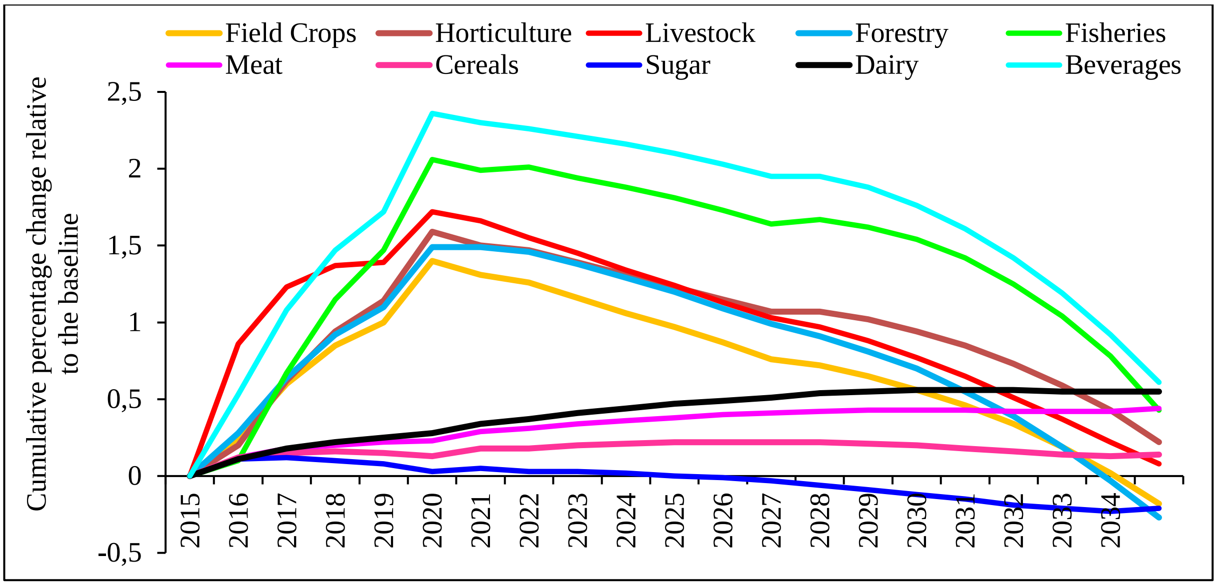

Figure 5.8: Expected impacts on individual agricultural and food industries' investment

In the database, the non-coal electricity industry has a capital/labour ratio of 3:1, implying it is a capital-intensive industry relative to the coal electricity industry. By assuming a technology improvement in the baseline of the non-coal electricity, it improves the competitiveness of this industry, which subsequently attracts higher investment in this industry relative to coal electricity. This is reflected in the investment results presented in Figure 5.9, which indicates the long-run policy impacts on all industries' investment by 2035. The non-coal electricity industry attracts the most investors as investment increases by 225 percent relative to the baseline by 2035 under the Focus policy scenario. Also, under the Allowances Removed and No Revenue Recycling policy scenarios, the non-coal electricity industry attracts the highest investment. This suggests that even if the South African government removes the tax-free allowances and the revenue recycling scheme, the non-coal electricity industry will still attract large investors as the country transforms into a low-carbon economy. On the opposite side, high-emitting industries like coal electricity, metal and steel lose investment as the country's economy adjusts towards low-carbon sectors. The increasing investments for non-coal electricity suggest a need to create an investment fund that will support green industries in the South African economy.

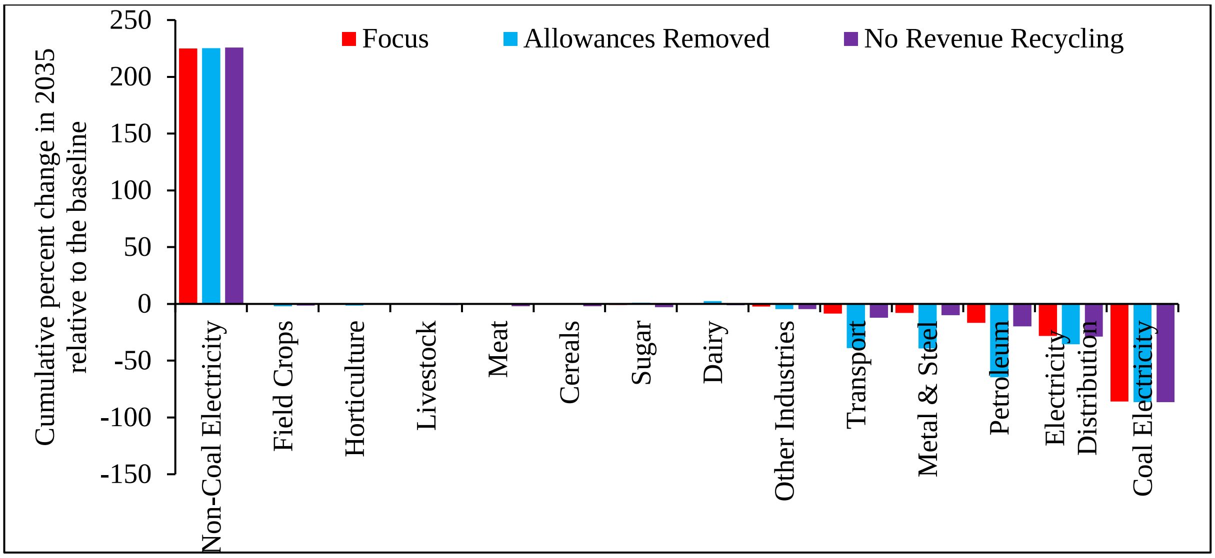

Figure 5.9: Expected long-term policy impacts on all industries' investment by 2035

Following the analysis of the tax implications on sectoral output and investments, Figure 5.10 and Figure 5.11 show the expected effects on sectoral employment. Both the agricultural and food industries are expected to gain employment as jobs increase under the Focus policy scenario relative to the baseline (Figure 5.10). The increase in employment relative to the baseline is caused by an increasing output explained above, which implies that the food sector will not be negatively affected by the introduction of the carbon tax policy in the country. The fisheries, meat and cereals industries are some of the industries that are expected to experience up to 1.2 percent growth in employment relative to the baseline when the carbon tax policy is implemented. This is caused by a limited passon effect from the agricultural industries which are fully exempted from paying the carbon tax under the Focus policy scenario.

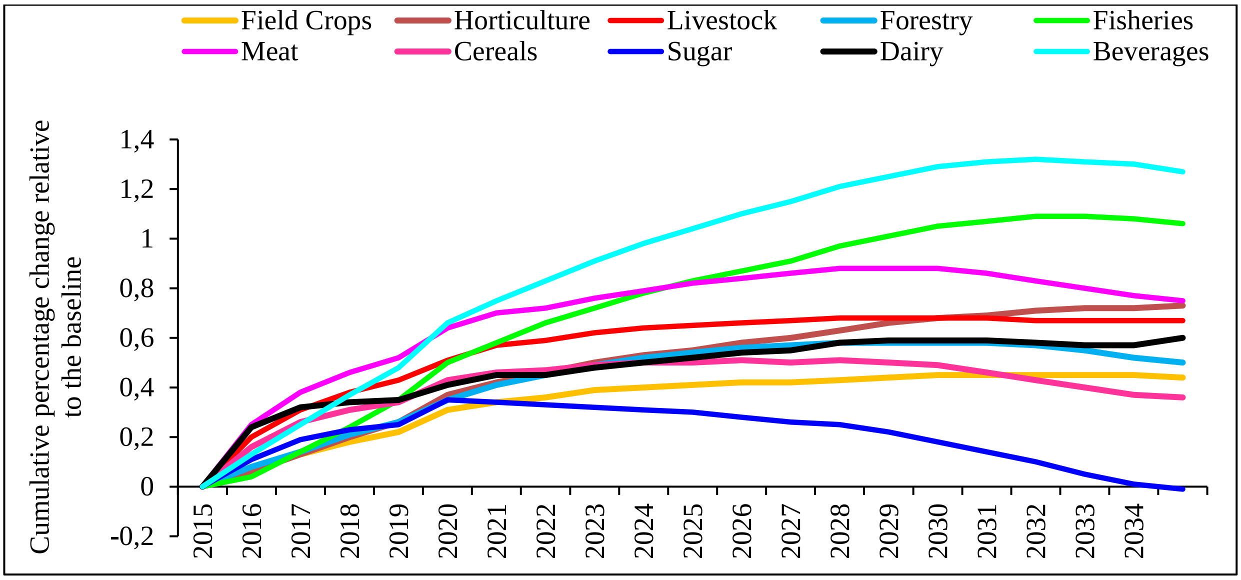

Figure 5.10: Expected effects on agricultural and food industries' employment

The non-coal electricity industry is expected to create more employment in the long run as the industry’s employment increases by 239 percent relative to the baseline by 2035 (Figure 5.11). On the opposite side, the coal electricity, transport services, metal and steel and other sectors are expected to lose employment in the long run as demand and output in these high-emitting industries decline in the future (Figure 5.11). It is this net effect on employment that leads to a minimal loss in aggregate employment as shown in Figure 5.4 above.

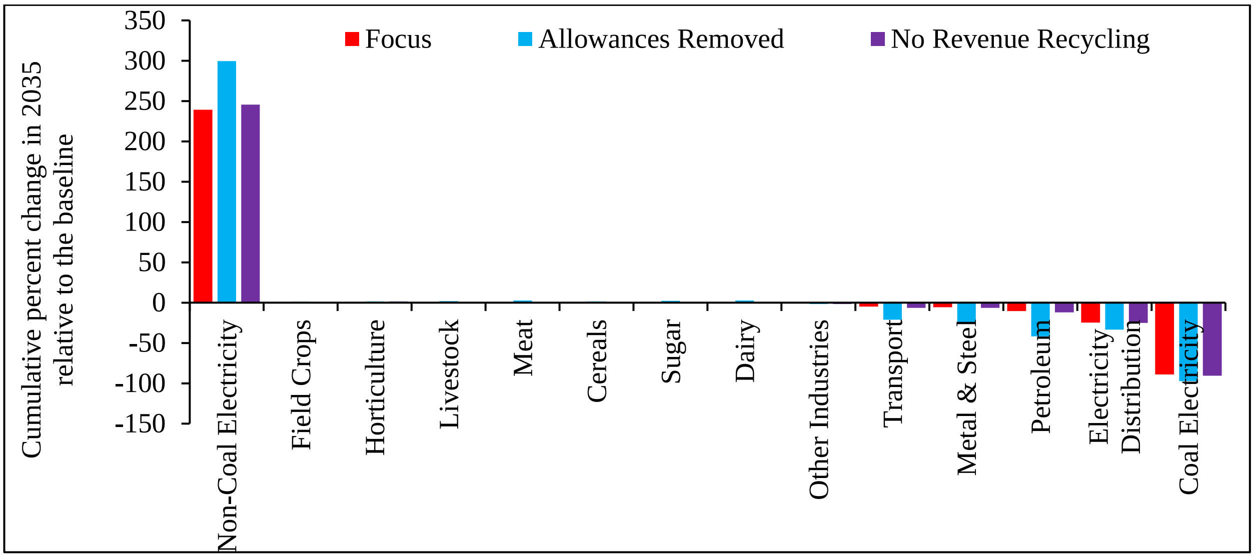

Figure 5.11: Expected long-term policy impacts on all industries' employment by 2035

The sectoral results indicate that the non-coal electricity industry will be the biggest winner when the carbon tax policy is implemented, whereas the high-emitting industries such as coal electricity, steel, petroleum and transport will be the biggest losers when the economy transforms into a low-carbon economy through the carbon tax policy. Moreover, the assessment of the carbon tax policy on the individual agricultural and food industries shows a minimum but positive policy effect largely because of tax-free allowances and revenue recycling schemes that cushion the food supply sectors against negative impacts. In addition, the sectoral results on food supply sectors provide an indication that the manner in which government removes the tax-free exemptions and treats the collected carbon tax revenue will determine the magnitude of the effects on the food supply in the country. This suggests that the policymakers in South Africa have crafted a plausible policy as prescribed in the latest carbon tax policy bill that was released in December 2017.

5.4 Sensitivity analysis

The macro and sectoral results discussed above contain a somewhat sensitivity analysis because they illustrate how macro-and microeconomic indicators will be affected under different policy scenarios. In addition to this analysis, the researcher conducted sensitivity tests on the elasticities to determine the sensitivity of CGE results to different elasticities. Furthermore, the sensitivity of the real GDP impact to different revenue recycling schemes was determined to measure the impact on the economy of different revenue recycling schemes that could be implemented. From a South African perspective, agriculture is one of the key exporting sectors accounting for an almost 10 percent share of total exports on average per annum. It is therefore critical that correct export demand elasticities are used in the model together with other trade elasticities. The next section analyses the sensitivity of the carbon tax policy effects on aggregate exports if different export demand elasticities are used in the model.

5.4.1 Export demand elasticities

In CGE modelling the use of credible export demand elasticity is important because it affects the rate at which exports react to a policy under consideration. The choice of export demand elasticity is often one critical area that undermines the results produce by CGE models. Given the importance of elasticities, Chapter four of this study was dedicated to estimating different sets of elasticities required for CGE models. This section seeks to illustrate the sensitivity of export volumes to export demand elasticities. A similar sensitivity analysis can be conducted on Armington and CET export supply elasticities, but for purposes of illustration, the researcher chose the export demand elasticities. Three simulations were conducted using the Focus policy scenario, namely: elasticity of -4; elasticity of - 2 and the actual export demand elasticity for commodities measured in Chapter four of this study. The first two cases are derived based on elasticities found in the literature. The sensitivity results are presented in Figure 5.12 and show that higher elasticities tend to exaggerate the reaction of export volume changes to the policy under consideration.

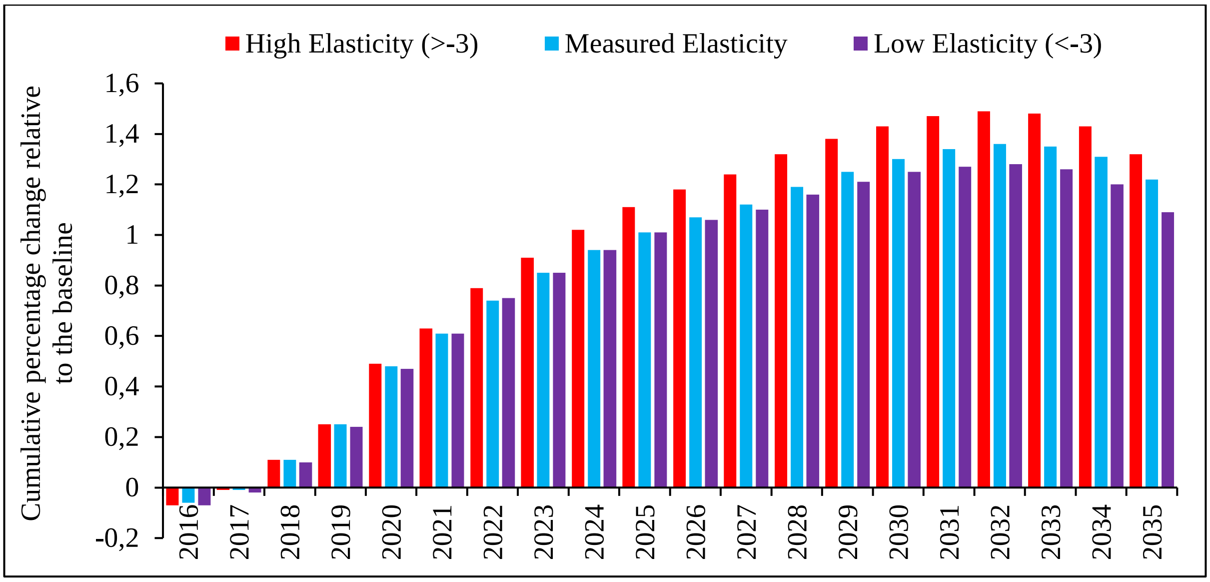

Figure 5.12: Impact of different export demand elasticities on export volume changes

The use of lower export demand elasticity underestimates the changes, which could yield misleading results and lead to wrong policy advice. The actual export demand elasticities measured in this study yield a well-behaved change in the export volumes. This sensitivity analysis validates the argument that using accurate and credible elasticities improves the CGE results.

5.4.2 Revenue recycling schemes

The recycling of the carbon tax revenue to minimise the impact on welfare is an integral part of the carbon tax design in South Africa. The manner in which the revenue is recycled back into the economy will have varying effects on the economy. This study evaluated two types of revenue recycling scheme approaches, namely: recycling through a rebate to all sectors based on production (the size of the rebate is determined by the size of the output) and recycling through a decrease in the Value Added Tax (VAT) rate on all goods that make up household spending. It is evident from the revenue recycling scheme sensitivity results presented in Figure 5.13 that the scheme which provides a rebate to industries has a great benefit to industries and the overall welfare of the country when the carbon tax is introduced. The GDP deviates by -0.91 percent relative to the baseline under the industry production rebate scheme as compared to -1.8 percent under the VAT rebate revenue scheme. This is caused by a greater support industry generated from direct subsidy in terms of production rebate which assists to cope with increasing input costs due to the taxing of key fuel inputs. While VAT rebates directly benefit households, they have a low impact in cushioning the whole economy against the negative impacts of policy.

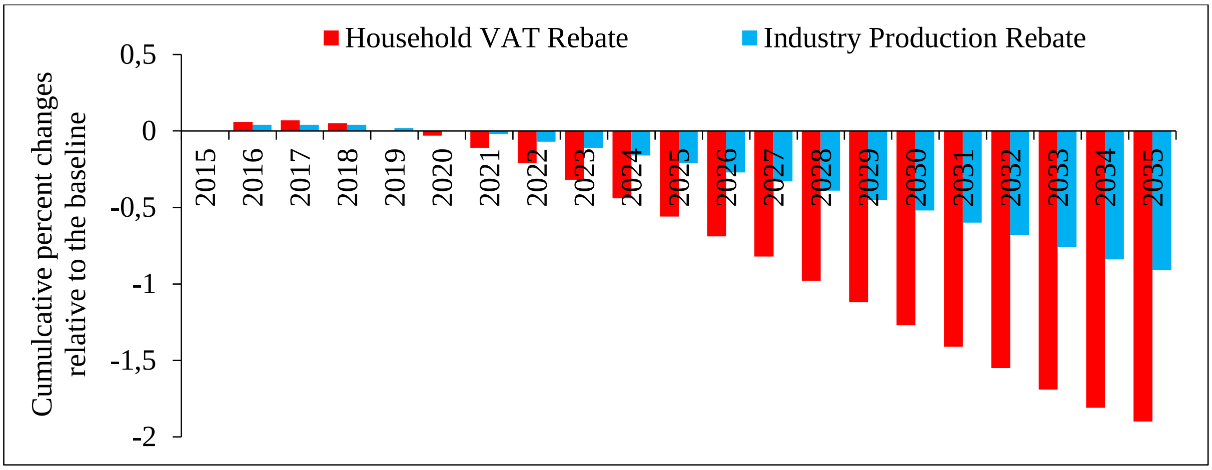

Figure 5.13: Impact of different revenue recycling schemes on real GDP growth

In addition to showing the expected impact of revenue schemes on GDP, Figure 5.14 indicates the expected impacts of different revenue recycling schemes on household consumption.

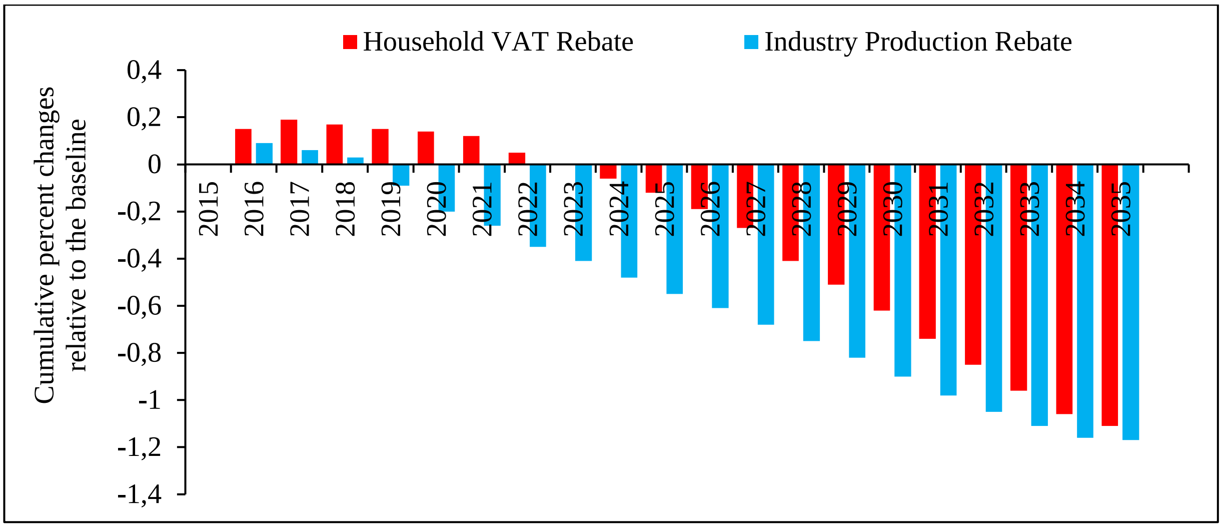

Figure 5.14: Impact of different revenue recycling options on household consumption

While the revenue option through household rebates provides less cushioning for the economy, it does benefit household consumption. Despite this minimal household gain, the net effect is still greater under the industry production rebate option. For example, the accumulative household consumption deviates by 1.11 percent under the household rebate option relative to the baseline as compared to 1.17 percent under the industry rebate option. Results on revenue recycling schemes presented in Figure 5.13 and 5.14, indicate that recycling the collected carbon tax revenue through the industry production rebate option will have a better net effect on the economy.

5.5 Summary

The results provide a clear indication that the carbon tax policy is an effective instrument to mitigate the growing GHG emissions in the country. Although the carbon tax does not assist the country to fully meet its emissions reduction target committed to under the Paris Agreement, it certainly moves the country closer to achieving this target. Combining the carbon tax with other emissions reduction approaches described by DEA (2017) in the country's NDC submitted to the UNFCCC would likely enable the country to reach its commitments under the Paris Climate Agreement. The results also show that there would be some adjustment cost incurred when the carbon tax policy is implemented. This adjustment cost is equivalent to a 0.91 percent decline in real GDP relative to the baseline by 2035, which is the same as a 0.05 percent decline in real GDP per annum over the next 25 years. This can be argued to be a relatively small cost necessary to achieve the greater benefit of reducing the growing emissions in the country.

The sectoral results show that the carbon tax policy is expected to have a minimal impact on the majority of industries. Moreover, the carbon tax policy is expected to have a positive impact on the agricultural and food industries largely because of the tax-free allowances provided for these industries, as well as revenue recycling schemes which cushion these industries against any negative effects associated with the implementation of the carbon tax policy. The results suggest that the manner in which tax-free allowances are removed will determine the magnitude of the policy impact on the economy. This is because when the tax-free allowances are removed, the impact on industries, including the agricultural and food industries, becomes significant and negative. The sensitivity analysis indicated the importance of using correct elasticities in order to improve the CGE results, thus avoiding the simulations that either over- or underestimate the policy impacts. The sensitivity results also suggest that government should consider recycling the revenue through an industry production rebate as it provides better support to industries and the economy as a whole. Overall, the results show that the agricultural and food industries are set to benefit when the carbon tax is implemented, provided the tax-free allowances and revenue recycling schemes are maintained and implemented effectively.

CHAPTER SIX
CONCLUSION AND POLICY RECOMMENDATIONS

6.1 Conclusion

The study was conducted with one primary purpose: to assess the carbon tax policy implications on the individual agricultural and food industries within a broader economic context. The study was motivated by the fact that most of the previous studies in the country have not focused on the agricultural and food sectors, thus limiting the understanding of the expected policy impacts on different agricultural and food industries. Knowing the effects of the policy will assist the policymakers and industry captains to gauge if the policy is well designed and does not cause significant harm to the food supply chain in the country.

The researcher adopted a dynamic CGE model, specifically the UPGEM, to assess the policy effects. To enable the analysis, three changes were made to the standard UPGEM, namely: creating theoretical extensions in the model to allow for environmental enhancement analysis; expanding the database to allow for detailed treatment of the agricultural, food and electricity industries; and estimating new trade elasticities for agricultural and food commodities to improve the functionality of the modified UPGEM. After making all the modifications, the policy shocks were designed to closely reflect the policy features described in the carbon tax bill released by the National Treasury of South Africa in December 2017. The design of the policy shocks included allowing for technology improvements in the non-coal electricity industry and taking into account all the industry-specific tax-free allowances provided in the 2007 carbon tax bill. In addition, the tax revenue recycling scheme that provided industry production rebates was incorporated in the policy designs.

The results show that the implementation of the carbon tax will lead to a significant decline in GHG emissions, reducing the country's emissions by 32.9 percent relative to the baseline by 2035. While achieving this emissions reduction, the policy is expected to cause minimal disturbances to the economy with the real GDP declining by 0.91 percent below the baseline in the Focus scenario. Both the emissions and GDP reductions were found to be slightly lower than the reductions found by previous studies such as Alton *et al.* (2014) and Van Heerden *et al*. (2016). The difference can be attributed to the technology improvement assumptions made in this study, which reduce the amount of emissions the economy is emitting prior to implementing the carbon tax. Moreover, the technology enhancements in the non-coal electricity industry, coupled with tax-free allowances and the revenue recycling scheme, minimise the impact of the carbon tax policy on the economy, hence the adjustment costs are lower than those found in previous studies. The macro results also show that policy effects on other macroeconomic indicators such as the aggregate employment, investment and household consumption, will be negatively affected but the impact will be minimal due to the aforementioned factors like tax-free allowances and others.

At the sectoral level, the biggest winner of the carbon tax policy is the non-coal electricity industry whilst the biggest losers are the coal electricity, petroleum, metal and steel industries. Transport services, manufacturing and trade industries are moderately affected whereas the agricultural and food industries would be positively affected when the carbon tax policy is implemented. The positive impact suggests that the policy has been well designed to have a positive effect on the food supply system. This can be largely attributed to the manner in which the carbon tax policy is designed, which includes full tax-free exemption to the agricultural industry and also a trade-exposed allowance to export-oriented sectors like food.

These policy designs assist the agricultural and food industries to retain their competitiveness, thus ensuring a minimal disturbance of food supply and food security in the country. Based on the results obtained, it is concluded that the policymakers have designed a plausible policy that mitigates the growing emissions but also cushions the agricultural, food and majority of other industries in the country against the negative effects associated with the introduction of the policy. South Africa is the first African state to implement the carbon tax and it is anticipated that many developing and developed countries will use South Africa's policy template to design their respective climate mitigation policies that do not disturb the food supply chain.

6.2 Policy recommendations

The carbon tax policy is expected to cause a minimal disturbance on the economy while being effective in reducing the growing GHG emissions in the country. This minimal economic disturbance is dependent on the manner in which the government treats the tax-free allowances and which revenue recycling scheme they apply. It is recommended that the government selects the industry production rebate recycling scheme to ensure that the industries' competitiveness is less affected by the introduction of the carbon tax policy. Furthermore, it is recommended that the full-tax free allowance provided to agriculture is maintained beyond the first five-year window of the policy implementation. To ensure food security in the country, the full-tax free allowances must be extended to the food manufacturing industries in order to ensure the food price increments are reduced, thus ensuring the affordability of food in the country.

It is evident from the results that the carbon tax policy alone is unable to assist the country to meet its GHG emissions reduction targets committed to under the Paris Climate Agreement. It is recommended that the government creates some incentive – call it a green fund – which will encourage investments in the research and development (R&D) field. The R&D green fund should assist the country to develop environmentally friendly solutions that will help the heavy-emitting industries like transport services, metal and steel to transform their current production into low-carbon production practices. From an agricultural perspective, the R&D green fund should assist farmers, especially livestock farmers, to formulate environmentally friendly practices that help to reduce emissions emitted from livestock manure, which is the biggest source of agricultural emissions.

Furthermore, the government should consider creating specific incentives for farmers to plant more trees to sink the emissions and adopt better agricultural practices. The fact that agriculture is not directly taxed under the current carbon tax policy design implies that its participation in reducing emissions is limited to indirect effects passed on from other sectors such as the petroleum and chemical industries. Creating an incentive to reduce agricultural emissions (e.g. from livestock and food waste) could improve the contribution of the agricultural sector to the country's efforts to mitigate growing emissions. This will enable the country to reduce more emissions, thus getting closer to meeting the Paris Agreement targets.

6.3 Future research

The study results showed that the introduction of a carbon tax will partly assist the country to achieve up to a 33 percent reduction in emissions by 2035 relative to the baseline. While the overall emissions are reduced, there is the possibility of an intra-industry carbon leakage within the country when the carbon tax is introduced. The carbon leakage between industries in the country was not evaluated in this study, which might be critical to know in the future. Understanding and controlling the carbon leakage within the economy will ensure that emissions are effectively reduced in the country. Secondly, expected GHG emissions reductions from the carbon tax policy fall short of the country's target of a 42 percent decline committed to under the Paris Agreement. Future research could evaluate other market-based policy instruments that can complement the carbon tax policy in reducing emissions. For example, future research could examine the potential impact of combining the carbon tax policy and border carbon adjustment policy.

Moreover, the results from this study indicated that the implementation of the carbon tax will increase imports into the country. The implementation of the carbon tax will affect some industry outputs, triggering demand for imported products to satisfy the local demand displaced by the increasing cost of production in the country. This relative decline in the country’s competitiveness is conditional to the implicit assumption that other countries in the world would not implement climate policies; hence their respective competitiveness is sustained relative to South Africa’s competitiveness after implementing the carbon tax policy. However, with the Paris Agreement in place, all signatories of the Paris Agreement are expected to make tangible efforts to reduce their respective emissions.

It is assumed that when all countries in the world take tangible steps in reducing their respective emissions, the imports towards South Africa will not increase because all countries will be facing production cost increments simultaneously, thus ensuring the level and fair playing ground as envisaged in the Paris Agreement. The implications of the world taking tangible steps towards reducing global emissions on South African imports fell outside the scope of this study. It is the researcher’s view that such research is best suited to be addressed by multinational CGE models such as the GTAP. This is another area identified for future research in order to strengthen our understanding of climate policy implications.

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Appendix A: Mapping of industry and commodity sets in the expanded database

Table A3.1: Industry sets mapped using Standard Industry Classification

INDUSTRY	Division SIC	Major SIC	Group SIC	Industry explanatory notes SIC 5th Edition of 1993
Field ccrops	11	111	1111 & 1160	Growing of cereals; other crops and organic fertilisers
Horticulture	11	111	1112 & 1113	Growing of vegetables; nursery; wine; fruits and nuts
Livestock	11	112	1121, 1122, 1130, 1151-2	Farming of cattle, sheep, goats, poultry, pigs, game and others
Forestry	12		1210 & 1220	Forestry; logging and related services
Fisheries	13	131-132	1310-1320	Fish and aquatic animals; hunting and commercial fish farming
Meat	30	301	3011-3012	Processing and preservation of beef; sheep; poultry and fish meat
Cereals	30	301-304	3013-3049	Processing and preserving of fruits and vegetables, grains, animal feed, food oils and fats as well as other foodstuffs
Sugar	30	304	3042 & 3043	Manufacturing of sugar and sugar confectionery
Dairy	30	302	3020	Manufacturing of dairy products
Tobacco and beverages	30	305-306	3051-3060	Manufacturing of wine, spirits, beer, soft drinks, mineral water and tobacco products
Textiles and footwear	31	311-317	3111-3170	Manufacturing of textiles; clothing and leather goods
Wood and paper	32	321-326	3210-3260	Manufacturing of wood products; paper and published printing
Coal lignite	21			Coal and lignite mining products
Crude gas	22			Crude gas
Electric gas	22			Natural gas
Other mining	23-29			Gold; uranium; metal ores; other mining, quarrying
Petroleum	33	331-332		Coke and refined petroleum

Chemicals	33	333-336		Chemicals and nuclear
Plastic and rubber	33	337-338		Plastic and rubber
Metal and steel	34-35	341-359		Glass; metals; steels and others
Manufacturing	36-39	361-395		Manufacturing of non-metallic; basic metals; furniture & equipment
Coal generation	41			Electricity generated from coal
Non-coal generation	41			Electricity generated from wind, solar, nuclear, gas and hydro
Electricity supply	41			Distribution of electricity
Water	42	412	4120	Collection; purification; distribution of water
Construction	50	501-505	5010-5050	Site; building; civil; roads; railway and street construction
Trade	61, 62 & 63	611-633	6110-6350	Wholesale, retail trade and motor vehicles
Hospitality	64	641 & 642	6410 & 6420	Hotels and restaurants
Transport services	71- 74	711-741	7111-7419	Land; air; water transport and supporting activities
Telecommunications	75	751	751-7520	TV & radio equipment and post and telecommunications
Business services	81- 88	811-889	8111-8899	Financial; insurance; real estate and business services
Government	91- 94	911-940	9111-9400	Public services including education; health; defence; and social services
Other services	95- 99, 01, 02, 03 & 09	951-990	9511-9909	Member organisations; private household; exterritorial organisations; foreign government representatives and other activities.

Table A3.2: Commodity sets mapped using Central Product Classification

COM	Division CPC	Major CPC	Commodity explanatory notes CPC Ver 2 of 2002
Field crops	01	011, 014, 018 & 019	Grains; oilseeds; sugarcane and oleaginous crops
Horticulture	01	012, 013, 015, 016 & 017	Fruits; vegetables; nuts; roots and tubers; spices and leguminous vegetables
Livestock	02	021, 022, 024 & 029	Bovine animals including game; poultry, eggs, pigs, and other animals
Forestry	03	031 & 032	Wood and non-wood forest products
Fisheries	04	041, 042 & 049	Live fish fresh or chilled and crustaceans and aquatic products
Meat	21	211 & 212	Processed beef; sheep; goat; game; fish and aquaculture products
Cereals	21	213 & 214	Prepared and preserved fruits; nuts and vegetables, processed grains, cotton and feed
Sugar	23	235 & 236	Sugar and sugar confectionery and chocolate
Dairy	22	221 & 222	Processed liquid milk and cream and dairy products
Tobacco and beverages	24 - 25		Wine of fresh grapes; spirits; liquors and beers, non-alcoholic beverages, tobacco products
Textiles and footwear	26, 27, 28 & 29	261 - 268, 271-179, 281-283 & 291 -296	Textiles; clothing and footwear
Wood and paper	31 & 32	311-319 & 321-328	Products of wood; pulp and paper products
Coal lignite	11		Coal and lignite products
Crude gas	12		Crude petroleum gas
Electric gas			Natural gas
Other mining	13, 14, 15 & 16		Uranium; metal ores; sand; salt; precious stones & other minerals
Petroleum	33	333, 334, 335	Petroleum oils and obtained from bituminous materials; other petroleum refined products
Chemicals	33, 34, 35	331, 332	Coke and semi-coke; basic chemicals and other chemicals
Plastic rubber	36	361, 362, 363	Plastic products and rubber products
Metal steel	37, 38, 39, 41, 42, 43, 45		Basic iron and steel, basic precious metals; copper; aluminium; refractory products; cement and plasters; other non-ferrous metals

Manufacturing	46, 47, 48 & 49		Glass; furniture; electrical equipment; transport equipment; waste/scraps; metals; machinery; radio and TV equipment; electrical equipment and medical appliances
Coal generation	17		Electricity generated from coal
Non-coal generation	17		Electricity generated from wind, solar, nuclear, gas and hydro
Electricity supply	69		Electricity distribution
Water	18 & 69	180 & 692	Natural water and water distribution
Construction	53 & 54	531-532 & 541-547	Construction and construction services
Trade	61 & 62	611-612 & 621-625	Wholesale and retail trade services
Hospitality	63	631-634	Accommodation; food and beverage services
Transport	64, 65, 66 & 67	641-642, 651-679	Passenger; freight, rental and supporting transport and transport equipment
Telecommunications	68 & 84	681 & 841-846	Telecommunication, postal & courier services and broadcasting services
Business services	71- 73, 81- 83	711-839 & 851-894	Financial; real estate; rental; business; legal; accounting and other business services
Government	91, 92, 93 & 94	911-949	Education; health; social, sewage and treatment services
Other services	85-98 & 99	951-990	Other services

Appendix B: Balanced UPGEM database forming initial solution

Table B3.1: Production matrix showing supply of commodities from different sources plus margins and taxes less subsidies on commodities

COMMODITIES	DOMESTIC INDUSTRY SUPPLY AT BASIC PRICES	IMPORT SUPPLY	TAXES LESS SUBSIDIES ON COMMODITIES	TRADE & TRANSPORT MARGINS	TOTAL COMMODITY SUPPLY AT PURCHASER'S PRICES
FieldCrops	36945.46	6901.61	2995.84	6618.71	53461.62
Horticulture	38999.13	583.23	898.44	2363.83	42844.63
Livestock	73708.62	2235.73	2095.32	6776.30	84815.97
Forestry	20090.84	86.85	656.57	747.96	21582.22
Fisheries	3716.16	99.28	187.05	1182.70	5185.19
Meat	49360.43	4078.12	5154.57	6956.86	65549.98
Cereals	140713.95	22339.19	8893.49	40446.52	212393.15
Sugar	15615.57	2049.42	982.43	6271.90	24919.32
Dairy	32192.07	906.95	1809.80	9197.62	44106.44
Beverages	77942.15	3172.07	45950.09	30954.57	158018.88
Textile	72921.93	40894.69	14369.84	20616.05	148802.51
Paper	114670.24	14602.41	8702.78	39455.20	177430.62
CoalLignite	89083.67	1996.15	1063.24	4773.09	96916.15
CrudeGas	22038.01	30714.25	1989.43	3342.81	58084.50
ElectricGas	18203.10	1694.48	449.97	0.00	20347.55
OtherMines	298415.41	48618.04	4071.02	5174.67	356279.14
Petroleum	88680.38	54267.85	46388.43	61461.87	250798.53
Plastic	49344.55	17411.11	5731.12	12297.81	84784.59
Metal	66093.13	9085.12	3814.90	28749.98	107743.12
Chemicals	164281.20	72482.53	13205.69	52958.99	302928.41
Manufacturing	543371.89	413862.97	53174.55	184762.56	1195171.96
CoalElectricity	39719.92	0.00	0.00	0.00	39719.92
NonCoalElectricity	5964.15	0.00	0.00	0.00	5964.15
ElectricitySupply	59543.11	1570.61	3342.16	0.00	64455.88
Water	38812.89	6.35	1831.66	0.00	40650.90
Construction	336379.20	503.40	5978.48	0.00	342861.08
Trade	536241.04	2437.30	2992.77	(471158.00)	70513.10

Hospitality	69237.72	14390.00	2627.49	0.00		86255.22
Transport	317959.45	65632.20	(4084.36)	(53952.00)		325555.29
Telecom	173442.55	10037.39	2945.50	0.00		186425.44
Business	1207560.17	28127.01	34254.77	0.00		1269941.95
Government	946346.97	1477.80	10139.41	0.00		957964.18
OtherServ	161354.45	12644.90	15084.57	0.00		189083.92
Total	5908949.50	884909.00	297697.00	0.00		7091555.50

Source: StatsSA, 2011

Table B3.2: Absorption matrix showing intermediate and final use of all commodities by main user groups

	Intermediate User	Final Users					TOTAL COMMODITY USE AT PURCHASER'S PRICE
COMMODITIES	INDUSTRY USE AT PURCHASER'S PRICE	CAPITAL FORMATION	HOUSEHOLD	EXPORT	GOVERNMENT	INVENTORIES	
FieldCrops	33785.12	0.00	14337.41	5309.65	0.00	29.43	53461.62
Horticulture	15657.47	0.00	16503.06	10664.48	0.00	19.62	42844.63
Livestock	42634.77	0.00	38221.72	3853.18	0.00	106.30	84815.97
Forestry	11540.51	0.00	7899.81	2216.77	0.00	(74.87)	21582.22
Fisheries	3577.78	0.00	786.80	869.74	0.00	(49.13)	5185.19
Meat	11893.70	0.00	50121.23	3755.12	0.00	(220.07)	65549.98
CerealFV	51492.19	0.00	149507.79	10721.38	0.00	671.80	212393.15
Sugar	4885.30	0.00	16273.38	3643.96	0.00	116.69	24919.32
Dairy	12480.01	0.00	31008.48	711.83	0.00	(93.88)	44106.44
ToBeverages	34255.31	0.00	106468.36	16117.68	0.00	1177.53	158018.88
TextileFoot	49495.52	20.29	95523.25	4957.21	0.00	(1193.76)	148802.51
WoodPaper	141990.57	1.05	25267.06	14634.71	0.00	(4462.77)	177430.62
CoalLignite	51548.85	0.00	860.69	44512.61	0.00	(6.00)	96916.15
CrudeGas	44771.19	0.00	242.58	12397.26	0.00	673.47	58084.50
ElecGas	17631.29	0.00	0.00	1441.01	0.00	1275.25	20347.55
OtherMine	124984.84	0.00	470.31	225289.72	0.00	5534.28	356279.14

Petroleum	126577.11	485.40	100802.08	19409.70	0.00	3524.24	250798.53
PlasRuber	69316.43	2.46	12064.63	3386.87	0.00	14.20	84784.59
MetalSteel	75574.89	7473.61	14520.64	10513.90	0.00	(339.92)	107743.12
Chemicals	204185.40	0.00	62838.62	34571.17	0.00	1333.22	302928.41
Manufact	483203.71	268374.48	168743.22	303892.62	0.00	(29042.08)	1195171.96
CoalGen	39719.92	0.00	0.00	0.00	0.00	0.00	39719.92
NCoalGen	5964.15	0.00	0.00	0.00	0.00	0.00	5964.15
ElecSupply	44464.08	0.00	17701.65	1339.83	0.00	950.32	64455.88
Water	21180.14	0.00	18445.40	4.04	0.00	1021.32	40650.90
Construction	71880.48	248747.73	8240.40	455.53	0.00	13536.94	342861.08
Trade	67950.93	0.00	0.00	2472.70	0.00	89.48	70513.10
Hospitality	23752.96	0.00	48218.46	20236.63	0.00	(5952.83)	86255.22
Transport	190979.54	0.00	106350.46	32715.38	0.00	(4490.09)	325555.29
Telecom	128261.43	0.00	42942.38	14481.54	0.00	740.09	186425.44
Business	832912.33	25256.98	374242.94	30694.63	0.00	6835.08	1269941.95
Government	161621.60	0.00	161332.03	819.96	627873.00	6317.60	957964.18
OtherServ	73748.57	0.00	53189.11	61498.21	0.00	648.03	189083.92
Total	3273918.08	550362.00	1743123.93	897589.00	627873.00	(1310.51)	7091555.50

Source: StatsSA, 2011

Table B3.3: Primary factors of production

FACTOR TYPE	FACTOR CODE	BASELINE VALUE
Employment	V1LAB	1331206.19
Capital	V1CAP	1206518.94
Production tax	V1PTX	40695.99
Land	V1LAND	56610.30

Source: StatsSA, 2011, BFAP, 2017 and DAFF, 2017

Appendix C: Simulation results measuring the impact of the carbon tax policy

Table C5.1: Macro results

Variables	Scenarios	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
		Percentage change relative to the baseline																	
GHG Emissions	Focus	-3.6	-5.2	-7.3	-9.7	-11.8	-13.9	-16.0	-18.1	-20.2	-21.2	-22.3	-23.5	-24.6	-25.8	-27.0	-29.5	-32.1	-32.9
	AR	-3.6	-5.2	-7.3	-10.1	-12.9	-15.7	-18.9	-22.1	-25.3	-27.1	-28.6	-30.4	-32.1	-33.8	-35.5	-39.0	-42.4	-45.6
	NRR	-4.0	-5.7	-8.2	-10.7	-13.0	-15.3	-17.5	-19.8	-22.0	-23.1	-24.3	-25.5	-26.7	-27.9	-29.2	-31.7	-34.4	-36.9
GDP	Focus	0.04	0.02	0	-0.02	-0.07	-0.11	-0.16	-0.21	-0.27	-0.33	-0.39	-0.45	-0.52	-0.6	-0.68	-0.76	-0.84	-0.91
	AR	0.04	0.02	0	-0.03	-0.11	-0.2	-0.34	-0.52	-0.74	-1.01	-1.32	-1.65	-2.02	-2.41	-2.82	-3.24	-3.61	-3.84
	NRR	-0.3	-0.43	-0.6	-0.73	-0.88	-1.02	-1.16	-1.29	-1.4	-1.51	-1.63	-1.72	-1.81	-1.9	-1.97	-2.03	-2.07	-2.07
Employment	Focus	0.06	0.03	-0.01	-0.04	-0.1	-0.14	-0.18	-0.22	-0.26	-0.31	-0.35	-0.39	-0.44	-0.49	-0.53	-0.58	-0.61	-0.62
	AR	0.06	0.03	-0.01	-0.04	-0.12	-0.21	-0.33	-0.49	-0.66	-0.87	-1.11	-1.32	-1.54	-1.76	-1.97	-2.14	-2.22	-2.04
	NRR	-0.45	-0.57	-0.76	-0.85	-0.95	-1.02	-1.08	-1.12	-1.15	-1.17	-1.2	-1.19	-1.18	-1.15	-1.11	-1.05	-0.97	-0.85
Investments	Focus	0.33	0.31	0.13	0.03	-0.12	-0.25	-0.38	-0.51	-0.64	-0.76	-0.84	-0.97	-1.12	-1.28	-1.45	-1.61	-1.75	-1.83
	AR	0.33	0.31	0.13	0.03	-0.17	-0.42	-0.76	-1.22	-1.77	-2.42	-3.03	-3.79	-4.6	-5.43	-6.23	-6.94	-7.42	-7.31
	NRR	-1.31	-1.75	-2.47	-2.85	-3.14	-3.36	-3.52	-3.64	-3.72	-3.75	-3.81	-3.84	-3.87	-3.87	-3.84	-3.77	-3.65	-3.43
Exports	Focus	0.11	0.25	0.48	0.61	0.74	0.85	0.94	1.01	1.07	1.12	1.19	1.25	1.3	1.34	1.36	1.35	1.31	1.22
	AR	0.11	0.25	0.48	0.63	0.83	1.03	1.27	1.54	1.82	2.11	2.49	2.8	3.07	3.27	3.39	3.4	3.23	2.68
	NRR	0.42	0.45	0.59	0.5	0.39	0.26	0.12	-0.02	-0.16	-0.29	-0.34	-0.42	-0.51	-0.6	-0.69	-0.79	-0.92	-1.09

Table C5.2: Sectoral results

Sectors	Industry output			Industry employment			Industry investments		
	Focus	Allowances Removed	No Revenue Recycling	Focus	Allowances Removed	No Revenue Recycling	Focus	Allowances Removed	No Revenue Recycling
	Long term accumulative percentage change relative to the baseline								
Non-coal electricity	179.08	182.36	180.19	239.26	299.36	245.45	224.83	225.31	225.77
Field crops	0.39	0.2	0.07	0.44	0.22	0.18	-0.18	-1.93	-1.53
Horticulture	0.8	0.271	0.044	0.73	0.44	0.31	-0.22	-1.45	-0.56
Livestock	0.14	0.18	0.11	0.67	0.695	0.289	-0.08	-0.2	-0.8
Meat	0.84	0.29	-0.78	0.75	0.58	0.17	-0.09	-0.21	-2.11
Cereals	0.43	0.35	-0.91	0.36	0.169	-0.12	-0.42	-0.36	-1.99
Sugar	0.09	-0.81	-1.67	0.21	0.136	-0.7	-0.91	-1.17	-2.9
Dairy	0.62	-0.8	-0.66	0.6	0.54	-0.42	-0.12	-1.43	-1.93
Others	-0.49	-0.65	-0.58	-0.81	-1.86	-1.83	-2.18	-4.49	-4.47
Transport	-4.17	-17.88	-6.69	-4.82	-21.12	-6.54	-8.56	-38.84	-12.24
Metal & Steel	-5.11	-23.1	-6.95	-5.51	-25.32	-6.37	-8.07	-39.23	-9.8
Petroleum	-8.95	-34.5	-11.8	-10.32	-41.57	-12.18	-16.63	-64.4	-19.83
Electricity distribution	-24.12	-33.47	-25.73	-24.66	-33.3	-25.28	-28.07	-35.43	-28.72
Coal electricity	-64.85	-76.29	-67.83	-88.95	-97.14	-90.57	-86.01	-86.64	-86.39